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(54) **COMPOSITIONS AND METHODS FOR
USING NADH OXIDASES**

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17, 2010, provisional application No. 61/265,915,
filed on Dec. 2, 2009.

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C12P 1/00 (2006.01)

C12Q 1/26 (2006.01)

(52) **U.S. Cl.**

USPC **435/189**; 435/280; 435/41; 435/25

(58) **Field of Classification Search**

USPC 435/189, 280, 41, 25
See application file for complete search history.

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(57) **ABSTRACT**

The present disclosure relates generally to bacterial NADH
oxidases and, more particularly, to novel NADH oxidases
obtained from *Lactobacillus plantarum*, and derivatives
thereof that demonstrate enzymatic activity for NADH,
NADPH, or both NADH and NADPH. The compositions
comprising an NADH oxidase obtained from *L. plantarum* or
derivatives thereof include: isolated enzymes; recombinantly
produced enzymes and derivatives thereof, as well as cata-
lytically active portions thereof; nucleic acids encoding an
NADH oxidase obtained from *L. plantarum*, derivatives
thereof, and portions thereof. The methods of the present
invention include isolation of NADH oxidases obtained from
L. plantarum, derivatives thereof, and portions thereof, and
methods for enzymatic reactions comprising NADH oxidase
obtained from *L. plantarum*, including the production of
enantiomer-enriched organic compounds.

13 Claims, 3 Drawing Sheets

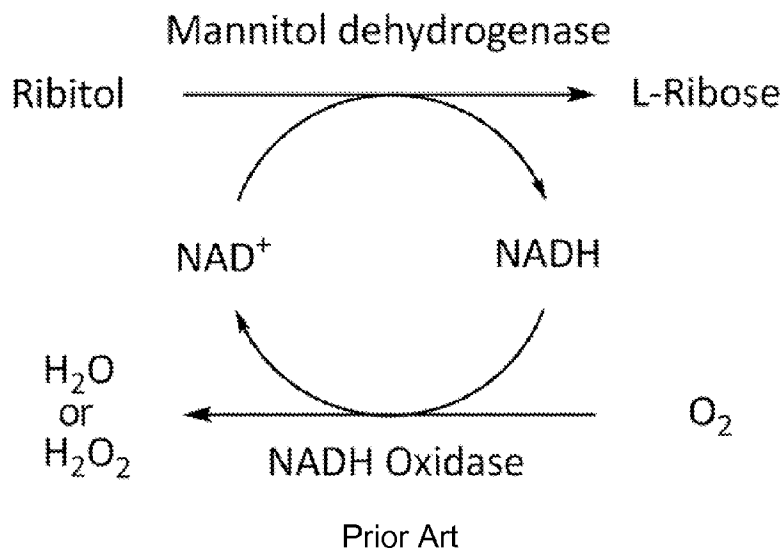


FIGURE 1

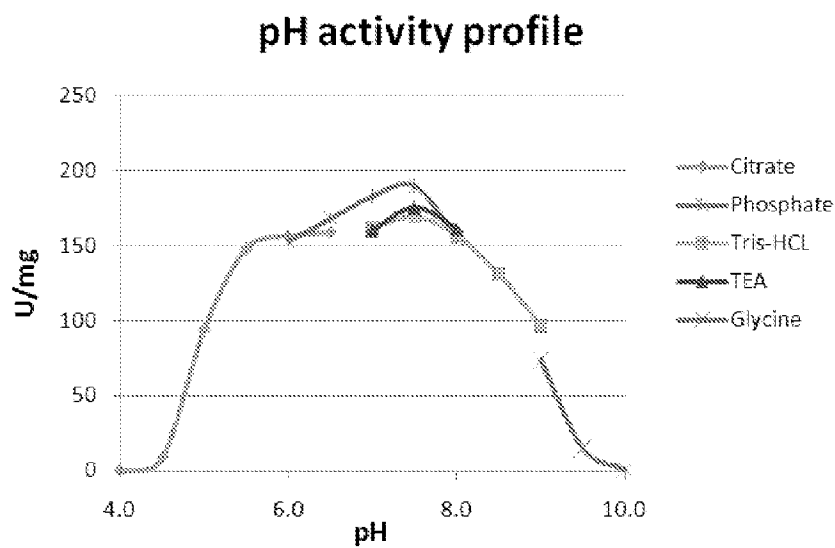


FIGURE 2

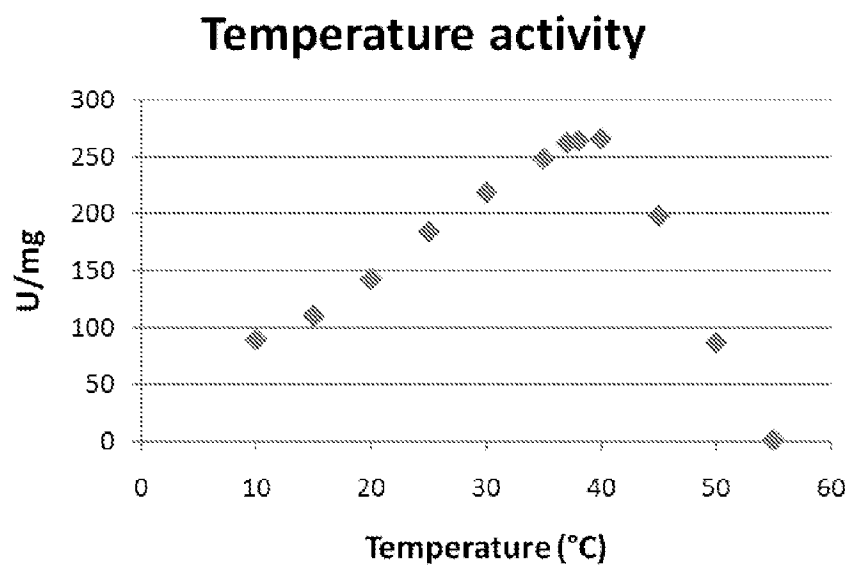


FIGURE 3

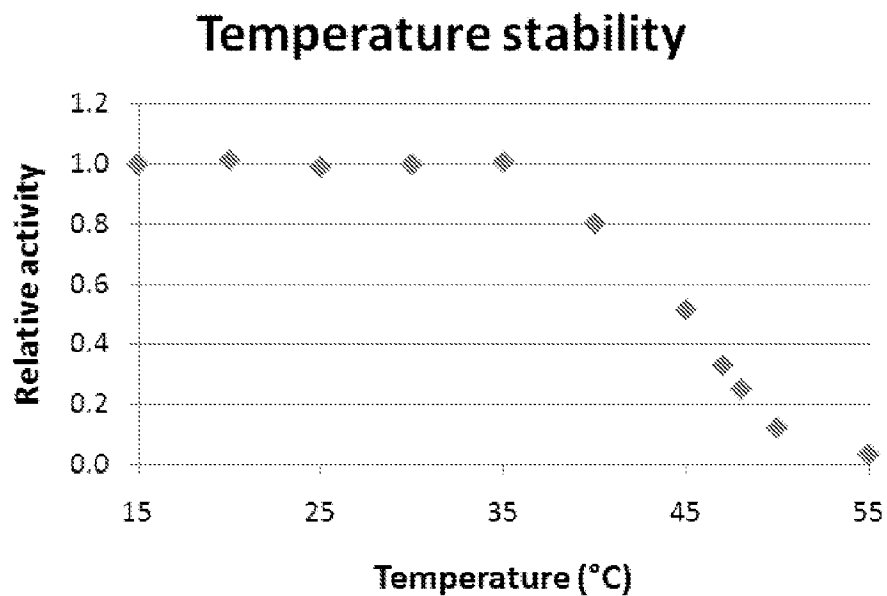


FIGURE 4

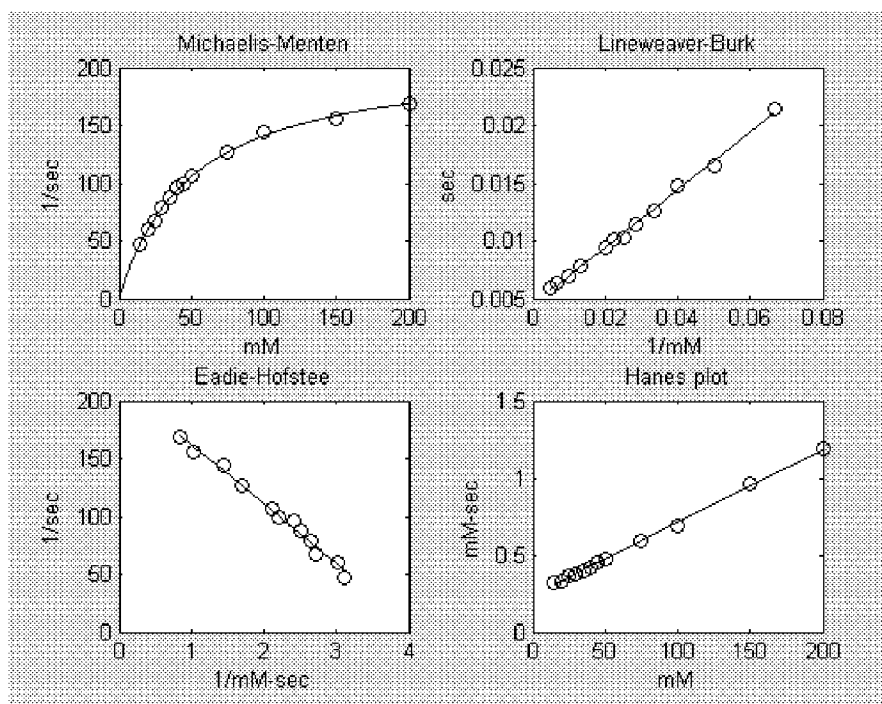


FIGURE 5

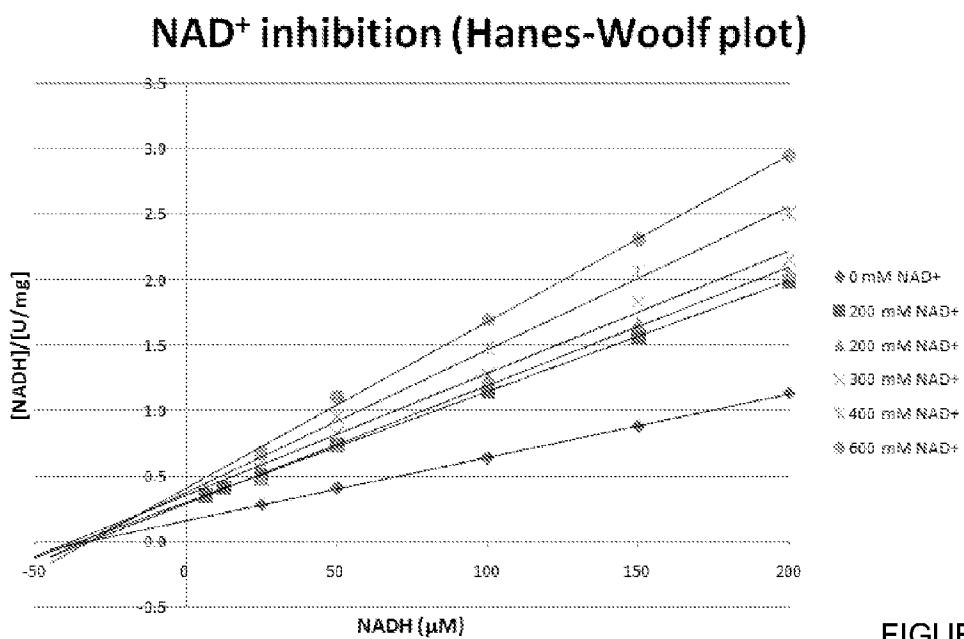


FIGURE 6

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COMPOSITIONS AND METHODS FOR USING NADH OXIDASES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims, under 35 U.S.C. §119(e), the benefit of U.S. Provisional Application Ser. No. 61/265,915, filed 2 Dec. 2009, and U.S. Provisional Application Ser. No. 61/383,858, filed 17 Sep. 2010, the entire contents and substance of which are hereby incorporated by reference as if fully set forth below.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with U.S. Government support under Grant No. 2 R44AI65127-02 awarded by the National Institutes of Health. The U.S. Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

1. Technical Field

The various embodiments of the present disclosure relate generally to bacterial NADH oxidases and, more particularly, to NADH oxidases obtained from *Lactobacillus plantarum*, and derivatives thereof that demonstrate enzymatic activity for NADH, NADPH, or both NADH and NADPH.

