

Description

Title of Invention: Novel Hydrolase Protein

Technical Field

[0001]

The present invention relates to a novel hydrolase protein that can be used in the production of (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, and a use thereof.

Background Art

[0002]

(1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid is an intermediate that is useful for the production of various types of HCV NS3 protease inhibitors that are currently under development as therapeutic agents for hepatitis C. Non Patent Document 1 describes a method of hydrolyzing dimethyl 2-vinylcyclopropane-1,1-dicarboxylate with an enzyme to obtain (1S,2S)-1-methoxycarbonyl-2-vinylcyclopropanecarboxylic acid. In this method, however, the optical selectivity of the enzyme has been insufficient, and the optical purity of the obtained (1S,2S)-1-methoxycarbonyl-2-vinylcyclopropanecarboxylic acid has been 90%e.e. Thus, this method has been unsuitable as an industrial method for producing an intermediate for medicaments.

[0003]

The genome sequence of *Bacillus subtilis* ATCC23857 has been known, and the amino acid sequence of para-nitrobenzyl esterase derived from the *Bacillus subtilis* ATCC23857 (which may be hereinafter referred to as "PNBE23857") has been registered under GenBank Accession No. ZP_03593235.

Prior Art Documents

Non Patent Documents

[0004]

Non Patent Document 1: C. Fliche et al., Synth. Commun. 24(20), 2873-2876 (1994)

Summary of Invention

Object to be Solved by the Invention

[0005]

It is an object of the present invention to provide a novel hydrolase protein, which is used when dialkyl 2-vinylcyclopropane-1,1-dicarboxylate is hydrolyzed with an enzyme, so as to

efficiently obtain (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid that is useful as an intermediate for producing therapeutic agents for hepatitis C.

Means for Solving the Object

[0006]

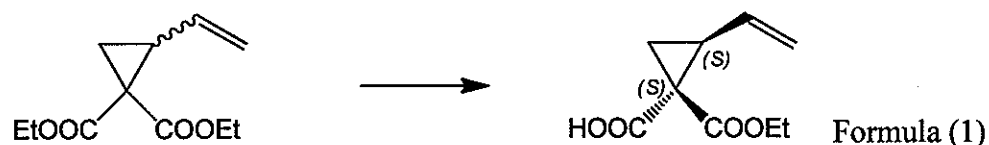
As a result of intensive studies directed towards achieving the aforementioned object, the present inventors have found that a para-nitrobenzyl hydrolase protein derived from *Bacillus subtilis* hydrolyzes diethyl 2-vinylcyclopropane-1,1-dicarboxylate at good selectivity, so as to efficiently obtain (1S,2S)-1-ethoxycarbonyl-2-vinylcyclopropanecarboxylic acid. In addition, the inventors have cloned a para-nitrobenzyl hydrolase gene of a related *Bacillus subtilis*, based on the DNA sequence information of a known *Bacillus subtilis*-derived para-nitrobenzyl hydrolase protein, and they have then confirmed the activity of a para-nitrobenzyl hydrolase protein encoded by the cloned gene. As a result, the inventors have succeeded in obtaining a novel homolog, which catalyzes the above-mentioned hydrolytic reaction at higher selectivity than that of a known para-nitrobenzyl hydrolase protein. Thereafter, the present inventors have performed the homology modeling of the above novel homolog based on the known three-dimensional structure information of the para-nitrobenzyl hydrolase protein, and have conducted a test of introducing mutations into amino acid residues close to a substrate-binding site. As a result, the inventors have succeeded in producing a hydrolase protein, which catalyzes the above-mentioned hydrolytic reaction at much higher selectivity. The present invention has been completed based on these findings.

[0007]

The present invention provides the following invention.

[1] A hydrolase protein, which consists of the amino acid sequence shown in any one of SEQ ID NOS. 2 to 5, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 1]

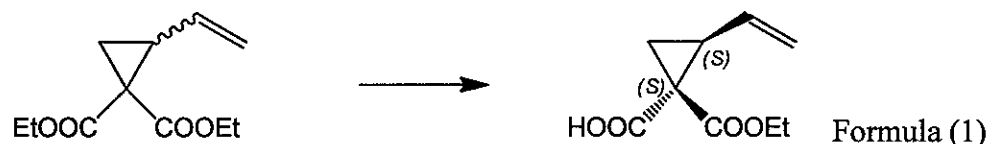


[0008]

[2] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 70, 106, 107, 108, 219, 270, 271, 272, 273, 274, 275, 276, and 313 are substituted with

other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

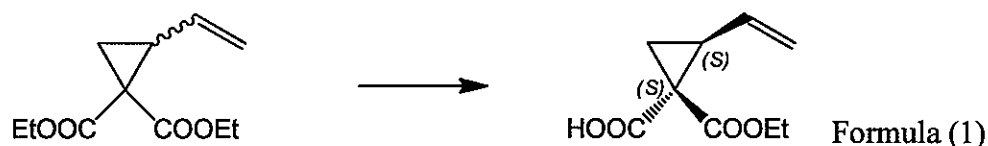
[Formula 2]



[0009]

[3] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 188, 190, 193, 215, 216, 217, 314, 358, 362, and 363 are substituted with other amino acids whose side chains have higher bulkiness than that of wild-type amino acids, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

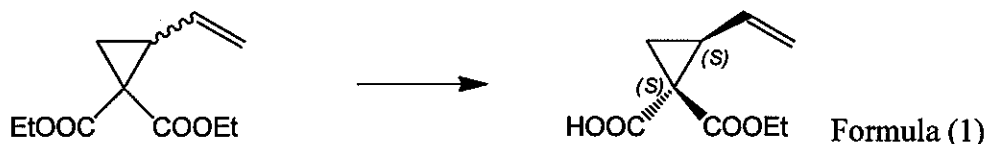
[Formula 3]



[0010]

[4] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequences shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 70, 106, 107, 108, 219, 270, 271, 272, 273, 274, 275, 276, and 313 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and one or more amino acids at amino acid numbers 188, 190, 193, 215, 216, 217, 314, 358, 362, and 363 are substituted with other amino acids whose side chains have higher bulkiness than that of wild-type amino acids, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 4]



[0011]

[5] The hydrolase protein according to [2] or [4], wherein, in the amino acid sequence shown

in any one of SEQ ID NOS. 1 to 5, at least one of amino acids at amino acid numbers 70, 270, 273, and 313 is substituted with another amino acid.

[0012]

[6] The hydrolase protein according to [5], wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, at least the leucine at amino acid number 70 is substituted with any one of aspartic acid, asparagine, serine, threonine, and glycine.

[0013]

[7] The hydrolase protein according to [5] or [6], wherein, in the amino acid sequence shown in SEQ ID NO. 3 or 4, the leucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine.

[0014]

[8] The hydrolase protein according to [5] or [6], wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1, 2, and 5, the isoleucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine.

[0015]

[9] The hydrolase protein according to any one of [5] to [8], wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 273 is substituted with either arginine or histidine.

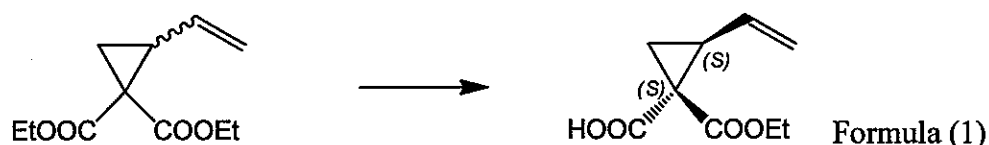
[0016]

[10] The hydrolase protein according to any one of [5] to [9], wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 313 is substituted with any one of methionine, alanine, and proline.

[0017]

[11] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in SEQ ID NO. 4, the leucine at amino acid number 70 is substituted with aspartic acid, the leucine at amino acid number 270 is substituted with any one of glutamine, glutamic acid and alanine, the leucine at amino acid number 273 is substituted with arginine, and the leucine at amino acid number 313 is substituted with methionine, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

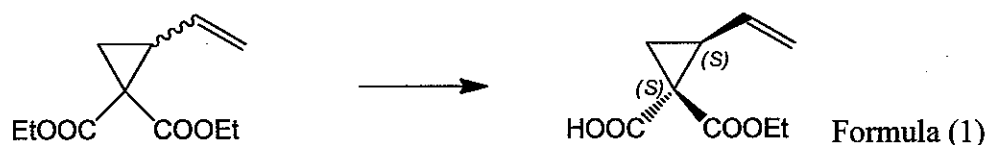
[Formula 5]



[0018]

[12] A hydrolase protein, which consists of an amino acid sequence having homology of 90% or more with the amino acid sequence of the hydrolase protein according to [1] to [11], or an amino acid sequence comprising a substitution, deletion, and/or addition of one or several amino acids with respect to the amino acid sequence of the hydrolase protein according to [1] to [11], and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 6]



[0019]

[13] A DNA encoding the hydrolase protein according to any one of [1] to [12].