2. Description of Related Art

Enantiomerically pure compounds (EPCs), especially amino and hydroxy acids as well as alcohols, amines, and lactones are increasingly useful in the pharmaceutical, food, and crop protection industries as building blocks for novel compounds not accessible through fermentation as well as for asymmetric synthesis templates. For example, interest in the production of L-nucleosides such as L-ribose, L-mannose and L-glucose has arisen for a number of L-nucleoside-based pharmaceutical compounds. Emtricitabine and Clevudine are some examples of pharmaceutical compounds that are based on L-nucleosides, and a number of these pharmaceuticals are currently approved or in clinical trials.

One advantageous route to a wide variety of EPCs is the use of dehydrogenases, to afford either reduction of keto compounds or oxidation of alcohol or amine groups. The repertoire of dehydrogenases useful for synthesis of EPCs encompasses alcohol dehydrogenases (ADHs), D- and L-lactate dehydrogenases (LDHs), D- or L-hydroxyisocaproate dehydrogenases (D- or L-HicDHs), or amino acid dehydrogenases such as leucine dehydrogenase (LeuDH), phenylalanine dehydrogenase (PheDH), or glutamate dehydrogenase (GluDH). Monooxygenases have been used to synthesize, regio- and enantioselectively, lactones from cyclic ketones useful in the flavor and fragrance industries.

Dehydrogenases and monooxygenases require nicotinamide-based cofactors, such as NAD⁺ and NADP⁺ or their reduced equivalents, NADH and NADPH, to function. Economic use of dehydrogenases and cofactor necessitates cofactor regeneration. Cofactor costs, for example, \$31 per gram for NAD⁺ and \$232 per gram of NADP⁺, have to be considered and having cofactors regenerated would cut costs by the turnover number for such cofactors, between 100 and up to 600,000.

Cofactor regeneration with alcohol dehydrogenases can be performed by using the same enzyme for in-situ substrate conversion and cofactor regeneration, usually employing isopropanol as co-substrate, as demonstrated with (S)-ADH

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from *Thermoanaerobium brockii* for both NADH and NADPH and with (R)-ADH from *L. brevis* for NADPH; this coupled-substrate approach, however, suffers from equilibrium limitations. The more common coupled-system approach, employing a separate second enzyme for regeneration, has been developed for reducing oxidized cofactors, NAD⁺ or NADP⁺, to NADH or NADPH. By far the most successful regeneration enzyme is formate dehydrogenase (FDH) for regeneration to either NADPH or NADH, the latter even up to industrial scale. Other options include the use of glucose 6-phosphate dehydrogenase (to NADPH only) or of glucose dehydrogenase, GluDH. For the opposite direction of regeneration, however, from NADPH to oxidized cofactors NAD⁺ or NADP⁺, no universally accepted system exists.

For reductive reactions with dehydrogenases or for monooxygenases, NADPH has to be regenerated from NADP⁺. For this problem, the system formate dehydrogenase (FDH)/formate is now used almost universally, which is shown below:



FDH functions as a universal regeneration enzyme in tandem with dehydrogenases catalyzing extremely enantioselective reduction reactions.

There are some currently known NADH oxidases that are able to oxidize NADH to NAD⁺ with simultaneous reduction of O₂ to either H₂O₂ or H₂O. Four-electron reduction to benign H₂O is preferred over two-electron reduction to H₂O₂, which, even in small amounts, can deactivate either enzyme of the production-regeneration cycle. Addition of catalase as a possible remedy, to degrade the H₂O₂, increases complexity of the system to the point where three enzymes have to be coupled and adjusted as to their activity over time.

For oxidative reactions requiring regeneration of NADP⁺ from NADPH, prior to the present invention, no universal cofactor regeneration system was known. Alcohol dehydrogenase (ADH) itself can be utilized to catalyze both the oxidative production reaction as well as the reductive regeneration reaction by adding isopropanol which is oxidized to acetone, but such a scheme tends to be equilibrium-limited and plagued by deactivation of ADH. Both the ADH and the lactate dehydrogenase (LDH) systems cannot take NADPH, in contrast to glutamate dehydrogenase (GluDH), which has been utilized to reduce α-ketoglutarate to L-glutamate. NADH oxidases from thermophiles have been employed which regenerate NAD⁺ from NADH by reducing O₂ to H₂O₂.

What is needed are enzymes that regenerate NADH and NADPH to oxidized cofactors NAD⁺ and NADP⁺ and synthesis methods that employ such enzymes alone or in coupled reactions. What is also needed are enzymes that perform the oxidation of NADH to NAD⁺ with the concomitant reduction of molecular oxygen to water as a solution to the cofactor regeneration problem from NADH to NAD⁺. Further, what is needed are methods for efficiently isolating the enzymes.

BRIEF SUMMARY OF THE INVENTION

Various embodiments of the present invention are directed to bacterial NADH oxidases and, more particularly, to NADH oxidases obtained from *Lactobacillus plantarum*, and derivatives thereof that demonstrate enzymatic activity for NADH, NADPH, or both NADH and NADPH. A composition of the present invention comprises an isolated bacterial NADH oxidase, which is obtained from *Lactobacillus plantarum*. This isolated bacterial NADH oxidase can comprise the amino acid sequence of SEQ ID NO: 1, which is encoded by a

nucleic acid sequence comprising SEQ ID NO: 2. Such a nucleic acid sequence can be incorporated into a vector, which may in turn be introduced into a host cell.

In one embodiment of the present invention, isolated bacterial NADH oxidases obtained from *Lactobacillus plantarum* can regenerate NAD⁺. In another embodiment of the present invention, isolated bacterial NADH oxidases derived from *Lactobacillus plantarum* can regenerate NADP⁺. In yet another embodiment of the present invention, isolated bacterial NADH oxidases derived from *Lactobacillus plantarum* can regenerate both NADP⁺ and NAD⁺.

For example, an isolated bacterial NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺, comprises SEQ ID NO: 1, wherein SEQ ID NO: 1 comprises at least one amino acid mutation that facilitates enzymatic activity towards NADPH. A nucleic acid sequence that encodes a NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺ can hybridize under stringent conditions to the nucleic acid comprising SEQ ID NO: 2.

An isolated bacterial NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺, can comprise an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, and SEQ ID NO: 17. In an exemplary embodiment, an isolated bacterial NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺, can comprise an amino acid sequence of SEQ ID NO: 8 or SEQ ID NO: 16.

Examples of nucleic acid sequences that encode a NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺ that can hybridize under stringent conditions to the nucleic acid comprising SEQ ID NO: 2, include, but are not limited to nucleic acid sequences selected from the group consisting of SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 10, SEQ ID NO: 13, and SEQ ID NO: 18. In an exemplary embodiment, an isolated bacterial NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ or both NADP⁺ and NAD⁺, can be encoded by a nucleic acid sequence comprising SEQ ID NO: 10 or SEQ ID NO: 18.

Another aspect of the present invention comprises a method of producing an enantiomer-enriched organic compound, comprising: reacting a substrate with a first enzyme selective for producing an enantiomer, wherein the first enzyme requires a oxidized nicotinamide-based cofactor for catalytic activity; producing the enantiomer, its oxidized counterpart, and a reduced nicotinamide-based cofactor; and oxidizing the reduced nicotinamide-based cofactor with a second enzyme selective for a nicotinamide-based cofactor. In one embodiment of the present invention, the enantiomer comprises an L-nucleoside, and the second enzyme selective for a nicotinamide-based cofactor comprises a NADH oxidase obtained from *Lactobacillus plantarum*. In another embodiment of the present invention, the second enzyme selective for a nicotinamide-based cofactor can catalyze more than 113,000 turnovers per active site. In yet another embodiment of the present invention, the second enzyme selective for a nicotinamide-based cofactor can catalyze more than 100,000 turnovers per active site in the absence of an externally added reducing agent.

In this method, the NADH oxidase obtained from *Lactobacillus plantarum* can comprise SEQ ID NO: 1. In one embodiment of the present invention, isolated bacterial NADH oxidases obtained from *Lactobacillus plantarum* can

regenerate NAD⁺. In another embodiment of the present invention, isolated bacterial NADH oxidases derived from *Lactobacillus plantarum* can regenerate NADP⁺. In yet another embodiment of the present invention, isolated bacterial NADH oxidases derived from *Lactobacillus plantarum* can regenerate both NADP⁺ and NAD⁺. The isolated bacterial NADH oxidases derived from *Lactobacillus plantarum*, which regenerates NADP⁺ and NAD⁺, can comprise an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, or SEQ ID NO: 17. In an exemplary embodiment, the second enzyme selective for a nicotinamide-based cofactor comprises SEQ ID NO: 8 or SEQ ID NO: 18.

Other aspects and features of embodiments of the present invention will become apparent to those of ordinary skill in the art, upon reviewing the following description of specific, exemplary embodiments of the present invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic illustrating the conversion of ribitol to L-ribose through mannitol-1-dehydrogenase from *Apium graveolens* complemented with NADH cofactor regeneration using NADH oxidase.

FIG. 2 illustrates the activity profile of NADH oxidase from *Lactobacillus plantarum* V (NOX5) at different pHs.

FIG. 3 illustrates the activity profile of NOX5 at various temperatures.

FIG. 4 is a T₅₀³⁰ plot that demonstrates stability of NOX5 by incubating at different temperatures.

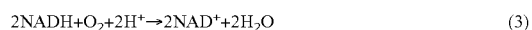
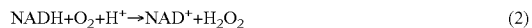
FIG. 5 is a plot of kinetics using different models: non-linear Michaelis-Menten, Lineweaver-Burk, Eadie-Hofstee, and Hanes-Woolf.

FIG. 6 graphically depicts a Hanes-Woolf plot of NAD⁺ inhibition pattern of NOX5.

DETAILED DESCRIPTION OF THE INVENTION

Throughout this description, various components can be identified as having specific values or parameters, however, these items are provided as exemplary embodiments. Indeed, the exemplary embodiments do not limit the various aspects and concepts of the present invention as many comparable parameters, sizes, ranges, and/or values can be implemented. The terms "first," "second," and the like, "primary," "secondary," and the like, do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Further, the terms "a," "an," and "the" do not denote a limitation of quantity, but rather denote the presence of "at least one" of the referenced item.

In general, NADH oxidases (E.C. 1.6.-.-) catalyze the oxidation of NADH by simultaneously reducing molecular O₂ to either hydrogen peroxide, H₂O₂, in a two-electron reduction (reaction 2), or directly to water in a four-electron reduction (reaction 3).



NADH oxidases contain a second cofactor, presumably covalently bound FAD, as evidenced by the consensus sequence GXT(H/S)AG near the N-terminus, and are widespread among different, evolutionary distinct organisms, such as humans, vertebrates, plants, *Drosophila* and different

strains of bacteria. Bacteria harbor both H₂O₂-forming and H₂O-forming NADH-oxidases. Owing to the deactivation of almost all proteins upon the exposure to H₂O₂, the H₂O-forming enzymes are superior as biocatalysts. Addition of catalase could potentially destroy the H₂O₂ formed, however, catalase itself features a very high K_M-value of 1.1 M, so that the enzyme is not particularly active at low H₂O₂ concentrations. Thermophilic bacteria usually only feature peroxide-producing NADH oxidases, which, despite their superior stability, render them unfavorable for catalytic purposes. Water-producing NADH-oxidases can be found in various organisms, such as *Streptococcus*, *Enterococcus*, *Lactobacillus*, *Mycobacterium*, *Methanococcus*, or *Leuconostoc*. These organisms can contain both water- as well as peroxide-producing enzymes.

The various embodiments of the present invention provide novel bacterial NADH oxidases. More specifically, the various embodiment of the present invention provide an NADH oxidase obtained from *Lactobacillus plantarum*, and derivatives thereof that demonstrate enzymatic activity for NADH, NADPH, or for both NADH and NADPH. The compositions comprising an NADH oxidase obtained from *L. plantarum* or derivatives thereof include: isolated enzymes; recombinantly produced enzymes and derivatives thereof, as well as catalytically active portions thereof; nucleic acids encoding an NADH oxidase obtained from *L. plantarum*, derivatives thereof, and portions thereof; vectors and plasmids comprising an NADH oxidase obtained from *L. plantarum*, derivatives thereof, and portions thereof; cells (i.e., prokaryotic or eukaryotic) comprising enzymes or nucleic acids encoding an NADH oxidase obtained from *L. plantarum*, derivatives thereof, and portions thereof. Compositions also include products made in enzymatic reactions in which an NADH oxidase obtained or derived from *L. plantarum* regenerates nicotinamide-based cofactors in the production of enantiomer-enriched organic compounds. The methods of the present invention include isolation of NADH oxidase obtained from *L. plantarum*, derivatives thereof, and portions thereof, and methods for enzymatic reactions comprising NADH oxidase obtained from *L. plantarum*.

As used herein, the term "NADH oxidase, which is obtained from *L. plantarum*" is understood to include the NADH oxidases isolated from *L. plantarum*, which are capable of oxidizing (sometimes referred to as "regenerating") NADH. An example of such an isolated NADH oxidase obtained from *L. plantarum* is illustrated by SEQ ID NO: 1. The term "NADH oxidase, which is obtained from *L. plantarum*" also encompasses an amino acid sequence that encodes an enzyme exhibiting oxidase activity for NADH that has substantial homology to SEQ ID NO 1. As used herein, the term "substantial homology" of an amino acid sequence means that an amino acid sequence includes a sequence that has at least 51%, 52%, 53%, 54%, 55%, 56%, 57%, 58%, 59%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, or 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, or 79%, preferably at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, or 89%, more preferably at least 90%, 91%, 92%, 93%, or 94%, and most preferably at least 95%, 96%, 97%, 98%, or 99% sequence identity, as compared to a reference sequence (e.g., SEQ ID NO: 1), provided that the enzymatic activity is retained or the purpose of the sequence is retained, e.g. coding for a protein having a specific enzymatic activity or a protein fragment having a particular binding capability or immunogenic capability.

An NADH oxidase obtained from *L. plantarum* can be encoded by a nucleic acid sequence that encodes an enzyme with oxidase activity for NADH, such as that described in

SEQ ID NO: 2. The purified nucleic acid sequence encoding an enzyme exhibiting oxidase activity has substantial homology to SEQ ID NO 2. As used herein, the term "substantial homology" of a nucleic acid sequence means that a nucleic acid sequence includes a sequence that has at least 51%, 52%, 53%, 54%, 55%, 56%, 57%, 58%, 59%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, or 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, or 79%, preferably at least 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, or 89%, more preferably at least 90%, 91%, 92%, 93%, or 94%, and most preferably at least 95%, 96%, 97%, 98%, or 99% sequence identity, as compared to a reference sequence (e.g., SEQ ID NO: 2).

As used herein, the term "NADH oxidase, which is derived from *L. plantarum*" is understood to include derivatives of a NADH oxidase isolated from *L. plantarum* that are capable of oxidizing NADH, NADPH, or both NADH and NADPH. NADH oxidases derived from *L. plantarum* include recombinant nucleic acid sequences derived from the bacterial oxidases of *L. plantarum*, recombinant proteins and peptides expressed by those sequences in heterologous hosts, and any nucleic acid or amino acid variants, mutants, or portions thereof (e.g., catalytically active portions) of bacterial oxidases from *L. plantarum* that are capable of oxidizing NADH, NADPH, or both NADH and NADPH. Thus, NADH oxidases, which are derived from *L. plantarum*, can include proteins and recombinant constructs having altered sequences obtained by mutational methods. Embodiments of mutations of the sequences and resulting proteins disclosed herein also include, but are not limited to, substitutions, insertions, deletions, additions, reversions, changes due to recombination, and other mutations known to those skilled in the art.

In one embodiment of the present invention, an NADH oxidase that is derived from *L. plantarum* can comprise SEQ ID NO: 1, wherein SEQ ID NO: 1 comprises at least one amino acid mutation that facilitates enzymatic activity towards NADPH. In another embodiment, an NADH oxidase that is derived from *L. plantarum* can comprise SEQ ID NO: 1, wherein SEQ ID NO: 1 comprises more than one amino acid mutation that facilitates enzymatic activity towards NADPH. One or more mutations to the amino acid sequence for an NADH oxidase that is derived from *L. plantarum* can confer enzyme activity to only NADH, to only NADPH, or to both NADH and NADPH.

In one embodiment, an NADH oxidase that is derived from *L. plantarum* may include amino acid mutations to accommodate the negative charge associated with the phosphate moiety of NADPH so as to confer enzymatic activity for NADPH. Basic amino acids, such as arginine, lysine, and histidine, are preferred residues for substitution at amino acid residue 178, which is a glycine in the native enzyme, and amino acid residue 179, which is a leucine in the native enzyme. Consequently, amino acid residues 178 and 179 may be mutated to any one basic amino acid and various combinations therebetween. Examples of such NADH oxidase derivatives include G178K (SEQ ID NO: 3), G178R (SEQ ID NO: 4), L179K (SEQ ID NO: 6), L179R (SEQ ID NO: 8), L179H (SEQ ID NO: 9), G178K/L179K (SEQ ID NO: 11), G178R/L179K (SEQ ID NO: 12), G178K/L179R (SEQ ID NO: 14), G178K/L179H (SEQ ID NO: 15), G178R/L179R (SEQ ID NO: 16), and G178R/L179H (SEQ ID NO: 17). These NADH oxidase derivatives are encoded by nucleic acids including G178K/R (SEQ ID NO: 5), L179K (SEQ ID NO: 7), L179R/H (SEQ ID NO: 10), G178K/R/L179K (SEQ ID NO: 13), and G178K/R/L179R/H (SEQ ID NO: 18).

The present invention also comprises nucleic acids that hybridize under stringent conditions with the single-stranded nucleic acids or their complementary single stranded nucleic acids of the present invention. Stringent conditions are well known to those skilled in the art; see Sambrook et al., (Molecular Cloning, A Laboratory Manual, Cold Spring Harbor Laboratory Press (1989), 1.101-1.104). Stringent conditions are established by conditions such as salt concentrations, temperature and amount of time for washing of the hybridized nucleic acids. For example, conditions include washing of hybridized nucleic acids in 0.1% SDS and 1.0x to 0.2xSSC, at temperatures from 50° C. to 68° C., for times of 0.5 to 1.0 hours.

The nucleic acids of the present invention can be incorporated into a vector. The term "vector" as used herein can refer to a cloning vector or an expression vector. A cloning vector refers to a plasmid, phage DNA, a cosmid, or other DNA molecule that is able to replicate autonomously in a host cell. A cloning vector is characterized by one or a number of restriction endonuclease recognition sites at which such DNA sequences may be cut in a determinable fashion without loss of an essential biological function of the vector, and into which a DNA fragment (e.g., SEQ ID NO: 2) may be spliced in order to bring about its replication and cloning. The cloning vector may further contain a marker suitable for use in the identification of cells transformed with the cloning vector (e.g., an antibiotic resistance marker).

An expression vector is similar to a cloning vector but is capable of expressing a gene which has been cloned into it, after transformation into a host. The cloned gene is usually placed under the control of (i.e., operably linked to) a variety of elements for controlling expression of the gene, including promoter sequences, transcription initiation sequences, enhancer sequences, selectable elements, and reporter genes. Examples of suitable expression vectors include, but are not limited to, plasmids, phagemids, cosmids, artificial chromosomes, such as a yeast artificial chromosome (YAC), a bacterial artificial chromosome (BAC), or a P1-derived artificial chromosome (PAC), and bacteriophages, such as lambda phage or M13 phage.

The present invention comprises compositions comprising NADH oxidases obtained or derived from *L. plantarum* and methods of making and using such oxidases, wherein the oxidases regenerate NAD⁺, NADP⁺, or NAD⁺ and NADP⁺. The ability of an oxidase to oxidize one or both of these cofactors renders it an extremely useful catalyst for coupled enzymatically-catalyzed oxidations. Thus, the present invention comprises bacterial oxidases that regenerate both NADP⁺ and NAD⁺. The present invention also comprises novel NADH oxidases that reduce oxygen directly to water, which also makes such enzymes useful in coupled enzymatic reactions.

The NADH oxidases of the present invention participate in enzymatic reactions where there is a conversion of a substrate into a product. In a particularly preferred embodiment of the present invention, the product comprises an enantiomer-enriched organic compound. Consequently, the substrate can include a racemic mixture, such as an alcohol to a ketone, and upon enzymatic reaction will result in a highly enantiomer-enriched unreacted optical antipode of the original molecule, such as an alcohol. Dehydrogenases are capable of very specific enantiomeric selection and are used to prepare enantiomerically pure alcohols, hydroxy acids and amino acids as well as the corresponding ketones and keto acids. The dehydrogenase reaction requires the regeneration of the NADH or NADPH for cofactor activity, and thus, the NADH oxidases of the present invention have utility in coupled reactions with

dehydrogenases including, but not limited to, alcohol dehydrogenase, lactate dehydrogenase and amino acid dehydrogenase. Products from such reactions include the resolution of racemic mixtures, such resolution dependent on the selectivity of the dehydrogenase used, and resulting in the unreacted racemate from the original racemic mixture, and the product of the enzyme reaction. For example, from a racemic mixture of an R/S-alcohol, in a reaction with an S-alcohol dehydrogenase, the resulting products are the unreacted enantiomer, the R-alcohol, and the resulting product, e.g., a ketone.

The NADH oxidases of the present invention are involved in synthesis methods comprising enzyme reactions where the substrates have one or more chiral centers. An embodiment of the present invention comprises a method of producing an enantiomer-enriched organic compound, comprising: reacting a substrate with a first enzyme selective for producing an enantiomer, wherein the first enzyme requires an oxidized nicotinamide-based cofactor for catalytic activity; producing the enantiomer and a reduced nicotinamide-based cofactor; and oxidizing the reduced nicotinamide-based cofactor with a second enzyme selective for a nicotinamide-based cofactor. In such methods, the second enzyme selective for a nicotinamide-based cofactor comprises a NADH oxidase obtained or derived from *L. plantarum*. The oxidized nicotinamide-based cofactors can include NAD⁺, NADP⁺, or both NAD⁺ and NADP⁺. Embodiments of the present invention comprise isolated bacterial oxidases derived from *L. plantarum* that use NADH and NADPH as a cofactor. In a preferred embodiment, isolated bacterial oxidases derived from *L. plantarum* that use NADH and NADPH as a cofactor include SEQ ID NO: 8 or SEQ ID NO: 16.

The compositions of the present invention also comprise combinations of all or a portion of one or more of SEQ ID NO: 2, SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 10, SEQ ID NO: 13, and SEQ ID NO: 18 with other nucleic acid sequences to encode chimera proteins, or the nucleic acids of NADH oxidases combined with proteins or attached to solid supports such as beads. Such chimera proteins or other combinations may or may not retain the enzyme activity of NADH oxidases. For example, a nucleic acid construct that codes for a chimera protein is constructed from SEQ. ID NO: 2 and sequences for an antibody protein or binding fragment thereof. Such a chimera can be used in antibody labeling experiments.

The present invention also comprises compositions comprising the NADH oxidases disclosed herein that include immobilization of the enzymes on heterogeneous substrates. For example, the enzymes may be immobilized or attached to other proteins, through methods such as chemical linking of the proteins, attached to inert substrates such as microtiter plates, chromatography materials, balls, beads or other substances. The invention contemplates the use of such immobilized enzymes in methods of synthesis, measurement, analysis or other methods wherein enzymes are used. These methods for immobilizing and using such immobilized enzymes are known to those skilled in the art.

The compositions of the present invention also comprise antibodies and other specific binding partners, such as substrates, of NADH oxidases, and immunogenic epitopes thereof. Such antibodies may be polyclonal or monoclonal, and include fragments such as Fab, FC, heavy chains, light chains, constant, variable, or hypervariable fragments or regions, and any type of antibody include but are not limited to IgM, IgG, IgA, IgD, and IgE.

The compositions of the present invention also contemplate the inclusion of any cofactors, metals or other com-

pounds or molecules necessary for activity or stability of the NADH oxidases of the present invention. However, it should be noted that the NADH oxidases of the present invention demonstrate stability in the absence of an exogenous reducing agent, such as dithiothreitol (DTT) or β -mercaptoethanol.

The present invention also comprises host cells comprising the nucleic acids disclosed herein, particularly SEQ ID NO: 2, SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 10, SEQ ID NO: 13, and SEQ ID NO: 18. Examples of such host cells include, but are not limited to, prokaryotes or eukaryotes, such as *Pseudomonas*, *Streptomyces*, *Arthrobacter*, *Bacillus*, *Staphylococcus*, *Enterococcus*, especially *Escherichia coli*, *Candida*, *Hansenula*, *Pichia* and various eukaryotic cells using for example viral-based expression systems. The host cells in which the nucleic acids are cloned are useful for propagation and production of a sufficient amount of the recombinant enzyme or enzymes. The methods for cloning, propagating and producing recombinant proteins in cellular systems are well known in the art.