[0020]

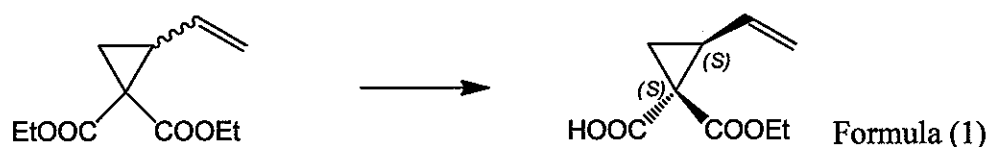
[14] The DNA according to [13], which consists of the following nucleotide sequence:

(a) the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10;

(b) a nucleotide sequence of a DNA capable of hybridizing under stringent conditions with the DNA consisting of the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10, wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1); or

(c) a nucleotide sequence comprising a substitution, deletion, and/or addition of one or several nucleotides with respect to the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10, wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 7]



[0021]

[15] A method for producing (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, which comprises allowing the hydrolase protein according to any one of [1] to [12] to act on dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to produce

(1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

Effects of Invention

[0022]

The hydrolase protein of the present invention has high selectivity, and thus, it is able to preferentially generate (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, when it hydrolyzes dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to produce 1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid. Specifically, according to the hydrolase protein of the present invention, (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, which is useful as an intermediate for producing therapeutic agents for hepatitis C, can be produced by an industrially applicable method, more efficiently than conventional methods. A method for producing (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid using the hydrolase protein of the present invention can be used in production of a therapeutic agent for hepatitis C and an intermediate thereof. The compound produced by the production method of the present invention can be used as a raw material or an intermediate for producing therapeutic agents for hepatitis C.

Embodiments for Carrying out the Invention

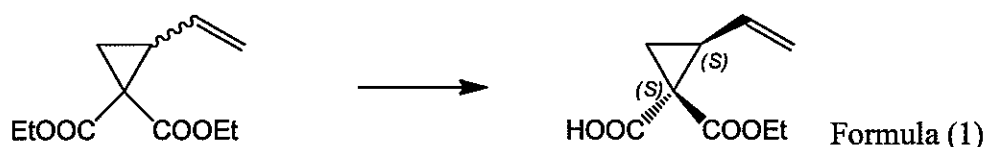
[0023]

Hereinafter, the embodiments for carrying out the present invention will be described in detail.

(1) Hydrolase Protein of the Present Invention

The hydrolase protein of the present invention is characterized in that it consists of the amino acid sequence shown in any one of SEQ ID NOS. 2 to 5, or a mutated amino acid sequence thereof, and in that it has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the formula (1). Herein, the sequence shown in SEQ ID NO. 1 is the amino acid sequence of para-nitrobenzyl esterase derived from *Bacillus subtilis* ATCC23857 (PNBE23857, GenBank Accession No. ZP_03593235).

[Formula 8]



It is to be noted that Et in the formula (1) represents an ethyl group.

[0024]

In the present invention, selectivity means optical selectivity, which is a property of preferentially generating a certain isomer so as to generate an optically active compound. Specifically, that is a property of hydrolyzing dialkyl 2-vinylcyclopropane-1,1-dicarboxylate, so as to preferentially generate (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

In order to hydrolyze dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to efficiently obtain (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, the following selectivity points are required for the hydrolase protein.

[0025]

< 1R2S/1S2S Ratio >

First of all, dialkyl 2-vinylcyclopropane-1,1-dicarboxylate includes two types of stereoisomers, namely, a (2R) form and a (2S) form. Unless there are special conditions in which stereoinversion occurs at position 2, basically, only the (2S) form can be a raw material for the (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid of interest.

When the hydrolase protein hydrolyzes dialkyl (2S)-2-vinylcyclopropane-1,1-dicarboxylate, it needs to have selectivity towards preferentially hydrolyzing only a pro-R alkoxycarbonyl group out of two alkoxycarbonyl groups bound to a prochiral carbon at position 1, thereby preferentially generating (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid. It is to be noted that "pro-R" is a notation for distinguishing two Xs on CX₂YZ. The summary of this notation is as follows. The priority of individual substituents on C is determined according to the CIP rules. At the time, it is assumed that one of the two Xs has a higher priority than that of the other X. The priority relationship with Y and Z is not changed. Based on the provisional priority, whether the chirality of central carbon is R or S is determined according to the RS notation. When the chirality is an R form, the preferential X is defined as pro-R. When the chirality is an S form, the preferential X is defined as pro-S.

This selectivity can be subjected to comparison, using, as an indicator, the ratio between the (1S,2S) form and (1R,2S) form in the 1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid generated as a result of the hydrolysis. As the ratio of the amount of the (1R,2S) form generated to the amount of the (1S,2S) form generated is decreased, the yield of the (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid is increased, and thus, it becomes advantageous for industrialization.

[0026]

< Optical Purity (%e.e.) of 1S2S Form >

When a racemic form of dialkyl 2-vinylcyclopropane-1,1-dicarboxylate is used as a substrate, the (2R) form is hydrolyzed with the hydrolase protein, so as to generate a (1S,2R) form

and a (1R,2R) form. At this time, the amount of the generated (1R,2R) form, which is an enantiomer of the (1S,2S) form of interest, is preferably reduced to the minimum. That is to say, the hydrolase protein needs to have selectivity towards preferentially hydrolyzing only a pro-R alkoxycarbonyl group out of two alkoxycarbonyl groups bound to a prochiral carbon at position 1 of dialkyl (2R)-2-vinylcyclopropane-1,1-dicarboxylate, thereby preferentially generating (1S,2R)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, and/or selectivity towards preferentially hydrolyzing dialkyl (2S)-2-vinylcyclopropane-1,1-dicarboxylate, rather than dialkyl (2R)-2-vinylcyclopropane-1,1-dicarboxylate. Both of the aforementioned selectivities can be subjected to comparison, using the enantiomer excess (%e.e.) of the (1S,2S) form to the (1R,2R) form in the 1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid generated as a result of the hydrolysis. The higher the enantiomer excess of the (1S,2S) form, the lower the possibility of affecting the subsequent production process or the physiological activity of the produced medicament. Thus, it is advantageous for industrialization.

[0027]

< 1S2R/1S2S Ratio >

As described above, the hydrolase protein hydrolyzes the pro-R alkoxycarbonyl group out of the two alkoxycarbonyl groups bound to a prochiral carbon at position 1 of the dialkyl (2R)-2-vinylcyclopropane-1,1-dicarboxylate, so that it can generate the (1S,2R)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid that is a diastereomer of the (1S,2S) form of interest. In order to reduce the influence on the subsequent production process, the mixing of this (1S,2R) form is preferably reduced to the minimum.

This selectivity can be subjected to comparison, based on the ratio between the amount of the (1S,2S) form and the amount of the (1S,2R) form in the generated 1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid. The lower the ratio of the amount of the (1S,2R) form to the amount of the (1S,2S) form, the lower the possibility of affecting the subsequent production process or the physiological activity of the produced medicament. Thus, it is advantageous for industrialization.

[0028]

Accordingly, the selectivity in the present invention is based on the indicator that is the "1R2S/1S2S ratio," "optical purity (%e.e.) of the 1S2S form," or "1S2R/1S2S ratio" in the 1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

That is, the "activity of catalyzing the reaction represented by the formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1" of the present invention can be determined using, as an indicator, the "1R2S/1S2S ratio," "optical purity (%e.e.) of the 1S2S form," or "1S2R/1S2S ratio" in the

1-ethoxycarbonyl-2-vinylcyclopropanecarboxylic acid as a product.

[0029]

Preferred embodiments of the hydrolase protein of the present invention include the following (a), (b), (c), and (d):

(a) a hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 70, 106, 107, 108, 219, 270, 271, 272, 273, 274, 275, 276, and 313 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and which has activity of catalyzing the reaction represented by the above formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1;

(b) a hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 188, 190, 193, 215, 216, 217, 314, 358, 362, and 363 are substituted with other amino acids whose side chains have higher bulkiness than that of wild-type amino acids, and which has activity of catalyzing the reaction represented by the above formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1;

(c) a hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequences shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 70, 106, 107, 108, 219, 270, 271, 272, 273, 274, 275, 276, and 313 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and one or more amino acids at amino acid numbers 188, 190, 193, 215, 216, 217, 314, 358, 362, and 363 are substituted with other amino acids whose side chains have higher bulkiness than that of wild-type amino acids, and which has activity of catalyzing the reaction represented by the above formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1; and

(d) the hydrolase protein described in (a) or (c) above, which consists of an amino acid sequence in which at least one of amino acids at amino acid numbers 70, 270, 273, and 313 is substituted with another amino acid, and which has activity of catalyzing the reaction represented by the above formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1.

In the present invention, the hydrolase protein described in (d) above is particularly preferable.

[0030]

With regard to the term "bulkiness" used in the description "amino acids whose side chains have lower bulkiness than that of wild-type amino acids" or "amino acids whose side

chains have higher bulkiness than that of wild-type amino acids,” the value indicated as “Bulkiness” in Table 3 of J. Theoret. Biol., 1968, 21, 170 can be specifically used as an indicator. The value of bulkiness of each amino acid is specifically as follows.