The nucleic acids disclosed herein that code for the NADH oxidases as described herein, are preferably suitable for the production of whole-cell catalysts. The invention provides a whole-cell catalyst containing a cloned gene for a first enzyme selective for producing an enantiomer (e.g., a dehydrogenase) and a cloned gene for a NADH oxidase, as disclosed herein. The whole-cell catalyst according to one embodiment of the invention can comprise a NADH oxidase, preferably a bacterial oxidase obtained or derived from *L. plantarum* that can regenerate NAD⁺, NADP⁺, or both NAD⁺ and NADP⁺. More preferably, the NADH oxidase is one or more of the NADH oxidases disclosed herein and encoded for by SEQ ID NO: 2, SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 10, SEQ ID NO: 13, and SEQ ID NO: 18. The production of such an organism is known to the person skilled in the art as disclosed in PCT/EP00/08473 and PCT/US00/08159, which are hereby incorporated by reference.

The advantage of such an organism is the simultaneous expression of at least two different enzymes, and as a result the whole cell catalyst recombinant organism is only used for the enzymatic reaction. In order to match the expression of the enzymes with respect to their reaction rates, the coding nucleic acids may be cloned into various plasmids having different copy numbers and/or promoters of different strengths. In one embodiment, the enzymes are encoded on plasmids with similar copy numbers in a host cell and/or under the control of promoters of similar strength. With enzyme systems matched in this way there is advantageously no accumulation of a possible inhibiting intermediate compound(s), and the reaction under consideration may proceed at an optimal overall rate.

Methods of the present invention comprise methods for growing and isolating bacterial NADH oxidases, particularly bacterial oxidases obtained or derived from *L. plantarum* capable of regenerating NAD⁺, NADP⁺, or both NAD⁺ and NADP⁺. One embodiment comprises growing host organisms, such as *Lactobacillus plantarum*, and isolating the NADH oxidases by methods known to those skilled in the art, such as ammonium or acid precipitation, chromatography methods, and other protein purification techniques.

The nucleic acids according to the invention can be used for the production of recombinant NADH oxidases, which include NADH oxidases obtained or derived from *L. plantarum*. Recombinant techniques known in the art can be used to produce the enzymes described herein in an amount sufficient for an industrial process from host cells carrying the nucleic acids encoding the enzyme of interest. The production of the recombinant enzymes according to the invention is

carried out by genetic engineering processes as described in, for example, Sambrook supra, Balbas P & Bolivar F. 1990; Design and construction of expression plasmid vectors in *E. coli*, Methods Enzymology 185, 14-37; Vectors: A Survey of Molecular Cloning Vectors and Their Uses. R. L. Rodriguez & D. T. Denhardt, Eds: 205-225). With regard to the general procedure (PCR and fusion PCR, inverse PCR, cloning, expression etc.), reference may be made to the following literature and the references cited therein: Riley J, Butler R, Finnear R, Jenner D, Powell S, Anand R, Smith J C, Markham A F (1990). A novel, rapid method for the isolation of terminal sequences from yeast artificial chromosome (YAC) clones. Nucl Acids Res. 18, 8186; Triglia T, Peterson M G, Kemp D J (1988). A procedure for in vitro amplification of DNA segments that lie outside the boundaries of known sequences. Nucleic Acids Res. 16, 8186; Sambrook J, Fritsch E F, Maniatis T (1989). Molecular Cloning. Cold Spring Harbour Laboratory Press; Vectors: A Survey of Molecular Cloning Vectors and Their Uses. R. L. Rodriguez & D. T. Denhardt, II.

The bacterial oxidase enzymes described herein may be used in the free form as homogeneously purified compounds, or as enzymes produced by recombinant technology. Furthermore the enzymes may also be employed as a constituent of an intact host organism or in conjunction with the macerated cell mass of the host organism purified to an arbitrarily high degree. It is also possible to use the enzymes in immobilized form (Bhavender P. Sharma, Lorraine F. Bailey and Ralph A. Messing, "Immobilisierte Biomaterialien—Techniken und Anwendungen", Angew. Chem. 1982, 94, 836-852). The immobilization is preferably carried out by lyophilisation (Dordick et al. J. Am. Chem. Soc. 194, 116, 5009-5010; Okahata et al. Tetrahedron Lett. 1997, 38, 1971-1974; Adlercreutz et al. Biocatalysis 1992, 6, 291-305). It is most particularly preferred to carry out the lyophilisation in the presence of surfactants such as aerosol OT, polyvinylpyrrolidone, polyethylene glycol (PEG) or Brij 52 (diethyleneglycolmonocetyl ether) (Goto et al. Biotechnol. Techniques 1997, 11, 375-378). The use as CLECs is also possible (St Clair et al. Angew Chem Int Ed Engl 2000 January, 39(2), 380-383).

The present invention also comprises using NADH oxidases obtained or derived from *L. plantarum* having NAD⁺, NADP⁺, or both NAD⁺ and NADP⁺ regeneration activity (e.g., G178K (SEQ ID NO: 3), G178R (SEQ ID NO: 4), L179K (SEQ ID NO: 6), L179R (SEQ ID NO: 8), L179H (SEQ ID NO: 9), G178K/L179K (SEQ ID NO: 11), G178R/L179K (SEQ ID NO: 12), G178K/L179R (SEQ ID NO: 14), G178K/L179H (SEQ ID NO: 15), G178R/L179R (SEQ ID NO: 16), and G178R/L179H (SEQ ID NO: 17)). These NADH oxidase derivatives are encoded by nucleic acids including G178K/R (SEQ ID NO: 5), L179K (SEQ ID NO: 7), L179R/H (SEQ ID NO: 10), G178K/R/L179K (SEQ ID NO: 13), and G178K/R/L179R/H (SEQ ID NO: 18)) and any mutations thereof, for the production of chiral enantiomer-enriched organic compounds such as, for example, alcohols, amino acids, or nucleosides, in coupled enzymatic reactions. Such compounds are useful in pharmaceutical preparations, in agricultural uses, for food, and crop protection industries as well as building blocks for novel compounds not accessible through fermentation and for asymmetric synthesis templates. For example, compounds are produced that are effective in treatment of humans and other animals for hypertension, diabetes, cardiovascular disease, cancer, infectious disease, and conditions involving the brain, eyes, heart, lungs, liver, immune system, urinary organs, reproductive organs, integumentary system, nervous system and other conditions where pharmaceutical agents are effective.

All patents, patent applications, and references included herein are specifically incorporated by reference in their entireties.

It should be understood, of course, that the foregoing relates only to exemplary embodiments of the present invention and that numerous modifications or alterations may be made therein without departing from the spirit and the scope of the invention as set forth in this disclosure. Therefore, while embodiments of this invention have been described in detail with particular reference to exemplary embodiments, those skilled in the art will understand that variations and modifications can be effected within the scope of the invention as defined in the appended claims. Accordingly, the scope of the various embodiments of the present invention should not be limited to the above discussed embodiments, and should only be defined by the following claims and all equivalents.

The present invention is further illustrated by way of the examples contained herein, which are provided for clarity of understanding. The exemplary embodiments should not be construed in any way as imposing limitations upon the scope thereof. On the contrary, it is to be clearly understood that resort may be had to various other embodiments, modifications, and equivalents thereof which, after reading the description herein, may suggest themselves to those skilled in the art without departing from the spirit of the present invention or the scope of the appended claims.

EXAMPLES

Example 1

NADH Oxidase Isolated from *Lactobacillus plantarum*

Among the different systems that can be chosen for cofactor regeneration, the use of NADPH oxidases stand out with a number of advantages. NADPH oxidases utilize NADPH and oxygen as co-substrates, both which would not need to be added externally for a regeneration system. (FIG. 1). This would prevent complication of the system by introducing additional substrates. The reaction would either produce water or hydrogen peroxide as final products, and the latter can be easily eliminated through the use of catalases.

Overoxidation of the catalytically active cysteine residue has been shown to be a limitation in production for previous NADPH oxidases. All of the previously discovered NADPH oxidases have shown to have a cysteine residue that is catalytically active. This thiol is oxidized to sulfenic acid and reduced back to the thiol as a part of the NADPH reduction mechanism. Studies have also shown that during this redox cycle the cysteine can also be overoxidized, producing a sulfinic or sulfonic acid, killing the enzymatic activity. This has been overcome to some extent by using reducing agents such as dithiothreitol (DTT) and β -mercaptoethanol. These reducing agents have shown to prevent overoxidation, thus elongating the catalytically active enzyme lifetime.

As demonstrated in this Example, NADH oxidase from *Lactobacillus plantarum* V is different in that it has a higher productivity indicated by its total turnover number (TTN) and is more stable against overoxidation as compared to its predecessors. While the native enzyme only showed activity on NADH, mutations in the substrate binding pocket were introduced to change its specificity and to accommodate NADPH.

Materials and Methods

Cloning and Site-Directed Mutagenesis.

The gene encoding NADH oxidase from *Lactobacillus plantarum* V was cloned out from the original plasmid through PCR using the following primers: forward primer (SEQ ID NO: 19) (5'-TGCATGCATGCCATGGTTATGAAAGTTATTGTAATTGGTTGTACCCA-3') and reverse primer (SEQ ID NO: 20) (5'-CCGCCGCCGCCGCTCGAGTTATTCAGTGACAGCTTCGGCC-3'). The PCR product was then gel purified with a Qiagen gel extraction kit and cloned into a pET-28a vector (Novagen, Inc.) using restriction sites NcoI and XhoI. The plasmid was then transformed into BL21(DE3)pLysS for expression.

Single and double mutations were performed on residues G178 and L179 into K, R and K, R, H respectively, through overlap and quickchange PCR using the following forward primers and their complementary reverse primers; G178K/R (SEQ ID NO: 21) (5'-GCAAGGTAAGGAAGTCACACTAATTGATARRTTACCACGGATTTTAAATAAATACTTAGACAA-3'), L179H/R (SEQ ID NO: 22) (5'-AGGTAAGGAAGTCACACTAATTGATGGTTCRYCCACGGATTTTAAATAAATACTTAGACAAAAG-3'), L179K (SEQ ID NO: 23) (5'-AGGTAAGGAAGTCACACTAATTGATGGTAAACCACGGATTTTAAATAAATACTTAGACAAA-3'), G178K/R/L179R/H (SEQ ID NO: 24) (5'-GCAAGGTAAGGAAGTCACACTAATTGATARRCRYCCACGGATTTTAAATAAATACTTAGACAAAAG-3'), G178K/R/L179K (SEQ ID NO: 25) (5'-GCAAGGTAAGGAAGTCACACTAATTGATARRAAACCACGGATTTTAAATAAATACTTAGACAAA-3'). Degenerate codons for K/R and H/R were used as ARR and CRY respectively.

Overexpression.

Growth and overexpression was carried out in MagicMedia™ *E. coli* Expression Medium (Invitrogen) with a final concentration of 30 $\mu\text{g. mL}^{-1}$ of kanamycin and chloramphenicol. A dual temperature protocol was used for growth, starting out at 30° C. for 6 hours, and then continued at room temperature for an additional 22 hours. Cultures were harvested by centrifugation in a Beckman centrifuge with a JS-5.2 rotor at 4000 rpm for 20 minutes in 50 mL conical tubes. The resulting cell pellet was either frozen, and stored at -80° C. or purified directly.

Enzyme Assay and Protein Determination.

Standard assays were performed at 25° C. in 100 mM TEA buffer (pH 7.5) with 5 mM DTT in cuvettes with either a 1 cm or 1 mm path length, depending on the concentration of substrate. Initial activity was measured by following the absorbance change using a Beckman Coulter DU 800 UV/Vis spectrophotometer at 340 nm. Activity of the enzyme was calculated using an extinction coefficient of NAD(P)H, ϵ , as 6.22 $\text{mM}^{-1} \text{cm}^{-1}$. Unless otherwise noted, a substrate concentration of 0.2 mM NADPH was used for assays. 1 unit (U) of activity is defined as 1 mol min^{-1} .

The protein concentration was determined by a Bradford assay. BSA was used as standards, and the absorbance was measured on a biophotometer. SDS-page analysis was performed to determine purity.

Purification.