[0031]

Ala (alanine): 11.50

Arg (arginine): 14.28

Asp (aspartic acid): 11.68

Asn (asparagine): 12.82

Cys (cysteine): 13.46

Glu (glutamic acid): 13.57

Gln (glutamine): 14.45

Gly (glycine): 3.40

His (histidine): 13.69

Leu (leucine): 21.40

Ile (isoleucine): 21.40

Lys (lysine): 15.71

Met (methionine): 16.25

Phe (phenylalanine): 19.80

Pro (proline): 17.43

Ser (serine): 9.47

Thr (threonine): 15.77

Trp (tryptophan): 21.67

Tyr (tyrosine): 18.03

Val (valine): 21.57

[0032]

That is to say, the description “one or more amino acids ... are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids” is used to mean that the amino acids are substituted with amino acids each having the above-described bulkiness value that is smaller than that of wild-type amino acids. On the other hand, the description “one or more amino acids ... are substituted with other amino acids whose side chains have higher bulkiness than that of wild-type amino acids” is used to mean that the amino acids are substituted with amino acids each having the above-described bulkiness value that is larger than that of wild-type amino acids.

In particular, the hydrolase protein of the present invention is preferably a hydrolase protein wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or

more leucine or isoleucine residues at amino acid numbers 70, 270, 273, and 313 are substituted with amino acids each having the above-described bulkiness value that is smaller than their bulkiness values.

[0033]

Examples of such a hydrolase protein include the following (e), (f), (g), (h), and (i):

(e) the hydrolase protein described in (d) above, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, at least the leucine at amino acid number 70 is substituted with any one of aspartic acid, asparagine, serine, threonine, and glycine;

(f) the hydrolase protein described in (d) or (e) above, wherein, in the amino acid sequence shown in SEQ ID NO. 3 or 4, the leucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine;

(g) the hydrolase protein described in (d) or (e) above, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1, 2, and 5, the isoleucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine;

(h) the hydrolase protein described in any one of (d) to (g) above, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 273 is substituted with either arginine or histidine; and

(i) the hydrolase protein described in any one of (d) to (h) above, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 313 is substituted with any one of methionine, alanine, and proline.

[0034]

The hydrolase protein of the present invention is particularly preferably a hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in SEQ ID NO. 4, the leucine at amino acid number 70 is substituted with aspartic acid, the leucine at amino acid number 270 is substituted with any one of glutamine, glutamic acid and alanine, the leucine at amino acid number 273 is substituted with arginine, and the leucine at amino acid number 313 is substituted with methionine, and which has activity of catalyzing the reaction represented by the above formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1.

[0035]

The hydrolase protein of the present invention further includes a hydrolase protein, which consists of an amino acid sequence having homology of 90% or more with the amino acid sequence of the above-described hydrolase protein of the present invention, or an amino acid sequence comprising a substitution, deletion, and/or addition of one or several amino acids with respect to the amino acid sequence of the above-described hydrolase protein of the present

invention, and which has activity of catalyzing the reaction represented by the formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1.

[0036]

In the present invention, the term "homology of 90%" in the description "an amino acid sequence having homology of 90% or more with the amino acid sequence of the above-described hydrolase protein of the present invention" is used to mean that the concerned amino acid sequence has homology or identity of 90% or more, preferably 93% or more, more preferably 95% or more, and particularly preferably 98% or more, with the amino acid sequence of the hydrolase protein of the present invention.

[0037]

In the present invention, the term "one or several" in the description "a substitution, deletion, and/or addition of one or several amino acids" is used to mean, for example, about 1 to 40, preferably about 1 to 20, more preferably about 1 to 10, and further preferably about 1 to 5 amino acids.

[0038]

The origin of the hydrolase protein of the present invention is not particularly limited. It may be a natural enzyme derived from microorganisms and the like, or a genetically recombinant protein.

[0039]

Such a natural enzyme can be preferably obtained from *Bacillus subtilis*. Specifically, the hydrolase protein of the present invention can be obtained from strains such as *Bacillus subtilis* NBRC3026, *Bacillus subtilis* NBRC3108, *Bacillus subtilis* NBRC3027, and *Bacillus subtilis* NBRC3013, by ordinary methods for extracting and purifying enzymes. Specific examples of the extraction method include: extraction methods involving cell disruption, such as fragmentation, homogenization, a sonic treatment, an osmotic shock procedure and a freezing-thawing process; extraction with a surfactant; and a combination of these methods. Specific examples of the purification method include salting-out using ammonium sulfate, sodium sulfate, etc., centrifugation, dialysis, ultrafiltration, adsorption chromatography, ion exchange chromatography, hydrophobic chromatography, reversed phase chromatography, gel filtration, gel permeation chromatography, affinity chromatography, electrophoresis, zymography, and a combination of these methods.

[0040]

A gene of the hydrolase protein of the present invention is cloned according to a known method, and the cloned gene is then introduced into a suitable host to allow it to express therein, so that the hydrolase protein of the present invention can be obtained as a genetically recombinant

protein. For example, on the basis of information regarding the nucleotide sequence of a gene encoding the hydrolase protein of the present invention, probes or primers that are specific to the gene of the hydrolase protein of the present invention are designed. Using the probes or primers, a DNA encoding the hydrolase protein of the present invention is isolated or amplified from a DNA library (e.g. a genomic DNA library, a cDNA library, etc.) of *Bacillus subtilis* NBRC3026, *Bacillus subtilis* NBRC3108, *Bacillus subtilis* NBRC3027, *Bacillus subtilis* NBRC3013 or the like. Then, the DNA is inserted into a vector by gene recombination. Thereafter, the vector is introduced into host cells, so that the DNA is expressed therein, thereby obtaining the hydrolase protein of the present invention.

[0041]

(2) DNA of the Present Invention

According to the present invention, there is provided a DNA encoding the above-described hydrolase protein of the present invention.

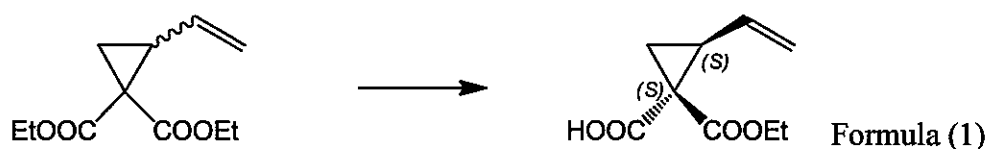
Specific examples of the DNA of the present invention include those consisting of the following nucleotide sequences (a), (b), and (c):

(a) the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10;

(b) a nucleotide sequence of a DNA capable of hybridizing under stringent conditions with the DNA consisting of the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10, wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing the reaction represented by the following formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1; and

(c) a nucleotide sequence comprising a substitution, deletion, and/or addition of one or several nucleotides with respect to the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10, wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing the reaction represented by the following formula (1) at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1:

[Formula 9]



[0042]

The DNA encoding the hydrolase protein of the present invention is a DNA that is cloned from *Bacillus subtilis* NBRC3026, *Bacillus subtilis* NBRC3108, *Bacillus subtilis* NBRC3027 or *Bacillus subtilis* NBRC3013, or a DNA which is obtained by introducing a mutation to the

aforementioned DNA. Since the nucleotide sequence of the concerned DNA has been determined by the present invention, a DNA can also be synthesized based on the determined nucleotide sequence. Furthermore, a DNA can also be isolated from a DNA library (e.g. a genomic DNA library, a cDNA library, etc.) of microorganisms such as *Bacillus subtilis* by hybridization using, as a probe, an oligonucleotide produced based on the determined nucleotide sequence, or by PCR using, as a primer, an oligonucleotide produced based on the determined nucleotide sequence. Still further, the DNA of the hydrolase protein of the present invention may not only be separated from natural microorganisms, but may also be synthesized by a known DNA synthesis method, such as the method described in U.S. Patent No. 6,472,184 or U.S. Patent No. 5,750,380.

[0043]

In the present invention, the "DNA capable of hybridizing under stringent conditions with ..." means a DNA comprising a nucleotide sequence having homology of 80% or more, preferably 90% or more, and more preferably 95% or more, with the DNA having the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10 or a complementary sequence thereof, by BLAST analysis. Moreover, the hybridization under stringent conditions can be carried out by a method, which comprises performing a reaction at a temperature from 40°C to 70°C, and preferably from 60°C to 65°C in an ordinary hybridization buffer, and then washing the reaction product in a washing solution having a salt concentration of, for example, 15 mM to 300 mM, and preferably 15 mM to 60 mM.

[0044]

In the present invention, the term "one or several" in the description "a substitution, deletion, and/or addition of one or several nucleotides" is used to mean, for example, about 1 to 30, preferably about 1 to 20, more preferably about 1 to 10, and further preferably about 1 to 5 nucleotides.

[0045]

A person skilled in the art can readily select a substitution, deletion, and/or addition of amino acids, which does not substantially affect enzyme activity. In addition, the DNA encoding the hydrolase protein of the present invention having a substitution, deletion, and/or addition of amino acids, which does not substantially affect enzyme activity, can be obtained from a natural mutant strain or a variety, for example.

[0046]

A DNA having a nucleotide sequence comprising a substitution, deletion, and/or addition of one or several nucleotides with respect to the nucleotide sequence of any one of SEQ ID NOS. 7 to 10 can be produced by ordinary mutation operations such as a method using a mutation

inducer or site-directed mutagenesis. These mutation operations can be readily carried out, for example, using commercially available kits such as PrimeSTAR Mutagenesis Basal Kit (Takara Bio Inc.) or QuikChange Site-Directed Mutagenesis Kit (manufactured by Stratagene).

[0047]

(3) Recombinant Vector and Transformant

According to the present invention, there is further provided a recombinant vector having the DNA of the present invention. In order to prepare a recombinant vector, in general, the DNA of the present invention and a promoter suitable for host microorganisms are inserted into a vector, so that the 5'-terminal side of the coding region of the DNA of the present invention can be ligated to the downstream of the promoter. Alternatively, an expression vector containing a promoter may be used, and the DNA of the present invention may be inserted into the expression vector.

[0048]

The expression vector is not particularly limited, as long as it can replicate and proliferate in host microorganisms. Examples of such an expression vector include a plasmid vector, a shuttle vector, and a phage vector. Specific examples of the plasmid vector include pBR322, pUC18, pHSG298, pUC118, pSTV28, pTWV228, and pHY300PLK (all of these plasmid vectors are available from, for example, Takara Bio Inc.), and pET Expression Vector Series (manufactured by Novagen). Examples of shuttle vector for the *E. coli*/coryneform bacteria include: the plasmid pCRY30 described in JP Patent Publication (Kokai) No. 3-210184 A (1991); the plasmids pCRY21, pCRY2KE, pCRY2KX, pCRY31, pCRY3KE and pCRY3KX described in JP Patent Publication (Kokai) No. 2-276575 A (1990); the plasmids pCRY2 and pCRY3 described in JP Patent Publication (Kokai) No. 1-191686 A (1989); pAM330 described in JP Patent Publication (Kokai) No. 58-67679 A (1983); pHM1519 described in JP Patent Publication (Kokai) No. 58-77895 A (1983); pAJ655, pAJ611 and pAJ1844 described in JP Patent Publication (Kokai) No. 58-192900; pCG1 described in JP Patent Publication (Kokai) No. 57-134500 A (1982); pCG2 described in JP Patent Publication (Kokai) No. 58-35197 A (1983); pCG4 and pCG11 described in JP Patent Publication (Kokai) No. 57-183799 A (1982), and their derivatives. In addition, an example of the phage vector is a λ FixII vector (available from Stratagene).

[0049]

A promoter possessed by host microorganisms can be generally used as a promoter for the expression of a DNA encoding the hydrolase protein of the present invention. However, the promoter used herein is not limited thereto. The promoter is not particularly limited, as long as it has a nucleotide sequence derived from a prokaryote for initiating transcription of the DNA of

the hydrolase protein of the present invention. Specific examples of such a promoter include a lactose operon promoter, a tryptophan operon promoter, a λ phage-derived PL promoter, and a tryptophan-lactose hybrid (tac) promoter [H. A. Bose et al., Proc. Natl. Acad. Sci. U. S. A., Vol. 80, p.21 (1983)]. Among these promoters, an inducible promoter can also be used for the purpose of improving expression efficiency. For example, in the case of the aforementioned lactose operon promoter, gene expression can be induced by adding lactose or isopropyl- β -D-thiogalactoside (IPTG).

[0050]

According to the present invention, there is further provided a transformant, which is obtained by introducing the DNA of the present invention or a recombinant vector into host cells. The host, into which the DNA of the present invention or a recombinant vector is to be introduced, is not particularly limited. Hosts, which have activity of hydrolyzing dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to compounds other than (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, are not preferably used. Moreover, hosts, which have activity of converting the generated (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid to another compound, are not preferable, either.

The host that can be used in the present invention can be selected by allowing a host candidate to come into contact with dialkyl 2-vinylcyclopropane-1,1-dicarboxylate or with (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid as a product of interest, and then analyzing a compound obtained as a result of the contact.

Specific examples of the host microorganisms that can be used in the present invention include bacteria such as *Escherichia* sp. (e.g. *Escherichia coli*). Moreover, bacteria such as *Actinomycetes* sp., *Bacillus* sp., *Serratia* sp., *Pseudomonas* sp., *Corynebacterium* sp., *Brevibacterium* sp., *Rhodococcus* sp., *Lactobacillus* sp., *Streptomyces* sp., *Thermus* sp., and *Streptococcus* sp., which have the above-described properties, can also be used as hosts, into which the DNA of the present invention or a recombinant vector is to be introduced.

[0051]

Specific examples of such host microorganisms that can be used herein include *Escherichia coli*, *Bacillus subtilis*, *Bacillus brevis*, *Bacillus stearothermophilus*, *Serratia marcescens*, *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Corynebacterium glutamicum*, *Brevibacterium flavum*, *Brevibacterium lactofermentum*, *Rhodococcus erythropolis*, *Thermus thermophilus*, *Streptococcus lactis*, *Lactobacillus casei*, and *Streptomyces lividans*, which have the above-described properties.

Furthermore, the above-described microorganisms, which have the activity of

hydrolyzing dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to compounds other than (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid or the activity of converting the generated (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid to another compound, can be used as hosts, into which the DNA of the present invention or a recombinant vector is to be introduced, by disrupting a gene encoding the enzyme protein having the aforementioned activity by the existing method.

[0052]

Examples of a method of introducing a gene into the above-described host microorganisms, which can be applied herein, include: transformation methods such as a competent cell method [Journal of Molecular Biology, Vol. 53, p. 159 (1970)] and a pulse wave electrification method [J. Indust. Microbiol., Vol. 5, p. 159 (1990)]; a transduction method using phage [E. Ohtsubo, Genetics, Vol. 64, p. 189 (1970)]; a conjugal transfer method [J. G. C. Ottow, Ann. Rev. Microbiol., Vol. 29, p. 80 (1975)]; and a cell fusion method [M. H. Gabor, J. Bacteriol., Vol. 137, p. 1346 (1979)]. From these methods, a method suitable for host microorganisms may be selected, as appropriate.

[0053]

In addition to the above-described gene expression method using an expression vector, the gene may also be allowed to express by a homologous recombination technique whereby the DNA encoding the hydrolase protein of the present invention ligated to a promoter is directly introduced into the chromosome of a host microorganism, or by a technique of introducing the gene using transposon, an insertion sequence or the like. Accordingly, the transformant of the present invention is sufficient, as long as the enzyme of the present invention is expressed therein. The method of introducing the gene into a host is not limited.

[0054]

(4) Production of Hydrolase Protein of the Present Invention Using Transformant

According to the present invention, the transformant obtained as described above may be cultured, and the hydrolase protein of the present invention may be then obtained from the culture.

[0055]

The transformant can be cultured in an ordinary nutritive medium containing a carbon source, a nitrogen source, inorganic salts, various types of vitamins, etc. Examples of the carbon source used herein include: sugars such as glucose, sucrose, fructose and maltose; alcohols such as ethanol and methanol; organic acids such as citric acid, malic acid, succinic acid, maleic acid and fumaric acid; and blackstrap molasses. As a nitrogen source, ammonia, ammonium sulfate, ammonium chloride, ammonium nitrate, urea and the like are used singly or in combination.

Examples of the inorganic salts used herein include potassium monohydrogen phosphate, potassium dihydrogen phosphate, and magnesium sulfate. Other than these substances, nutritive substances such as peptone, meat extract, yeast extract, corn steep liquor, casamino acid, and various types of vitamins such as biotin, may be added to the medium.

[0056]

The culture is generally carried out under aerobic conditions involving aeration stirring, shaking, or the like. The culture temperature is not particularly limited, as long as it allows host microorganisms to grow. In addition, the pH applied during the culture is not particularly limited, either, as long as it allows host microorganisms to grow. During the culture, the pH value can be adjusted by addition of acid or alkali.

[0057]

An enzyme can be collected from the culture according to a known collection method, using the activity of the enzyme as an indicator. It is not always necessary to purify the collected enzyme to a homogeneous state. The enzyme may be purified up to a purification degree that depends on intended use.

[0058]

As a roughly purified fraction or a purified enzyme used in the present invention, there may be used a cell mass separated from cell broth obtained as a result of the cultivation of a transformant; a disrupted product obtained by disrupting the cell broth or the cell mass by means such as ultrasonic wave or friction under pressure; an extract containing the hydrolase protein of the present invention, which is obtained by extracting the disrupted product with water or the like; a crude preparation of the hydrolase protein of the present invention, which is obtained by further performing a treatment such as ammonium sulfate fractionation or column chromatography on the above-described extract; or a purified enzyme preparation. Furthermore, a product obtained by immobilizing the above-described cell mass, disrupted product, extract, roughly purified fraction or purified enzyme on a carrier may also be used.

[0059]

The above-described cell mass, cell mass disrupted product, extract, or purified enzyme can be immobilized on a suitable carrier such as an acrylamide monomer, alginic acid or carrageenan, according to a known ordinary method of immobilizing such cell mass or the like on a carrier. For example, when the cell mass is immobilized on the carrier, the cell mass, which has just been recovered from the culture or has been washed with a suitable buffer such as an approximately 0.02 to 0.2 M phosphate buffer (pH 6 to 10), can be used.