Purification of NOX5 was carried out at 4° C. or on ice to prevent denaturation of the enzyme. Cell pellets were resuspended in 15 mL of 10 mM Tris-HCl buffer (pH 7.5) with 5 mM DTT (Buffer A) and sonicated at 14 watts for 30 seconds nine times in an ice water bath. Sonicated cells were centrifuged at 15000 rpm in a Beckman J2-21 with a JA-21 rotor for 30 minutes. The clarified cell lysate was transferred to a

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dialysis membrane and dialyzed against 250 mL of Buffer A with 50% ammonium sulfate for 2 hours. The dialysis membrane was then transferred to fresh buffer and further dialyzed for 2 hours. The solution was then centrifuged at 15000 rpm for 30 minutes. The resulting supernatant was filtered through a 0.8 μ M filter and 0.2 μ M filter in series. The filtrate was loaded onto a HIPREP™ 16/10 Butyl column on an AKTA. A reverse gradient separation was performed starting from Buffer A with 30% ammonium sulfate to 15%. The fractions with the highest activity were collected and dialyzed against a Buffer A for 2 hours. After exchanging the fresh buffer, the sample was dialyzed for an additional 2 hours. The sample was loaded on a HIPREP™ 16/10 DEAE anionic exchange column on the AKTA. Separation was achieved with Buffer A containing NaCl, a gradient of 150 mM to 250 mM. The resulting fractions were assayed, and the fractions with highest activity were collected as pure protein. The purified protein was either stored in 4° C. or in -20° C. with 25% glycerol.

pH Activity.

Enzyme pH activity profiles were obtained at 25° C. using 100 mM buffers with the following salts: sodium citrate from pH 4.0 to pH 6.5; sodium phosphate from pH 6.0 to pH 8.0; TEA from pH 7.0 to pH 8.0; Tris-HCl from pH 7.0 to pH 9.0; glycine from pH 9.0 to pH 10.0.

Temperature Activity.

Temperature dependent activity was studied by incubating the enzyme at different temperatures. After one minute of incubation, the standard assay was carried out. A temperature range of 10 to 55° C. was chosen for this study.

Temperature Stability.

Temperature stability was studied by incubating the enzyme at various temperatures for 30 minutes. The enzyme solution was then cooled down and assayed at 25° C. This study covered a temperature range of 15° C. to 55° C.

Kinetic Parameters.

Depending on the enzyme, a substrate concentration range from 1.5 μ M up to 984 μ M was investigated to determine the k_{cat} and K_M of NADPH. This was conducted with an excess of oxygen present in the system. The reaction was initiated by mixing two separate 2x solutions of each the substrate and enzyme. The specific activity was measured, and the kinetic parameters were calculated from that data.

Inhibition effects of NAD⁺ and H₂O₂ were measured by incubating the enzyme with possible inhibitors for 30 minutes before the assay. For NAD⁺, 0.2, 0.3, 0.4 and 0.6 mM were chosen and for H₂O₂, 25, 50, 100 and 200 μ M were investigated.

Amplex Red Assay.

An Amplex Red Hydrogen Peroxide/Peroxidase Assay Kit (Invitrogen) was used to determine the amount of hydrogen peroxide (H₂O₂) produced during turnover. Various amounts of substrates were reacted and assayed to detect the presence of H₂O₂. The reactions were carried out in the provided 50 mM sodium phosphate buffer (pH 7.4). Standards for the calibration curve were made with the same reaction buffer.

Total Turnover Number (TTN).

Standard kinetic assays were performed with small amounts of enzyme. Assays were carried out for two to three hours until there was no more enzymatic conversion of the substrate.

Results and Discussion

NADH oxidase V from *Lactobacillus plantarum* (NOX5) consists of 1350 bp and has a predicted size of 49 kDa. Sequencing of the gene (SEQ ID NO. 1) showed a nucleotide mutation of C to T at position 45, but the resulting amino acid sequence (SEQ ID NO. 2) was the same as the predicted sequence.

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Purification of NOX5 resulted in a yield of 14% of the total units and a 12.7 fold increase of specific activity. Purified NOX 5 shows a strong band at 49 kDa in SDS-page analysis. Table 1 is a table of purification. "Lysate" refers to clarified lysate; "AS50 dia." refers to the supernatant from centrifuged sample dialyzed against 50% ammonium sulfate; "Butyl dia." refers to the fractions collected from HIPREP™ 16/10 Butyl column dialyzed against 100 mM TEA pH 7.5 and 5 mM DTT; and "DEAE" refers to fractions collected from HIPREP™ 16/10 DEAE column.

TABLE 1

	Volume (ml)	Units (U)	Protein (mg)	Sp. ac. (U mg ⁻¹)	Purification Fold	Yield (%)
Lysate	20	1843.5	139.3	13.24	1.0	100
AS50 dia.	7	930.0	88.5	10.51	0.8	50
Butyl dia.	37.5	379.3	4.7	80.72	6.1	21
DEAE	20	261.9	1.6	167.5	12.7	14

Enzyme Activity and Stability.

NADPH oxidases will mostly be used in cofactor regeneration, as water and hydrogen peroxide are not of great interest for final products. As the true value of these enzymes are shown when they are coupled with other enzymes, the study of reaction conditions, especially in terms of pH and temperature, were necessary to maximize activity and stability.

NOX5 showed a rather broad pH activity range. Maximum activity was found at pH 7.5, but the enzyme was fairly active from pH 5.5 to 8.0. (FIG. 2). This is a range that is common for many NADPH oxidases. The upper limit is also compatible with dehydrogenases that are active in alkaline conditions. Although it would be difficult to have a single corresponding maximum for both enzymes, a person of ordinary skill in the art could identify optimal conditions for a dehydrogenase and NOX5.

The temperature activity profile showed that maximum instantaneous activity was found at 40° C., and the activity quickly reached zero beyond that. (FIGS. 3 and 4). Using an Arrhenius model, the activation energy, E_a , was calculated as 32.7 kJ mol⁻¹, and the deactivation energy, E_d , was calculated as -93.6 kJ mol⁻¹. The temperature that exhibited half of the original activity, T_{50}^{30} , was estimated to be 45° C. At 55° C., the enzyme was inactive. Enthalpy of deactivation, ΔH , was calculated to be 4.98 kJ·mol⁻¹.

Kinetic Parameters.

The data was fitted with four different models: non-linear Michaelis-Menten, Lineweaver-Burk, Eadie-Hofstee and Hanes. Through non-linear fitting, k_{cat} and K_M of the wild type were measured to be 211.6 s⁻¹ and 50.2 μ M, respectively with an R² of 0.998. (FIG. 5).

Possible product inhibitory effects were investigated by incubating the enzyme with different concentrations of NAD⁺. NAD⁺ exhibited a non-competitive inhibition pattern where the U_{max} mg⁻¹ decreased as the inhibitor concentration increased while $K_{M,app}$ was consistent. Analysis of the different concentrations showed that the K_i of NAD⁺ was 289 μ M. (FIG. 6).

To determine whether NOX5 is a water or hydrogen peroxide producing enzyme, an amplex red assay was performed. The presence of H₂O₂ can be confirmed by incubating the standard assay mixture with amplex red and peroxidase. Produced resorufin can be detected using a fluo-

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rescence spectroscopy analysis. NOX5 produced H_2O_2 at a 2.63% ratio of NADH strongly suggesting that it is a water forming NADPH oxidase.

Total Turnover Number (TTN).

Total turnover number (TTN) is a measurement of catalyst productivity. For biocatalysts, TTN is defined as the total amount of product produced over the lifetime of an enzyme. Calculations of TTN were performed by dividing the change of NADPH concentration by the amount of enzyme that was used for each assay. In the standard assay conditions with the presence of DTT the TTN was found to be about 168,000, consistently, at 25° C. (data not shown).

This experiment was repeated to see if the presence of reducing agents had any effect on the total turnover number. The stock solution of enzyme was dialyzed against 250 mL of 10 mM Tris-HCl (pH 7.5) for two hours. The solution was then exchanged and dialyzed for an additional 2 hours. The TTN was then measured with the dialyzed enzyme with and without reducing agents. DTT and β -mercaptoethanol (β -ME) were used at a concentration of 5 mM. The TTN for the sample with no reducing agents, DTT and β -ME were 128,000, 168,000 and 107,000, respectively. The presence of DTT had a positive effect, but it was not as dramatic compared to the NADH oxidase from *Lactobacillus sanfranciscensis*. β -ME did not have a positive effect at all and actually decreased the TTN.

To examine TTN limitation possibilities, three properties were investigated: i) thermal stability of enzyme at 25° C.; ii) presence of hydrogen peroxide (H_2O_2) and stability of enzyme against it; and iii) product (NAD^+) inhibition in the system.

Thermal stability at 25° C. was measured by incubating the enzyme for extended periods of time. The enzyme was then assayed to check the remaining activity (data not shown). The thermal stability at 25° C. was investigated in order to show the relevance of thermal degradation during turnover. Through this study, it can be concluded that the enzyme shows to be inactive before it is thermally deactivated.

The effect of H_2O_2 was studied with a concentration range up to 200 μM , which would be the total amount produced from a standard assay if the enzyme was a hydrogen peroxide producing NADPH oxidase. Even at high concentrations, there was no change found in the initial specific activity (data not shown), thus showing that the enzyme is indeed quite stable against H_2O_2 .

The presence of NAD^+ inhibition, and its pattern was known. However, even at high concentrations of NAD^+ , there was a reasonable amount of activity. So, it would be difficult to conclude that NAD^+ had inhibited the reaction completely.

Example 2

Mutation of NADH Oxidase from *Lactobacillus plantarum* for NADPH Activity

Since the wild type NOX5 had activity exclusively towards NADH, and had little to no activity towards NADPH, mutational options were investigated to introduce NADPH activity. Crystal structure comparisons of NADPH oxidase from *Lactobacillus sanfranciscensis* and a homology model of NOX5 from *Lactobacillus plantarum* showed differences in where the 2'-phosphate would be located. The one from *L. sanfranciscensis* had a histidine, which would be able to accommodate the negative charge but NOX5 only had hydrophobic residues in that area. Based on this knowledge, different basic residues were chosen for mutation in that region.

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Single mutations were done on residues G178 and L179 into K, R and K, R, H respectively, and double mutations were also investigated with different combinations of the single mutations. The mutation of G178H was excluded due to the fact that the enzyme would then have two histidines next to each other, creating steric hindrance in the binding pocket. The resulting mutants were expressed on small scale and assayed at the cell lysate level. Table 2 provides the NOX5 mutants and the activity of the mutants at the cell lysate level.

Among the mutants, L179R retained the highest amount of NADH activity, and G178R/L179R had the highest activity for NADPH. Although not wishing to be bound by any particular theory, it is believed that a positive charge is introduced through the mutation at L179R, and the additional mutation at G178R stabilizes the positioning, effectively decreasing the amount of free rotation of L179R through hydrogen bonding. It seems reasonable for arginine to have the largest effect, as it has the most options for hydrogen bonding. The low activity of L179H can be explained by the presence of an adjacent proline causing steric hindrance.

TABLE 2

Mutant	NADH activity (U/mg)	NADPH activity (U/mg)
Wild Type	10.0	0.00
G178K	3.92	0.46
G178R	1.51	0.23
L179K	5.14	1.03
L179R	7.32	1.76
L179H	1.37	0.64
G178K/L179K	0.84	3.11
G178K/L179R	2.00	5.68
G178K/L179H	1.24	3.85
G178R/L179K	0.94	3.56
G178R/L179R	2.64	6.00
G178R/L179H	0.64	0.52

Study of mutants L179R and G178R/L179R. L179R and G178R/L179R were selected for further purification. Table 3 provides kinetic parameters of wild-type (WT) and mutant NADPH oxidases. L179R was not as active as the wild-type having a $k_{cat, \text{NADH}}$ of 122.0 s^{-1} . However, the K_M, NADH was much lower at 6.56 μM , improving the k_{cat}/K_M by more than 4-fold. The mutant also showed NADPH activity but had a very high K_M of 489.6 μM . The double mutant G178R/L179R also had the same trend for NADH as L179R but to a larger extent. The $k_{cat, \text{NADH}}$ was 34.0 s^{-1} and the K_M, NADH was 34.0 μM , resulting in a k_{cat}/K_M of 13.2 $\mu\text{M}^{-1}\text{s}^{-1}$. It also showed a k_{cat}/K_M for NADPH at 11.7 $\mu\text{M}^{-1}\text{s}^{-1}$, where at, NADPH was 114.1 s^{-1} and the K_M, NADPH was 9.76 μM . Overall, both enzymes were improvements over the wild-type, in terms of k_{cat}/K_M .

TABLE 3

enzyme	NADH			NADPH		
	k_{cat} (s^{-1})	K_M (μM)	k_{cat}/K_M ($\mu\text{M}^{-1}\text{s}^{-1}$)	k_{cat} (s^{-1})	K_M (μM)	k_{cat}/K_M ($\mu\text{M}^{-1}\text{s}^{-1}$)
WT	211.6	50.2	4.22	—	—	—
L179R	122.0	6.56	18.6	146.4	489.6	0.30
G178R/L179R	34.0	2.57	13.2	114.1	9.76	11.7

The TTN of the mutants were measured and the same trend, where the presence of reducing agents did not affect the enzyme to a great extent, was found. The double mutant

successfully exhibited NADPH activity, expanding the range of applications where this enzyme could be used.