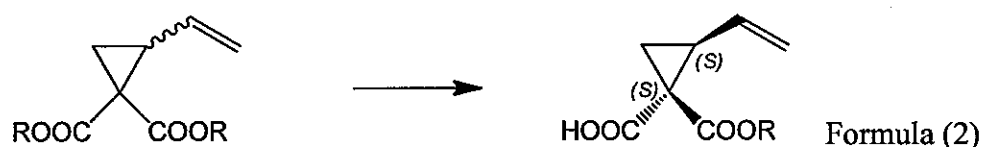
[0060]

(5) Production of (1S,2S)-1-Alkoxycarbonyl-2-Vinylcyclopropanecarboxylic Acid Using

Hydrolase Protein of the Present Invention

According to the present invention, there is provided a production method represented by the following formula (2), namely, a method for producing (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, which comprises allowing the hydrolase protein of the present invention to act on dialkyl 2-vinylcyclopropane-1,1-dicarboxylate, so as to produce the (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

[Formula 10]



In the formula (2), R represents an alkyl group containing 1 to 10 carbon atoms, an aralkyl group containing 7 to 20 carbon atoms or an aryl group containing 6 to 12 carbon atoms, each of which may be optionally substituted.

[0061]

An example of the alkyl group containing 1 to 10 carbon atoms which may be optionally substituted, which is represented by R, is a substituted or unsubstituted, linear, branched or cyclic alkyl group containing 1 to 10 carbon atoms. A substituted or unsubstituted, linear, branched or cyclic alkyl group containing 1 to 6 carbon atoms is more preferable. Among these groups, preferred examples include a methyl group, an ethyl group, an isopropyl group, a normal propyl group, a normal butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a normal pentyl group, an isopentyl group, a tert-pentyl group, a neopentyl group, a normal hexyl group, a cyclopropyl group, a cyclobutyl group, a cyclopentyl group, and a cyclohexyl group. An alkyl group containing 1 to 4 carbon atoms is particularly preferable.

[0062]

The aralkyl group containing 7 to 20 carbon atoms which may be optionally substituted, which is represented by R, is preferably a substituted or unsubstituted aralkyl group containing 7 to 12 carbon atoms. Among these groups, preferred examples include a benzyl group, a 4-methylbenzyl group, a 4-methoxybenzyl group, a 4-chlorobenzyl group, a 4-bromobenzyl group, a 2-phenylethyl group, a 1-phenylethyl group, and a 3-phenylpropyl group.

[0063]

Examples of the aryl group containing 6 to 12 carbon atoms which may be optionally substituted, which is represented by R, include a phenyl group, a 1-naphthyl group, a 2-naphthyl group, an o-methylphenyl group, a m-methylphenyl group, a p-methylphenyl group, an

o-methoxyphenyl group, a m-methoxyphenyl group, a p-methoxyphenyl group, a 2,3-dimethylphenyl group, a 2,4-dimethylphenyl group, a 2,5-dimethylphenyl group, a 2,6-dimethylphenyl group, a 3,4-dimethylphenyl group, a 3,5-dimethylphenyl group, a 2,3,5-trimethylphenyl group, a 2,3,6-trimethylphenyl group, a 2,4,6-trimethylphenyl group, an o-nitrophenyl group, a m-nitrophenyl group, and a p-nitrophenyl group.

R is preferably a methyl group, an ethyl group, a tert-butyl group, or a benzyl group, and is more preferably an ethyl group.

[0064]

When the hydrolase protein of the present invention is allowed to act on dialkyl 2-vinylcyclopropane-1,1-dicarboxylate, a purified or roughly purified hydrolase protein of the present invention, a microorganism that generates the hydrolase protein of the present invention (e.g. a transformant having a DNA encoding the hydrolase protein of the present invention, etc.), or a treated product thereof, is allowed to act on the dialkyl 2-vinylcyclopropane-1,1-dicarboxylate, so as to produce (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

[0065]

The reaction method is not particularly limited. Dialkyl 2-vinylcyclopropane-1,1-dicarboxylate used as a substrate is added to a liquid containing the hydrolase protein of the present invention, and the reaction can be then carried out at an appropriate temperature (e.g. approximately 10°C to 40°C) or under an appropriate pressure (e.g. around atmospheric pressure). Thereby, (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid can be produced.

[0066]

The method of fractionating the (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid of interest from the reaction mixture is not particularly limited. A separation or purification method that is known to a person skilled in the art can be applied. Examples of the applicable separation or purification method include, but are not limited, solvent extraction, crystallization, resin adsorption, and column chromatography.

[0067]

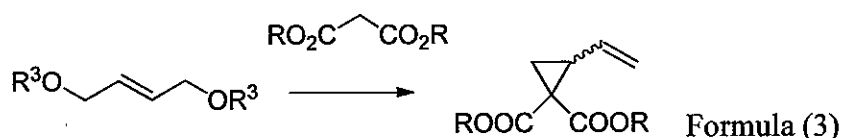
The hydrolase protein of the present invention can be particularly preferably used in a method of hydrolyzing diethyl 2-vinylcyclopropane-1,1-dicarboxylate to produce (1S,2S)-1-ethoxycarbonyl-2-vinylcyclopropanecarboxylic acid.

[0068]

Moreover, the dialkyl 2-vinylcyclopropane-1,1-dicarboxylate of the present invention

can be produced by the reaction represented by the following formula (3):

[Formula 11]



Specifically, the raw material compound of the formula (3) is allowed to react with a malonic ester in the presence of an alkali metal alkoxide or alkali metal hydride, so as to produce the dialkyl 2-vinylcyclopropane-1,1-dicarboxylate of the present invention.

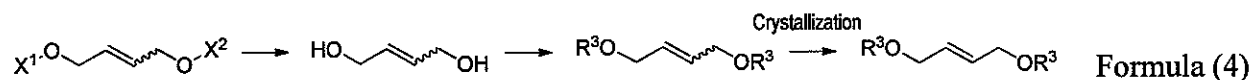
[0069]

In the formula (3), wherein R^3 represents an arylsulfonyl group containing 6 to 12 carbon atoms, an alkylsulfonyl group containing 1 to 10 carbon atoms or an aralkylsulfonyl group containing 7 to 20 carbon atoms, each of which may be optionally substituted. Examples of R^3 include a benzenesulfonyl group, a p-toluenesulfonyl group, a 1-naphthalenesulfonyl group, a 2-naphthalenesulfonyl group, a methanesulfonyl group, an ethanesulfonyl group, a propanesulfonyl group, a trifluoromethanesulfonyl group, and a benzylsulfonyl group. R^3 is preferably a methanesulfonyl group, a benzenesulfonyl group, and a p-toluenesulfonyl group. Among these groups, a p-toluenesulfonyl group is particularly preferable. And, R has the same definitions as those described above.

[0070]

Herein, the raw material compound of the formula (3) can be produced according to a known method, such as the method described in Frederic Dolle et al., Bioorg. Med. Chem. 2006, 14, 1115-1125, etc. Otherwise, the raw material compound of the formula (3) can also be produced by the reaction represented by the following formula (4):

[Formula 12]



[0071]

Specifically, 1,4-butanediol is allowed to react with the compound represented by R^3X , followed by crystallization, so as to produce the raw material compound of the formula (3). Alternatively, a commercially available raw material compound is hydrolyzed with an acid or a base to obtain 1,4-butanediol, and the obtained 1,4-butanediol is then allowed to react with the compound represented by R^3X , followed by crystallization, so as to produce the raw material compound of the formula (3).

In the formula (4), X^1 represents a hydrogen atom or R^1 , and X^2 represents a hydrogen atom or R^2 , wherein R^1 and R^2 each independently represent an alkylcarbonyl group containing 2 to 11 carbon atoms, an aralkylcarbonyl group containing 8 to 21 carbon atoms or an arylcarbonyl group containing 7 to 13 carbon atoms, each of which may be optionally substituted, provided that X^1 and X^2 do not simultaneously represent hydrogen atoms. Preferably, X^1 is R^1 , and X^2 is R^2 . More preferably R^1 and R^2 each represent an acetyl group, an ethylcarbonyl group, a tert-butylcarbonyl group, or a benzoyl group. Further preferably, R^1 and R^2 each represent an acetyl group.

[0072]

Using the (1S,2S)-1-ethoxycarbonyl-2-vinylcyclopropanecarboxylic acid obtained in the present invention, there can be produced

(1R,2S)/(1S,2R)-1-amino-1-ethoxycarbonyl-2-vinylcyclopropane that is an intermediate useful for the production of various types of HCV NS3 protease inhibitors and the like, which are currently under development as therapeutic agents for hepatitis C, and a salt thereof.

[0073]

The present invention will be described more in detail in the following examples. However, these examples are not intended to limit the scope of the present invention.

[Examples]

[0074]

Example 1: Cloning of para-Nitrobenzyl Esterase Gene (pnbA; SEQ ID NOS. 6 to 10)

(1) Gene Cloning

Bacillus subtilis ATCC23857, *Bacillus subtilis* NBRC3026, *Bacillus subtilis* NBRC3108, *Bacillus subtilis* NBRC3027, and *Bacillus subtilis* NBRC3013 were each cultured overnight in liquid media designated by their culture collection institutes. Thereafter, a chromosomal DNA was prepared from each of the obtained cell masses, using DNeasy Blood & Tissue Kit (manufactured by QIAGEN).

[0075]

Based on a gene sequence (hereinafter referred to as pnbA23857, SEQ ID NO. 6) encoding para-nitrobenzyl esterase derived from *Bacillus subtilis* ATCC23857 whose genome sequence had been known (hereinafter referred to as PNBE23857, GenBank Accession No. ZP_03593235, SEQ ID NO. 1), primers for amplifying a full-length para-nitrobenzyl esterase gene, pnbA F and pnbA R were designed and synthesized. The nucleotide sequences of the two primers are shown in SEQ ID NO. 11 (pnbA F) and SEQ ID NO. 12 (pnbA R) in the sequence listing, respectively.

Using, as a template, each of the chromosomal DNAs prepared from the individual strains, and also using pnbA F and pnbA R as primers, a DNA fragment with a size of approximately 1.5 kbp was amplified by a polymerase chain reaction (PCR).

In this PCR, the reaction was carried out using Easy-A High Fidelity PCR Cloning Enzyme (manufactured by Agilent Technologies) under the conditions described in instruction manuals included with the kit. As for temperature conditions, after retention at 94°C for 2 minutes, a cycle (94°C, 30 seconds; 50°C, 30 seconds; and 72°C, 90 seconds) was repeated 35 times, and the reaction product was then retained at 72°C for 5 minutes, before termination of the reaction.

[0076]

(2) Preparation of Expression Vector

Using, as a template, the plasmid pKV32 that had been prepared according to the method described in JP Patent Publication (Kokai) No. 2005-34025 A, and also using the primer (pKVXmaIFW) shown in SEQ ID NO. 19 and the primer (pKVXmaIRV) shown in SEQ ID NO. 20, a fragment with a size of approximately 4 kbp was amplified by PCR. The amplified fragment was digested with the restriction enzyme XmaI, and thereafter, using Ligation-Convenience Kit (manufactured by Nippon Gene Co., Ltd.), it was subjected to self ligation to obtain a plasmid. The obtained plasmid was named as pKW32.

In this PCR, the reaction was carried out using KOD-plus-Ver. 2 (manufactured by Toyobo Co., Ltd.) under the conditions described in instruction manuals included with the kit. As for temperature conditions, after retention at 94°C for 2 minutes, a cycle (94°C, 15 seconds; 58°C, 30 seconds; and 68°C, 4 minutes) was repeated 30 times, and the reaction product was then retained at 68°C for 5 minutes, before termination of the reaction.

[0077]

(3) Preparation of Expression Plasmid

Using Ligation-Convenience Kit (manufactured by Nippon Gene Co., Ltd.), the DNA fragments obtained in (1) above were each inserted into the cloning vector pKW32 prepared in (2) above. Hereinafter, the obtained plasmids were referred to as ppnbA23857, ppnbA3026, ppnbA3108, ppnbA3027, and ppnbA3013.

[0078]

With regard to the plasmids ppnbA3026, ppnbA3108, ppnbA3027, and ppnbA3013, the DNA sequences that had been inserted into them were analyzed, and as a result, it was confirmed that they each contained a gene consisting of 1467-bp ORF. The obtained genes were named as pnbA3026, pnbA3108, pnbA3027, and pnbA3013, respectively. The DNA sequences of these genes were as shown in SEQ ID NOS. 7 (pnbA3026), 8 (pnbA3108), 9 (pnbA3027), and 10

(pnbA3013), respectively. The amino acid sequences encoded by these DNA sequences were named as PNBE3026, PNBE3108, PNBE3027, and PNBE3013, respectively. These amino acid sequences were as shown in SEQ ID NOS. 2 (PNBE3026), 3 (PNBE3108), 4 (PNBE3027), and 5 (PNBE3013), respectively. These amino acid sequences showed sequence identity of 97%, 91%, 90%, and 98%, respectively, with the amino acid sequence (SEQ ID NO. 1) of the known PNBE23857.

[0079]

Example 2: Comparison of Selectivity of Novel para-Nitrobenzyl Esterase

Using the 5 types of plasmids obtained in Example 1, *Escherichia coli* JM109 (manufactured by Takara Bio Inc.) was transformed according to an ordinary method. The obtained recombinant *Escherichia coli* were each subjected to a shaking culture at 30°C in a liquid LB medium containing 20 mg/l kanamycin and 0.2 mM IPTG. On the 20th hour of the culture, cells were collected.

The obtained cell mass was reacted in a 100 mM potassium phosphate buffer containing a 5 g/l racemic form of 1,1-diethoxycarbonyl-2-vinylcyclopropane (hereinafter referred to as "VCPDE") and 5% dimethyl sulfoxide at 30°C at pH 7 for 21 hours.

[0080]

After completion of the reaction, the reaction solution was analyzed by high performance liquid chromatography (HPLC) under the following conditions.

Column: CHIRALPAK AD-3 (4.6 x 250 mm, manufactured by Daicel Corporation)

Eluent: hexane : ethanol : trifluoroacetic acid = 95 : 5 : 0.1

Flow rate: 0.8 ml/min

Temperature: 30°C

Detection: UV 210 nm

[0081]

As a result of the analysis, generation of 1-ethoxycarbonyl-2-vinylcyclopropanecarboxylic acid (hereinafter referred to as "VCPME") was confirmed. Based on the obtained results, the "1R2S/1S2S ratio" that indicates the ratio between the (1S,2S) form and the (1R,2S) form in the generated VCPME, the "1S2S form optical purity" that indicates the enantiomer excess of the (1S,2S) form to the (1R,2R) form, and the "1S2R/1S2S ratio" that indicates the ratio between the (1S,2S) form and the (1S,2R) form, which were to be used as indicators of selectivity, were obtained. The results are summarized in Table 1. Moreover, the hydrolytic activity of the concerned substrate was not observed in a cell mass that had been transformed with only the plasmid pKW32. All of the enzymes exhibited a sufficiently low value of the "1R2S/1S2S ratio."

[0082]

The three types of enzymes, PNBE3026, PNBE3108, and PNBE3027, exhibited a higher value of the "1S2S form optical purity" than that of the enzyme PNBE23857 whose sequence had been known.

Moreover, the enzyme PNBE3013 exhibited a lower value of the "1S2R/1S2S ratio" than that of the enzyme PNBE23857 whose sequence had been known.

[0083]

[Table 1]

Table 1				
Enzyme Name	1R2S/1S2S Ratio	1S2S Form Optical Purity (%e.e.)	1S2R/1S2S Ratio	Remarks
PNBE23857	0.0222	93.1	0.953	Reference Example
PNBE3026	0.0263	94.2	0.970	The present Invention
PNBE3108	0.0504	97.0	1.01	The present Invention
PNBE3027	0.0404	97.4	0.998	The present Invention
PNBE3013	0.0433	89.2	0.863	The present Invention

[0084]

Synthesis Example

The VCPDE used in Example 1 was synthesized as follows.

93.4 g (583 mmol) of malonic acid diethyl ester and 1000 mL of toluene were added into a four-necked flask (2 L), and thereafter, 223 mL (569 mmol) of a 20% sodium ethoxide ethanol solution was added thereto as a base. The obtained mixture was stirred at room temperature for 1.5 hours, and 59.4 g of trans-1,4-dibromo-2-butene (278 mmol; a reagent manufactured by Sigma-Aldrich) was then added to the reaction solution. The obtained mixture was stirred at room temperature for 2 hours, and 109 mL (278 mmol) of a 20% sodium ethoxide ethanol solution was then added to the reaction solution. The obtained mixture was stirred at room temperature for 1 hour, and 29.1 g of trans-1,4-dibromo-2-butene (136 mmol; a reagent manufactured by Sigma-Aldrich) was then added to the reaction solution. The mixture was stirred at room temperature for 4 hours, and 347 mL of a 1 M sodium hydroxide aqueous solution was then added to the reaction solution. The mixture was stirred for 14 hours, and an organic

layer was then separated. Subsequently, the organic layer was washed with 132 mL of water twice, and was then dried over anhydrous sodium sulfate. The resultant was filtrated, and the obtained filtrate was concentrated at 40°C under reduced pressure, so as to obtain 99.3 g of 1,1-di-ethoxycarbonyl-2-vinylcyclopropane in the form of a crude product of a light yellow oily substance. This crude product contained 83.2 g of 1,1-di-ethoxycarbonyl-2-vinylcyclopropane (yield: 94.9%). However, this crude product did not contain a malonic diethyl ester.

[0085]

Example 3: Three-Dimensional Structure Modeling of Hydrolase Protein of the Present Invention (SEQ ID NO. 4)

A BLAST search was performed against Protein Data Bank (PDB) for the amino acid sequence of PNBE3027. Three types of crystal structures as described below were selected as reference structures. It is to be noted that the notation "A56V" indicates that the amino acid residue at position 56, alanine (A), is substituted with valine (V).