Example 3

Higher Operational Stability of *Lactobacillus plantarum* NAD(P)H Oxidase (Higher Total Turnover Number)

Comparison of NADPH oxidases. Table 4 provides a comparison of TTN with and without DTT, for NADH oxidases from *L. plantarum*, *Lactobacillus sanfranciscensis*, *Lactococcus lactis*.

TABLE 4

organism	enzyme	NADH		NADPH	
		TTN	TTN with DTT	TTN	TTN with DTT
<i>L. plantarum</i>	NOX5 WT	128,000	168,000	—	—
	L179R	181,000	149,000	—	—
	G178R/	108,000	128,000	105,000	118,000
	L179R	—	—	—	—
<i>L. sanfranciscensis</i>	NOX2	5,000	112,500	—	—
<i>L. lactis</i>	NOX2	38,740	78,480	—	—

NOX5 has shown a higher total turnover number with and even without any reducing agents. This is an indication of improved stability against overoxidation at the catalytically active cysteine residue. Since there are known effects of inhibition of DTT on certain rare sugar producing dehydrogenases, such as mannitol dehydrogenase from *Apium graveolens*, it is preferable for an NADPH oxidase to be stable without DTT. Also, improved stability without reducing agents would be a advantage in the pharmaceutical industry (or any other area that is related for the matter) where the presence of these reducing agents lack acceptability.

A broad study of NOX5 from *Lactobacillus plantarum* was conducted to study the possibility of an NADPH oxidase stable against overoxidation. In this study, pH and temperature characteristics were investigated to identify a common ground for enzyme coupled systems. Kinetic parameters were defined and the TTN was studied to discover the advantages compared to previous NADPH oxidases. Through this study, the high stability of this enzyme was proven with and without the presence of reducing agents.

As the wild-type enzyme demonstrates specificity for a NADH substrate, in order to be able to utilize NADPH, mutations were made to change the specificity of the enzyme. By positioning different positively charged residues to interact and accommodate the 2'-phosphate of NADPH, it was possible to find a mutation that would be of this effect. This will broaden the range and usage of this NADPH oxidase, that has higher stability against over oxidation than its predecessors.

SEQUENCE LISTING

SEQ ID NO: 1-NADH Oxidase Obtained from *Lactobacillus plantarum*
 MKVIVIGCTHAGTA AVNQILASNPDEVTIYERNDNVSFLSCGIALY
 LGGQVADPQGLFYSSPEQLAKLGATVHMQHDTVNTDKHEITVTDL
 KTGESKTDHYDKLVVTTGSPVPIPIDGIDSPNVYLCKNWTQAQNLW
 EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLDGLPRILNKYLD
 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM

-continued

SEQUENCE LISTING

5 AILCVGPRPNTGLLKGKVDNMANGSIKTNQYMQTSDPDIYAGDSVA
 VHYNPTKKDAYIPLATNAVROGTLVGLNIFKPTRKYMGTQSTSGMLL
 FGQTISSGGMTEHAQAENVPAAVTFEDNYPPEFMPPTKPVLMQLV
 YNPETREILGAQFMSEHDVQSANVISVMIQNHNTIDDLGFVDMFFQ
 PIYDRPFNYLNLGQAAIAHAAEAATVTE

SEQ ID NO: 2-NADH Oxidase Obtained from
Lactobacillus plantarum
 10 ATGAAAGTTATTGTAAATGGTGTACCCATGCCGCGACTGCTGCTGT
 TAATCAGATTTTAGCATCAAATCCAGATACTGAAGTGACGATTTATG
 AAAGAAATGACAATGCTCTCGTTCCTATCCTGTGGGATCGCACTTAC
 CTTGGCGGCCAAGTTGCTGATCCTCAAGGCCTATTTTATCCAGTCC
 TGAAACAGTTAGCTAAGTTAGGCGCAACTGTTTCATATGCAACATGATG
 15 TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
 AAGACTGGTGAATCTAAGACTGATCACTATGACAAAGTTAGTTGTGAC
 TACTGGTTTCAATGCGCTGTTATTCACCAATTGACGGCATCGATAGTC
 CCAATGTCTACTTATGCAAGAACTGGACGCGCAGCTCAGAATTTATGG
 GAAGCAGCCAAACAGCTAAGCGGGTCATTGTGATCGGTGGCGGTTA
 TATCGGTACTGAATTAGTTGAAGCTTACCAGAAGCAAGGTAAGGAAG
 20 TCACACTAATGATGGTTTACCACGGATTTTAAATAAATCACTTAGAC
 AAAGAAATCAGTACCGGGTTGAACAAAGCTTTGTTGATCAGCGTAT
 CAAGATGGCTTTGAATCAAATGGTGAAGGCTTCAGTGATGATGGTA
 AAGAAGTTACGGTCAAGACTGACAGGGGCACTACACAGCCGACATG
 GCGATTCTTTGTGTTGGCTTCCGGCCAAATACCGGCTTACTCAAGGG
 CAAGGTCGATATGAACGCTAATGGCTCGATCAAGACCAATGACTACA
 25 TGCAAACTTCTGATCCAGACATTTACGGGGCTGGTACTCGGTTGCT
 GTTCACTATAACCACTAAGAAAGATGCTTATATCCATTAGCAAC
 GAATGCGGTTCCGCAAGGAACCTTAGTTGGTTTGAACATCTTCAAGC
 CAACGCGGAAGTACATGGGGACACAATCACTTCTGGGTTAATGTTG
 TTCGGCCAAACCATCGTTTCACTCTGGGATGACCCTAGAACATGCACA
 GGCCGAAATGTTCCGGCAGCCGCTGTCACTTTTGAAGACAACCTACC
 30 GGCCAGAATTTATGCCAACCTAAGCCTGTTTAAATGCAATGGTT
 TACAATCCTGAAACTCGCGAAATCCTAGGTGCACAATTCATGAGTGA
 ACATGATGTTTCCGAATCAGCCAATGTGATTTCACTGATGATTCAA
 ATCAACAATACCATGACGACTTAGGGTTCGTAGATGATTTGCTCCAA
 CCAATTTACGACCGGCCATTTAATCTATTGAACTTACTTGGTCAAGC
 AGCGATTGCCCATGCGGCGCAAGCTGTCTACTGAATAA

35 SEQ ID NO: 3-NADH Oxidase Derived from
Lactobacillus plantarum, G178K mutant
 MKVIVIGCTHAGTA AVNQILASNPDEVTIYERNDNVSFLSCGIALY
 LGGQVADPQGLFYSSPEQLAKLGATVHMQHDTVNTDKHEITVTDL
 KTGESKTDHYDKLVVTTGSPVPIPIDGIDSPNVYLCKNWTQAQNLW
 EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLDGLPRILNKYLD
 40 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
 AILCVGPRPNTGLLKGKVDNMANGSIKTNQYMQTSDPDIYAGDSVA
 VHYNPTKKDAYIPLATNAVROGTLVGLNIFKPTRKYMGTQSTSGMLL
 FGQTISSGGMTEHAQAENVPAAVTFEDNYPPEFMPPTKPVLMQLV
 YNPETREILGAQFMSEHDVQSANVISVMIQNHNTIDDLGFVDMFFQ
 PIYDRPFNYLNLGQAAIAHAAEAATVTE

45 SEQ ID NO: 4-NADH Oxidase Derived from
Lactobacillus plantarum, G178R mutant
 MKVIVIGCTHAGTA AVNQILASNPDEVTIYERNDNVSFLSCGIALY
 LGGQVADPQGLFYSSPEQLAKLGATVHMQHDTVNTDKHEITVTDL
 KTGESKTDHYDKLVVTTGSPVPIPIDGIDSPNVYLCKNWTQAQNLW
 EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLDGLPRILNKYLD
 50 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
 AILCVGPRPNTGLLKGKVDNMANGSIKTNQYMQTSDPDIYAGDSVA
 VHYNPTKKDAYIPLATNAVROGTLVGLNIFKPTRKYMGTQSTSGMLL
 FGQTISSGGMTEHAQAENVPAAVTFEDNYPPEFMPPTKPVLMQLV
 YNPETREILGAQFMSEHDVQSANVISVMIQNHNTIDDLGFVDMFFQ
 PIYDRPFNYLNLGQAAIAHAAEAATVTE

55 SEQ ID NO: 5-NADH Oxidase Derived from
Lactobacillus plantarum, G178K/R mutants
 ATGAAAGTTATTGTAAATGGTGTACCCATGCCGCGACTGCTGCTGT
 TAATCAGATTTTAGCATCAAATCCAGATACTGAAGTGACGATTTATG
 AAAGAAATGACAATGCTCTCGTTCCTATCCTGTGGGATCGCACTTAC
 60 CTTGGCGGCCAAGTTGCTGATCCTCAAGGCCTATTTTATCCAGTCC
 TGAAACAGTTAGCTAAGTTAGGCGCAACTGTTTCATATGCAACATGATG
 TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
 AAGACTGGTGAATCTAAGACTGATCACTATGACAAAGTTAGTTGTGAC
 TACTGGTTTCAATGCGCTGTTATTCACCAATTGACGGCATCGATAGTC
 CCAATGTCTACTTATGCAAGAACTGGACGCGCAGCTCAGAATTTATGG
 GAAGCAGCCAAACAGCTAAGCGGGTCATTGTGATCGGTGGCGGTTA
 65 TATCGGTACTGAATTAGTTGAAGCTTACCAGAAGCAAGGTAAGGAAG
 TCACACTAATGATARRTTACCACGGATTTTAAATAAATCACTTAGAC

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SEQUENCE LISTING

AAAGAATTCAGTACCGGGTTGAACAAGACTTTGTTGATCACGGTAT
CAAGATGGCTTTGAATCAAATGGTGCAAGGCTTCAGTGATGATGGTA
AAGAAGTTACGGTCAAGACTGCAAGGGCAGCTACACAGCCGACATG
GCGATTCTTTGTGTTGGCTTCCGGCCAAATACCGGCTTACTCAAGGG
CAAGGTGATATGAACGCTAATGGCTCGATCAAGACCAATGACTACA
TGCAAACTTCTGATCCAGACATTTACGGGGCTGGTGACTCGGTTGCT
GTTCACTATAACCCAACTAAGAAAGATGCTTATATCCATTAGCAAC
GAATGCGGTTTCGCCAAGGAACCTTAGTTGGTTTGAACATCTTCAAGC
CAACGCGGAAGTACATGGGGACACAACTCACTTTTGAAGACAACCTACC
GGCCGAAATTTATGCCAACCACTAAGCCTGTTTTAATGCAATTGGTT
TTCGGCCAAACCATCGTTTCATCTGGGATGACCCTAGAACATGCACA
GGCCGAAATGTTCCGGCAGCCGCTGTCACTTTTGAAGACAACCTACC
GGCCGAAATTTATGCCAACCACTAAGCCTGTTTTAATGCAATTGGTT
TACAATCCTGAACTCGCGAAATCCTAGGTGCACAATTATCATGAGTGA
ACATGATGTTTCGCAATCAGCCAAATGATGTTTCACTGATGATTGAAA
ATCACAATACCAATTGACGACTTAGGGTTCGTAGATATGTTCTTCCAA
CCAATTTACGACCGGCCATTTAACTATTGAACTTACTTGGTCAAGC
ACCGATTGCCATGCGGGCGAAGCTGTCACTGAATAA

SEQ ID NO: 6-NADH Oxidase Derived from
Lactobacillus plantarum, L179K mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNNDVNSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGSGWPIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRIVIVGGGYIGTELVEAYQKQKKEVTLIDGKPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMNANGSIKTDNYMQTSDPDIYAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSLGML
FGQTISSGMTLEHAQAENVPAAAVTFEDNRYRPEFMPPTKPVLMQLV
YNPETREILGAQFMSEHDVVSQSANVISVMIQNHNTIDDLGFVDMFFQ
PIYDRPFNYLNLGQAAIAHAAEAATVE

SEQ ID NO: 7-NADH Oxidase Derived from
Lactobacillus plantarum, L179K mutant
ATGAAAGTTATTGTAATGGTGTACCCATGCCGGCACTGCTGCTGT
TAATCAGATTTTGAATCAAACTAGCTACTGAAGTGACGATTTATG
AAGAAATGACAATGTCCTGTTCTATCCTGTGGGATCGCACTTTAC
CTTGGCGGCCAAGTTGCTGATCCTCAAGGCCTATTTATTCCAGTCC
TGAAACAGTACTGAATTTAGGCGCAACTGTTTATGCAACATGATG
TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
AAGACTGGTGAATCTAAGACTGATCCTATGACAAGTTAGTTGTCAC
TACTGTTTATGCGGCTGTTATTCACCAATTGACGGCATCGATAGTC
CCAATGTCTACTTATGCAAGAACTGGACGCGCTCAGAAATTTATGG
GAAGCAGCCAAACAGCTAAGCGGGTCACTGTGATCGGTGGCGGTTA
TATCGTACTGAATAGTTAGGCGCAACTTACCAGAAGCAAGGTAAAGG
TCACACTAATGATGGTAAACCAAGGATTTTAAATAAATACTTAGAC
AAAGAATTCAGTACCGGGTTGAACAAGACTTTGTTGATCAGCGTAT
CAAGATGGCTTTGAATCAAATGGTGCAAGGCTTCAGTGATGATGGTA
AAGAAGTTACGGTCAAGACTGCAAGGGCAGCTACACAGCCGACATG
CGGATTTCTTTGTGTTGGCTTCCGGCCAAATACCGGCTTACTCAAGGG
CAAGGTGATATGAACGCTAATGGCTCGATCAAGACCAATGACTACA
TGCAAACTTCTGATCCAGACATTTACGGGGCTGGTGACTCGGTTGCT
GTTCACTATAACCCAACTAAGAAAGATGCTTATATCCCAATAGCAAC
GAATGCGGTTTCGCCAAGGAACCTTAGTTGGTTTGAACATCTTCAAGC
CAACGCGGAAGTACATGGGGACACAATCAACTTCTGGGTTAATGTTG
TTCGGCCAAACCATCGTTTCATCTGGGATGACCCTAGAACATGCACA
GGCCGAAATGTTCCGGCAGCCGCTGTCACTTTTGAAGACAACCTACC
GGCCGAAATTTATGCCAACCACTAAGCCTGTTTTAATGCAATTGGTT
TACAATCCTGAACTCGCGAAATCCTAGGTGCACAATTATCATGAGTGA
ACATGATGTTTCGCAATCAGCCAAATGATGTTTCACTGATGATTCAAA
ATCACAATACCAATTGACGACTTAGGGTTCGTAGATATGTTCTTCCAA
CCAATTTACGACCGGCCATTTAACTATTGAACTTACTTGGTCAAGC
ACCGATTGCCATGCGGGCGAAGCTGTCACTGAATAA

SEQ ID NO: 8-NADH Oxidase Derived from
Lactobacillus plantarum, L179R mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNNDVNSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGSGWPIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRIVIVGGGYIGTELVEAYQKQKKEVTLIDGKPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMNANGSIKTDNYMQTSDPDIYAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSLGML
FGQTISSGMTLEHAQAENVPAAAVTFEDNRYRPEFMPPTKPVLMQLV
YNPETREILGAQFMSEHDVVSQSANVISVMIQNHNTIDDLGFVDMFFQ
PIYDRPFNYLNLGQAAIAHAAEAATVE

20

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SEQUENCE LISTING

5 SEQ ID NO: 9-NADH Oxidase Derived from
Lactobacillus plantarum, L179H mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNNDVNSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGSGWPIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRIVIVGGGYIGTELVEAYQKQKKEVTLIDGKPRILNKYLD
10 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMNANGSIKTDNYMQTSDPDIYAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSLGML
FGQTISSGMTLEHAQAENVPAAAVTFEDNRYRPEFMPPTKPVLMQLV
YNPETREILGAQFMSEHDVVSQSANVISVMIQNHNTIDDLGFVDMFFQ
PIYDRPFNYLNLGQAAIAHAAEAATVE

15 SEQ ID NO: 10-NADH Oxidase Derived from
Lactobacillus plantarum, L179H/R mutants
ATGAAAGTTATTGTAATGGTGTACCCATGCCGGCACTGCTGCTGT
TAATCAGATTTTAGCATCAAATCCAGATACTGAAGTGACGATTTATG
AAAGAAATGACAATGCTCTCGTTCCTATCCTGTGGGATCGCACTTTAC
CTTGGCGGCCAAGTTGCTGATCCTCAAGGCCTATTTATCCAGTCC
20 TGAAACAGTACTAGTAAAGTTAGGCGCACTGTTTATATGCAACATGATG
TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
AAGACTGGTGAATCTAAGACTGATCCTATGACAAAGTTAGTTGTCAC
TACTGGTTCAATGCGGCTGTTATCCACCAATGACGGCATCGATAGTC
CCAATGTCTACTTATGCAAGAACTGGACGCGCAGCTCAGAAATTTATG
GAAGCAGCCAAACAGCTAAGCGGGTCACTGTGATCGGTGGCGGTTA
25 TATCGGTACTGAATTAGTTGAAGCTTACCAGAAGCAAGGTAAAGGAG
TCACACTAATGATGGTCRYCCACGGATTTTAAATAAATACTTAGAC
AAAGAATTCAGTACCGGGTTGAACAAGACTTTGTTGATCAGCGTAT
CAAGATGGCTTTGAATCAAATGGTGCAAGGGCTTCACTGATGATGGTA
AAGAAGTTACGGTCAAGACTGACAAGGGCAGCTACACAGCCGACATG
GCGATTTCTTTGTGTTGGCTTCCGGCCAAATACCGGCTTACTCAAGGG
30 CAAGGTGATATGAACGCTAATGGCTCGATCAAGACCAATGACTACA
TGCAAACTTCTGATCCAGACATTTACGGGGCTGGTGACTCGGTTGCT
GTTCACTATAACCCAACTAAGAAAGATGCTTATATCCCAATAGCAAC
GAATGCGGTTTCGCCAAGGAACCTTAGTTGGTTTGAACATCTTCAAGC
CAACGCGGAAGTACATGGGGACACAATCAACTTCTGGGTTAATGTTG
TTCGGCCAAACCATCGTTTCATCTGGGATGACCCTAGAACATGCACA
35 GGCCGAAATGTTCCGGCAGCCGCTGTCACTTTTGAAGACAACCTACC
GGCCGAAATTTATGCCAACCACTAAGCCTGTTTTAATGCAATTTGGTT
TACAATCCTGAAACTCGCGAAATCCTAGGTGCAACATGATGATGTA
ACATGATGTTTCGCAATCAGCCAAATGATGTTTCACTGATGATTCAAA
ATCACAATACCAATTGACGACTTAGGGTTCGTAGATATGTTCTTCCAA
CCAATTTACGACCGGCCATTTAACTATTGAACTTACTTGGTCAAGC
40 AGCGATTGCCATGCGGGCGAAGCTGTCACTGAATAA

SEQ ID NO: 11-NADH Oxidase Derived from
Lactobacillus plantarum, G178K/L179K mutants
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNNDVNSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGSGWPIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRIVIVGGGYIGTELVEAYQKQKKEVTLIDGKPRILNKYLD
45 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMNANGSIKTDNYMQTSDPDIYAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSLGML
FGQTISSGMTLEHAQAENVPAAAVTFEDNRYRPEFMPPTKPVLMQLV
YNPETREILGAQFMSEHDVVSQSANVISVMIQNHNTIDDLGFVDMFFQ
50 PIYDRPFNYLNLGQAAIAHAAEAATVE

SEQ ID NO: 12-NADH Oxidase Derived from
Lactobacillus plantarum, G178R/L179K mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNNDVNSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGSGWPIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRIVIVGGGYIGTELVEAYQKQKKEVTLIDGKPRILNKYLD
55 KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMNANGSIKTDNYMQTSDPDIYAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSLGML
FGQTISSGMTLEHAQAENVPAAAVTFEDNRYRPEFMPPTKPVLMQLV
YNPETREILGAQFMSEHDVVSQSANVISVMIQNHNTIDDLGFVDMFFQ
60 PIYDRPFNYLNLGQAAIAHAAEAATVE

SEQ ID NO: 13-NADH Oxidase Derived from
Lactobacillus plantarum, G178R/K/L179K mutants
ATGAAAGTTATTGTAATGGTGTACCCATGCCGGCACTGCTGCTGT
TAATCAGATTTTAGCATCAAATCCAGATACTGAAGTGACGATTTATG
65 AAAGAAATGACAATGCTCTCGTTCCTATCCTGTGGGATCGCACTTTAC
CTTGGCGGCCAAGTTGCTGATCCTCAAGGCCTATTTATCCAGTCC

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SEQUENCE LISTING

TGAACAGTTAGCTAAGTTAGGCGCAACTGTTTCATATGCAACATGATG
TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
AAGACTGGTGAATCTAAGACTGATCACTATGACAAGTTAGTTGTGCAC
TACTGGTTCATGGCCTGTTATTCCACCAATTGACGGCATCGATAGTC
CCAAATGTCTACTTATGCAAGAACTGGACGACGCTCAGAATTTATGG
GAAGCAGCCAAACAGCTAAGCGGGTCATTGTGATCGGTGGCGGTTA
TATCGGTACTGAATTAGTTGAAGCTTACCAGAAGCAAGGTAAGGAAG
TCACACTAATTGATARRAACACCAAGGATTTTAAATAAATACTTAGAC
AAAGAATTCAGTGACCGGGTTGAACAAGACTTTGTTGATCAGCGTAT
CAAGATGGCTTTGAATCAAAATGGTGAAGGCTTCAGTGATGATGGTA
AAGAAGTTACGGTCAAGACTGACAAGGCGAGTACACAGCCGACATG
GCGATTCTTTGTTGGTTCGCGCAAATACCGGCTTACTCAAGGG
CAAGGTCGATATGAACGCTAATGGCTCGATCAAGACCAATGACTACA
TGCAAACTTCTGATCCAGACATTTACGGGCTGGTGACTCGGTGCT
GTTCACTATAACCACTAAGAAAGATGCTTATATCCATTAGCAAC
GAATCGGTTTCGCAAGGAACCTTAGTTGGTTTGAACATCTTCAAGC
CAACGCGGAATGATACATGGGACACAGATCAACTTCTGGGTTAATGTTG
TTCGGCCAAACCATCGTTTCATCTGGGATGACCCTAGAACATGCACA
GGCCGAAAATGTTCCGGCAGCGCTGTCACTTTTGAAGACAACCTACC
GGCCAGAATTTATGCCAACCACTAAGCCTGTTTAAATGCAATTGGTT
TACAATCCTGAACCTCGCGAATCCTAGGTGCACAAATCATGAGTGA
ACATGATGTTTCGCAATCAGCAATGTGATTTCACTGATGATTCAAA
ATCACAATACCATTGACGACTAGGGTTCGTAGATATGTTCTTCCAA
CCAATTTACGACCGGCCATTTAACTATTGAACTTACTTGGTCAAGC
AGCGATTGCCCATGCGGCCGAGCTGTCACTGAATAA

SEQ ID NO: 14-NADH Oxidase Derived from
Lactobacillus plantarum, G178K/L179R mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNDNVSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGWSVPVIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLIDKRPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMANGSIKTDNYMQTSDPDIYGAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSGML
FGQTISSGMLTLEHAQAENVPAAAVTFEDNRYRPEMPTTKPVLMLQV
YNPETREILGAQFMSEHDVSQSANVISVMIQNHNTIDDLGFVDMFPFQ
PIYDRPFNYLNLGGQAAIAHAAEAETE

SEQ ID NO: 15-NADH Oxidase Derived from
Lactobacillus plantarum, G178K/L179H mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNDNVSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGWSVPVIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLIDKHPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMANGSIKTDNYMQTSDPDIYGAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSGML
FGQTISSGMLTLEHAQAENVPAAAVTFEDNRYRPEMPTTKPVLMLQV
YNPETREILGAQFMSEHDVSQSANVISVMIQNHNTIDDLGFVDMFPFQ
PIYDRPFNYLNLGGQAAIAHAAEAETE

SEQ ID NO: 16-NADH Oxidase Derived from
Lactobacillus plantarum, G178R/L179R mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNDNVSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGWSVPVIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLIDRRPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMANGSIKTDNYMQTSDPDIYGAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSGML
FGQTISSGMLTLEHAQAENVPAAAVTFEDNRYRPEMPTTKPVLMLQV
YNPETREILGAQFMSEHDVSQSANVISVMIQNHNTIDDLGFVDMFPFQ
PIYDRPFNYLNLGGQAAIAHAAEAETE