- para-Nitrobenzyl esterase Mutation: A56V, I60V, T73K, L144M, L313F, H322Y, A343V, M358V, Y370F, A400T, G412E, I437T, T459S (PDB id: 1C7J); sequence identity: 89%
- para-Nitrobenzyl esterase Mutation: I60V, L144M, P317S, H322R, L334S, M358V, Y370F (PDB id: 1C7I); sequence identity: 90%
- para-Nitrobenzyl esterase (PDB id: 1QE3); sequence identity: 91%

[0086]

A homology model was produced using Discovery Studio Modeling (hereinafter abbreviated as DS Modeling) Ver. 2.5. With regard to the obtained initial modeling structure, CHARMM (Chemistry at Harvard Macromolecular Mechanics) force yield was assigned to each atom, and structural optimization was then performed based on molecular mechanics calculation. For such structural optimization, 1000 steps of calculation were performed by the Steepest Decent method, and then, 5000 steps of calculation were performed by the Adapted Basis Newton-Raphson method.

[0087]

A substrate complex model was produced by coordinating an S form and an R form of VCPDE, which served as a substrate, in the direction of generating (1S,2S)-VCPME and in the direction of generating (1R,2R)-VCPME, respectively, with respect to the obtained homology model, thereby creating an initial structure, and then performing energy minimization. When such energy minimization was performed, the following distance constraint conditions were determined, while taking into consideration the hydrolytic reaction mechanism of esterase.

[0088]

- The distance between the nitrogen atoms of three amides (Gly106, Ala107, Ala190) which forms

an oxyanion hole and the carbonyl oxygen of an ester bond to be hydrolyzed, , is set not less than 2.0Å and not more than 3.0Å.

- The distance between the alcohol oxygen atom of the active site Ser189 and the carbonyl carbon of an ester bond to be hydrolyzed is set not less than 2.0Å and not more than 3.0Å.

The structures obtained by the aforementioned treatments were defined as a "1S2S model" and a "1R2R model."

[0089]

Example 4: Assumption of Amino Acid Residues Associated with Recognition of Substrates in para-Nitrobenzyl Esterase

First, all of amino acid residues that were partially or entirely present within 8Å from the carbon atom at position 2 of a vinyl group of VCPDE were extracted from each of the "1S2S model" and the "1R2R model," obtained in Example 3. Discovery Studio Visualizer v2.5.5.9350 was used to calculate the distance. The distance from an atom other than a hydrogen atom which was closest to the carbon atom at position of the vinyl group of VCPDE in each model in the extracted each amino acid residue, was defined as the distance from each amino acid residue. With regard to each of the extracted amino acid residues, the above-defined distance in the "1S2S model" was compared with the above-defined distance in the "1R2R model." As a result, amino acid residues, in which the distance in the "1S2S model" is closer than the distance in the "1R2R model," are shown in Table 2, and amino acid residues, in which the distance in the "1R2R model" is closer than the distance in the "1S2S model," are shown in Table 3.

[0090]

From the aforementioned results, it is assumed that, in the case of the amino acid residues shown in Table 2, the modified amino acid residues whose side chains have lower bulkiness than that of wild-type amino acids are able to exhibit advantageous selectivity towards generation of the (1S,2S) form of VCPME, and that in the case of the amino acid residues shown in Table 3, the modified amino acid residues whose side chains have higher bulkiness than that of wild-type amino acids are able to exhibit such advantageous selectivity.

[0091]

[Table 2]

Table 2

Amino Acid Residue	Position	1S2S Form Model		1R2R Form Model	
		Distance (Å)	Target Atom	Distance (Å)	Target Atom
GLY	106	7.11	C	7.43	C
ALA	107	5.05	CB	5.76	CB
PHE	108	6.39	CE2	7.44	CE2
ARG	219	6.44	CG	7.16	NE
LEU	270	7.98	O		
PHE	271	4.13	O	4.66	O
GLN	272	5.57	O	6.48	OE1
LEU	273	3.35	CD2	4.70	CD2
LEU	274	7.46	N		
PHE	275	7.47	O		
GLN	276	7.38	OE1		

[0092]

[Table 3]

Table 3

Amino Acid Residue	Position	1S2S Form Model		1R2R Form Model	
		Distance (Å)	Target Atom	Distance (Å)	Target Atom
GLU	188			7.48	OE2
ALA	190	6.12	N	6.09	N
MET	193	3.75	CE	3.61	CE
SER	215	7.15	O	6.03	O
GLY	216	7.33	CA	6.67	CA
ALA	217	7.90	N	7.62	N
PHE	314	4.95	CZ	3.94	CZ
MET	358			7.40	O
LEU	362	3.64	CD2	3.18	CD2
PHE	363	4.71	CZ	3.36	CZ

[0093]

In Table 2 and Table 3, the abbreviations of the target atoms (the atoms in the amino acid residues) are described according to the method determined by the Protein Data Bank (PDB).

Several examples will be given below.

CA = Carbon, Alpha

CB = Carbon, Beta

CG = Oxygen, Gamma

CD = Carbon, Delta

CE = Carbon, Epsilon

CZ = Carbon, Zeta

OE = Oxygen, Epsilon

[0094]

Example 5: Modification of para-Nitrobenzyl Esterase Gene by Mutation Introduction

Using the plasmid ppnbA3027 obtained in Example 1 as a template, and also using the primer (L70FW) shown in SEQ ID NO. 13 in the sequence listing and the primer (L70RV) shown in SEQ ID NO. 14 in the sequence listing, QuikChange Multi Site-Directed Mutagenesis Kit (manufactured by Stratagene) was employed to introduce random mutation into a nucleotide encoding the leucine at amino acid position 70 in the aforementioned plasmid. The obtained approximately 200 colonies were each subjected to a shaking culture at 30°C in a liquid LB medium containing 20 mg/l kanamycin and 0.2 mM IPTG, and on the 20th hour of the culture, cells were collected.

The obtained cell mass was reacted in a 100 mM potassium phosphate buffer containing a 5 g/l or 30 g/l racemic form of VCPDE and 5% dimethyl sulfoxide at 30°C at pH 7 for 21 hours.

Moreover, in the same way, using the primer (L313FW) shown in SEQ ID NO. 15 in the sequence listing and the primer (L313RV) shown in SEQ ID NO. 16 in the sequence listing, random mutation was introduced into a nucleotide encoding the leucine residue at amino acid number 313 in the aforementioned plasmid, and the obtained approximately 200 colonies were then reacted by the same method as that described above.

Furthermore, in the same way, using the primer (L270L273FW) shown in SEQ ID NO. 17 in the sequence listing and the primer (L270L273RV) shown in SEQ ID NO. 18 in the sequence listing, random mutation was introduced into nucleotides encoding the leucine residues at amino acid numbers 270 and 273 in the aforementioned plasmid. The obtained approximately 400 colonies were then reacted by the same method as that described above.

[0095]

After completion of the reaction, the reaction solution was analyzed by HPLC, applying

the same method and conditions as those in Example 2. The results regarding the reaction of each mutant strain, when the concentration of VCPDE as a substrate was set at 5 g/l, are shown in Table 4. The results regarding the reaction of each mutant strain, when the concentration of VCPDE as a substrate was set at 30 g/l, are shown in Table 5. With regard to the obtained clones, a plasmid DNA was extracted from each clone according to an ordinary method, and the DNA sequence thereof was then analyzed. As a result of the analysis, the amino acid residues in the mutation-introduced sites after completion of the mutation are shown in Table 4 and 5.

[0096]

As a result of a comparison made among No. 1 and Nos. 3 to 6 and 11 in Table 4, it was found that, when the leucine at amino acid number 70 was substituted with any one of aspartic acid, asparagine, serine, threonine, and glycine, the optical purity of the (1S,2S) form of the generated VCPME was improved. In addition, as a result of a comparison made between No. 1 as a wild type and Nos. 2, 7 and 13, it was also found that, when the leucine at amino acid number 313 was substituted with any one of methionine, alanine, and proline, the optical purity of the (1S,2S) form of the generated VCPME was improved. Moreover, it was found that in the case of Nos. 8, 10 and 15, the 1R2S/1S2S ratio in the generated VCPME was improved rather than that of a wild type by simultaneously substituting the leucine residues at amino acid numbers 70 and 313.

[0097]

Subsequently, as a result of a comparison between No. 1 of Table 4 and No. 16 of Table 5, it was confirmed that the 1S2S form optical purity was decreased by increasing the concentration of VCPDE as a substrate from 5 g/l to 30 g/l. Accordingly, it was clarified that the effect of the introduced mutation needs to be observed in the same substrate concentration. Moreover, as a result of a comparison between Nos. 19, 21 to 25 and No. 16 as a wild type in Table 5, it was confirmed that all of the 1R2S/1S2S ratio, 1S2S form optical purity, and 1S2R/1S2S ratio were improved by substituting the leucine at amino acid number 270 and the leucine at amino acid number 273 with other amino acid residues.

[0098]

[Table 4]

Table 4

No.	L70	L270	L273	L313	1R2S/1S2S Ratio	1S2S Form	
						Optical Purity (%e.e.)	1S2R/1S2S Ratio
1					0.0404	97.4	1.00
2				P	0.0315	97.7	1.01
3	G				0.0302	97.8	0.992
4	T				0.0298	97.8	0.995
5	S				0.0296	97.8	1.00
6	N				0.0293	97.9	1.00
7				A	0.0379	97.9	1.00
8	N			M	0.0213	97.9	1.00
9	D			A	0.0279	98.0	1.01
10	S			M	0.0224	98.0	1.00
11	D				0.0260	98.0	0.993
12	N			A	0.0307	98.0	1.01
13				M	0.0262	98.0	0.986
14	S			A	0.0309	98.2	1.01
15	D			M	0.0211	98.2	1.00

[0099]

[Table 5]

Table 5

No.	L70	L270	L273	L313	1R2S/1S2S Ratio	1S2S Form	
						Optical Purity (%e.e.)	1S2R/1S2S Ratio
16					0.0391	95.5	0.944
17				M	0.0373	96.1	1.02
18	D				0.0395	96.6	1.01
19		F	H		0.00436	96.7	0.704
20	D			M	0.0247	97.0	1.07
21		T	R		0.00458	97.1	0.692
22		G	R		0.00536	97.8	0.748
23		S	R		0.00503	98.3	0.420
24		A	R		0.00518	98.4	0.473
25		E	R		0.00375	98.8	0.310
26	D	Q	R	M	0.0973	98.9	0.461

[0100]

Individual symbols used in Table 4 and Table 5 represent the following.

P: Proline

G: Glycine

T: Threonine

S: Serine

N: Asparagine

A: Alanine

M: Methionine

D: Aspartic acid

F: Phenylalanine

H: Histidine

R: Arginine

E: Glutamic acid

Q: Glutamine

[0101]

Moreover, SEQ ID NOS. 1 to 20 in the present specification are defined as follows.

SEQ ID NO. 1: the amino acid sequence of the para-nitrobenzyl esterase derived from *Bacillus subtilis* ATCC23857 (PNBE23857, GenBank Accession No. ZP_03593235)

SEQ ID NO. 2: the amino acid sequence PNBE3026 of the hydrolase protein derived from *Bacillus subtilis* NBRC3026

SEQ ID NO. 3: the amino acid sequence PNBE3108 of the hydrolase protein derived from *Bacillus subtilis* NBRC3108

SEQ ID NO. 4: the amino acid sequence PNBE3027 of the hydrolase protein derived from *Bacillus subtilis* NBRC3027

SEQ ID NO. 5: the amino acid sequence PNBE3013 of the hydrolase protein derived from *Bacillus subtilis* NBRC3013

SEQ ID NO. 6: the gene sequence (pnbA23857) encoding the para-nitrobenzyl esterase derived from *Bacillus subtilis* ATCC23857 (PNBE23857, GenBank Accession No. ZP_03593235, SEQ ID NO. 1)

SEQ ID NO. 7: the nucleotide sequence pnbA3026 of a DNA encoding the hydrolase protein derived from *Bacillus subtilis* NBRC3026

SEQ ID NO. 8: the nucleotide sequence pnbA3108 of a DNA encoding the hydrolase protein derived from *Bacillus subtilis* NBRC3108

SEQ ID NO. 9: the nucleotide sequence pnbA3027 of a DNA encoding the hydrolase protein derived from *Bacillus subtilis* NBRC3027

SEQ ID NO. 10: the nucleotide sequence pnbA3013 of a DNA encoding the hydrolase protein derived from *Bacillus subtilis* NBRC3013

SEQ ID NO. 11: the primer pnbA F used to amplify a full-length para-nitrobenzyl esterase gene

SEQ ID NO. 12: the primer pnbA R used to amplify a full-length para-nitrobenzyl esterase gene

SEQ ID NO. 13: primer (L70FW)

SEQ ID NO. 14: primer (L70RV)

SEQ ID NO. 15: primer (L313FW)

SEQ ID NO. 16: primer (L313RV)

SEQ ID NO. 17: primer (L270L273FW)

SEQ ID NO. 18: primer (L270L273RV)

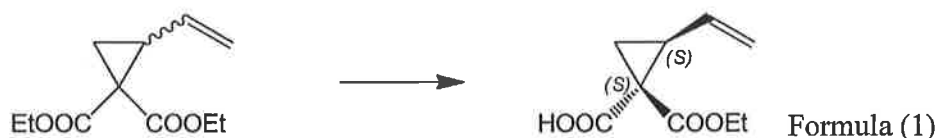
SEQ ID NO. 19: primer (pKVXmaIFW)

SEQ ID NO. 20: primer (pKVXmaIRV)

[Claims]

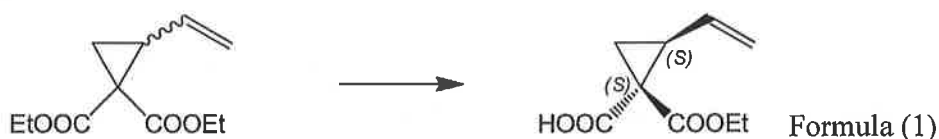
[Claim 1] A hydrolase protein, which consists of the amino acid sequence shown in any one of SEQ ID NOS. 2 to 5, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 1]



[Claim 2] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, one or more amino acids at amino acid numbers 70, 270, 273, and 313 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 2]



[Claim 3] The hydrolase protein according to claim 2, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, at least the leucine at amino acid number 70 is substituted with any one of aspartic acid, asparagine, serine, threonine, and glycine.

[Claim 4] The hydrolase protein according to claim 3, wherein, in the amino acid sequence shown in SEQ ID NO. 3 or 4, the leucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine.

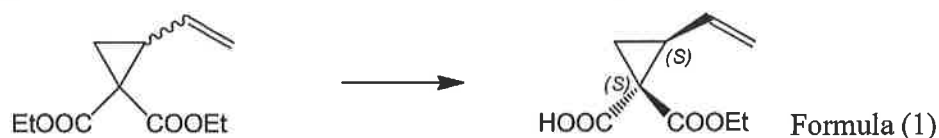
[Claim 5] The hydrolase protein according to claim 3, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1, 2, and 5, the isoleucine at amino acid number 270 is substituted with any one of serine, glutamine, glutamic acid, and alanine.

[Claim 6] The hydrolase protein according to any one of claims 3 to 5, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 273 is substituted with either arginine or histidine.

[Claim 7] The hydrolase protein according to any one of claims 3 to 6, wherein, in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5, the leucine at amino acid number 313 is substituted with any one of methionine, alanine, and proline.

[Claim 8] A hydrolase protein, which consists of an amino acid sequence wherein, in the amino acid sequence shown in SEQ ID NO. 4, the leucine at amino acid number 70 is substituted with aspartic acid, the leucine at amino acid number 270 is substituted with any one of glutamine, glutamic acid and alanine, the leucine at amino acid number 273 is substituted with arginine, and the leucine at amino acid number 313 is substituted with methionine, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 3]



[Claim 9] A hydrolase protein, which consists of an amino acid sequence having homology of 90% or more with the amino acid sequence of the hydrolase protein according to any one of claims 1 to 8, or an amino acid sequence comprising a substitution, deletion, and/or addition of one or several amino acids with respect to the amino acid sequence of the hydrolase protein according to any one of claims 1 to 8, wherein one or more amino acids which correspond to amino acid numbers 70, 270, 273, and 313 in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and which has activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 4]



[Claim 10] A DNA encoding the hydrolase protein according to any one of claims 1 to 9.

[Claim 11] The DNA according to claim 10, which consists of the following nucleotide sequence:

(a) the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10;

(b) a nucleotide sequence of a DNA capable of hybridizing under stringent conditions with the DNA consisting of a complementary strand of the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10,

wherein the nucleotide sequence encodes an amino acid sequence wherein one or more amino acids which correspond to amino acid numbers 70, 270, 273, and 313 in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and

wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1); or

(c) a nucleotide sequence comprising a substitution, deletion, and/or addition of one or several nucleotides with respect to the nucleotide sequence shown in any one of SEQ ID NOS. 7 to 10,

wherein the nucleotide sequence encodes an amino acid sequence wherein one or more amino acids which correspond to amino acid numbers 70, 270, 273, and 313 in the amino acid sequence shown in any one of SEQ ID NOS. 1 to 5 are substituted with other amino acids whose side chains have lower bulkiness than that of wild-type amino acids, and

wherein the nucleotide sequence encodes a hydrolase protein having activity of catalyzing, at higher selectivity than the protein consisting of the amino acid sequence shown in SEQ ID NO. 1, the reaction represented by the following formula (1):

[Formula 5]



[Claim 12] A method for producing (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid, which comprises allowing the hydrolase protein according to any one of claims 1 to 9 to act on dialkyl 2-vinylcyclopropane-1,1-dicarboxylate to produce (1S,2S)-1-alkoxycarbonyl-2-vinylcyclopropanecarboxylic acid.