SEQ ID NO: 17-NADH Oxidase Derived from
Lactobacillus plantarum, G178R/L179H mutant
MKVIVIGCTHAGTAAVNQILASNPDEVTIYERNDNVSFLSCGIALY
LGGQVADPQGLFYSSPEQLAKLGATVHMQHVDVTDVNTDKHEITVTDL
KTGESKTDHYDKLVVTTGWSVPVIPPIDGIDSPNVYLCKNWTQAQNLW
EAAKPAKRVIIVIGGGYIGTELVEAYQKQKEVTLIDRRPRILNKYLD
KEFTDRVEQDFVDHGIKMALNQMVQGFSDDGKEVTVKTDKGSYTADM
AILCVGFRPNTGLLKGKVDMMANGSIKTDNYMQTSDPDIYGAGDSVA
VHYNPTKKDAYIPLATNAVRQGTLVGLNIFKPTRKYMGTQSTSGML
FGQTISSGMLTLEHAQAENVPAAAVTFEDNRYRPEMPTTKPVLMLQV
YNPETREILGAQFMSEHDVSQSANVISVMIQNHNTIDDLGFVDMFPFQ
PIYDRPFNYLNLGGQAAIAHAAEAETE

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SEQUENCE LISTING

- 5 SEQ ID NO: 18-NADH Oxidase Derived from
Lactobacillus plantarum, G178K/R /L179R/H
mutants
ATGAAAGTTATTGTAATGGTTGTACCCATGCCGCGACTGCTGCTGT
TAATCAGATTTTAGCATCAAATCCAGATACTGAAGTGACGATTATG
AAAGAAATGACAATGTCTCGTTCCTATCCTGTGGGATCGCACTTTAC
CTTGGCGGCCAAGTTGCTGATCCTCAAGGCTATTTTATCCAGTCC
10 TGACAGTTAGCTAAGTTAGGCGCACTGTTTCATATGCAACATGATG
TGACGGATGTGAATACTGACAAACATGAAATTACGGTTACTGACTTA
AAGACTGGTGAATCTAAGACTGATCACTATGACAGGTTAGTTGTAC
TACTGGTTCATGGCCTGTTATCCACCATTGACGGCATCGATAGTC
CCAATGTCTACTTATGCAAGAACTGGACGCGACGCTCAGAATTTATGG
15 GAAGCAGCCAAACAGCTAAGCGGGTCATTGTGATCGGTGGCGGTTA
TATCGGTACTGAATTAGTTGAAGCTTACCAGAAGCAAGGTAAGGAAG
TCACACTAATTGATARRCRYCCACGGATTTTAAATAAATACTTAGAC
AAAGAATTCACTGACCGGGTTGAACAAGACTTTGTTGATCAGGTAT
CAAGATGGCTTGAATCAAAATGGTGCAAGGCTTCACTGATGATGGTA
AAGAAGTTACGGTCAAGACTGACAAGGCGAGTACACAGCCGACATG
20 GCGATTCTTGTGTTGGCTTCGGCCAAATGACAGGCTTAGTTCAAGGG
CAAGGTCGATATGAACGCTAATGGCTCGATCAAGCCATGACTACA
TGCAAACTTCTGATCCAGACATTTACGGGGCTGGTGACTCGGTTGCT
GTTCACTATAACCCAACTAAGAAAGATGCTTATATCCATTAGCAAC
GAATGCGGTTTCGCAAGGAACCTTAGTTGGTTGAACATCTTCAAGC
CAACGCGGAAGTACATGGGGACACAATCAACTTCTGGGTTAATGTTG
TTCGGCCAAACCATCGTTTCATCTGGGATGACCTAGAACATGCACA
25 GGCCGAAAATGTTCCGGCAGCGCTGTCACTTTTGAAGACAACCTACC
GGCCAGAATTTATGCCAACCACTAAGCCTGTTTAAATGCAATTGGTT
TACAATCCTGAAACTCGCGAAATCCTAGGTGCACAATTCATGAGTGA
ACATGATGTTTCGCAATCAGCCAAATGTGATTTCACTGATGATTCAAA
ATCACAATACCATTGACGACTTAGGGTTCGTAGATATGTTCTTCCAA
CCAATTTACGACCGGCCATTTAACTATTGAACTTACTTGGTCAAGC
30 AGCGATTGCCCATGCGGCCGAGCTGTCACTGAATAA

SEQ ID NO: 19-Forward Cloning Primer for NADH
Oxidase from *Lactobacillus plantarum*
TGATGTCATGCCATGGTTATGAAAGTTATTGTAATTGGTTGTACCCA

- 35 SEQ ID NO: 20-Reverse Cloning Primer for NADH
Oxidase from *Lactobacillus plantarum*
CCGCGCGCGCGCTCGATTATTCAGTGACAGCTTCGGCC

SEQ ID NO: 21-Forward Primer for NADH Oxidase
for *Lactobacillus plantarum* G178K/R mutants
40 GCAAGGTAAGGAAGTCACACTAATTGATARRTTACCACGGATTTTAA
ATAAATACTTAGACAA

SEQ ID NO: 22-Forward Primer for NADH Oxidase
for *Lactobacillus plantarum* L179H/R mutants
AGGTAAGGAAGTCACACTAATTGATGGTCRCCACGGATTTTAAATA
AATACTTAGACAAAG

- 45 SEQ ID NO: 23-Forward Primer for NADH Oxidase
for *Lactobacillus plantarum* L179K mutant
AGGTAAGGAAGTCACACTAATTGATGGTAAACCACGGATTTTAAATA
AATACTTAGACAA

- 50 SEQ ID NO: 24-Forward Primer for NADH Oxidase
for *Lactobacillus plantarum* G178K/R/L179R/H
mutants
GCAAGGTAAGGAAGTCACACTAATTGATARRCRYCCACGGATTTTAA
ATAAATACTTAGACAAAG

- 55 SEQ ID NO: 25-Forward Primer for NADH Oxidase
for *Lactobacillus plantarum* G178K/R/L179K
mutants
GCAAGGTAAGGAAGTCACACTAATTGATARRAAACCACGGATTTTAA
ATAAATACTTAGACAA

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1. A. Zaks, "Industrial biocatalysis", *Curr. Opin. Chem. Biol.*
2001, 5, 130-136.
65 2. A. Liese and M. V. Filho, "Production of fine chemicals
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603.

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 Thr Gln Ser Thr Ser Gly Leu Met Leu Phe Gly Gln Thr Ile Val Ser
 325 330 335
 Ser Gly Met Thr Leu Glu His Ala Gln Ala Glu Asn Val Pro Ala Ala
 340 345 350
 Ala Val Thr Phe Glu Asp Asn Tyr Arg Pro Glu Phe Met Pro Thr Thr
 355 360 365
 Lys Pro Val Leu Met Gln Leu Val Tyr Asn Pro Glu Thr Arg Glu Ile
 370 375 380
 Leu Gly Ala Gln Phe Met Ser Glu His Asp Val Ser Gln Ser Ala Asn
 385 390 395 400
 Val Ile Ser Val Met Ile Gln Asn His Asn Thr Ile Asp Asp Leu Gly
 405 410 415

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Phe Val Asp Met Phe Phe Gln Pro Ile Tyr Asp Arg Pro Phe Asn Tyr
 420 425 430

Leu Asn Leu Leu Gly Gln Ala Ala Ile Ala His Ala Ala Glu Ala Val
 435 440 445

Thr Glu
 450

<210> SEQ ID NO 5
 <211> LENGTH: 1353
 <212> TYPE: DNA
 <213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 5

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tcctgtggga tcgcacttta ccttgccggc caagttgctg atcctcaagg cctattttat    180
tccagtccctg aacagttagc taagttaggc gcaactgttc atatgcaaca tgatgtgacg    240
gatgtgaata ctgacaaaca tgaaattacg gttactgact taaagactgg tgaatctaag    300
actgatcact atgacaagtt agttgtcact actggttcac ggctgttat tccaccaatt    360
gacggcatcg atagtcccaa tgtctactta tgcaagaact ggacgcacgc tcagaattta    420
tgggaagcag ccaaaaccagc taagcgggtc attgtgatcg gtggcgggta tatcggtact    480
gaattagttg aagcttacca gaagcaaggt aaggaagtca cactaattga tarrrttacca    540
cggattttta ataaatactt agacaaagaa ttcactgacc gggttgaaca agactttgtt    600
gatcacggta tcaagatggc tttgaatcaa atgggtgcaag gcttcagtga tgatggtaaa    660
gaagttacgg tcaagactga caagggcagc tacacagccg acatggcgat tctttgtgtt    720
ggcttcgggc caaataccgg cttactcaag ggcaaggctg atatgaacgc taatggctcg    780
atcaagacca atgactacat gcaaaacttct gatccagaca ttacggggc tgggtgactcg    840
gttgctgttc actatacccc aactaagaaa gatgcttata tcccattagc aacgaatgcg    900
gttcgccaa gaaacctagtt tggtttgaac atcttcaagc caacgcggaa gtacatgggg    960
acacaatcaa cttctggggtt aatggtgttc ggccaaacca tcgtttcatc tgggatgacc   1020
ctagaacatg cacaggccga aatgtttccg gcagccgctg tcaactttga agacaactac   1080
cggccagaat ttatgccaac cactaagcct gttttaatgc aattgggtta caatcctgaa   1140
actcgcgaaa tcctaggtgc acaattcatg agtgaacatg atgtttcgca atcagccaat   1200
gtgatttcag tgatgattca aaatcacaa accattgacg acttaggggt cgtagatatg   1260
ttcttccaac caatttacga ccggccattt aactatttga acttacttgg tcaagcagcg   1320
attgcccatg cggccgaagc tgctactgaa taa                                1353

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<210> SEQ ID NO 6
 <211> LENGTH: 450
 <212> TYPE: PRT
 <213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 6

Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
 1 5 10 15

Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
 20 25 30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
 35 40 45

Gly 50	Gln 60	Val 70	Ala 80	Asp 90	Pro 100	Gln 110	Gly 120	Leu 130	Phe 140	Tyr 150	Ser 160	Ser 170	Pro 180	Glu 190	
Gln 65	Leu 75	Ala 85	Lys 95	Leu 105	Gly 115	Ala 125	Thr 135	Val 145	His 155	Met 165	Gln 175	His 185	Asp 195	Val 205	Thr 215
Asp 225	Val 235	Asn 245	Thr 255	Asp 265	Lys 275	His 285	Glu 295	Ile 305	Thr 315	Val 325	Thr 335	Asp 345	Leu 355	Lys 365	Thr 375
Gly 385	Glu 395	Ser 405	Lys 415	Thr 425	Asp 435	His 445	Tyr 455	Asp 465	Lys 475	Leu 485	Val 495	Val 505	Thr 515	Thr 525	Gly 535
Ser 545	Trp 555	Pro 565	Val 575	Ile 585	Pro 595	Pro 605	Ile 615	Asp 625	Gly 635	Ile 645	Asp 655	Ser 665	Pro 675	Asn 685	Val 695
Tyr 705	Leu 715	Cys 725	Lys 735	Asn 745	Trp 755	Thr 765	His 775	Ala 785	Gln 795	Asn 805	Leu 815	Trp 825	Glu 835	Ala 845	Ala 855
Lys 865	Pro 875	Ala 885	Lys 895	Arg 905	Val 915	Ile 925	Val 935	Ile 945	Gly 955	Gly 965	Gly 975	Tyr 985	Ile 995	Gly 1005	Thr 1015
Glu 1025	Leu 1035	Val 1045	Glu 1055	Ala 1065	Tyr 1075	Gln 1085	Lys 1095	Gln 1105	Gly 1115	Lys 1125	Glu 1135	Val 1145	Thr 1155	Leu 1165	Ile 1175
Asp 1185	Gly 1195	Lys 1205	Pro 1215	Arg 1225	Ile 1235	Leu 1245	Asn 1255	Lys 1265	Tyr 1275	Leu 1285	Asp 1295	Lys 1305	Glu 1315	Phe 1325	Thr 1335
Asp 1345	Arg 1355	Val 1365	Glu 1375	Gln 1385	Asp 1395	Phe 1405	Val 1415	Asp 1425	His 1435	Gly 1445	Ile 1455	Lys 1465	Met 1475	Ala 1485	Leu 1495
Asn 1505	Gln 1515	Met 1525	Val 1535	Gln 1545	Gly 1555	Phe 1565	Ser 1575	Asp 1585	Asp 1595	Gly 1605	Lys 1615	Glu 1625	Val 1635	Thr 1645	Val 1655
Lys 1665	Thr 1675	Asp 1685	Lys 1695	Gly 1705	Ser 1715	Tyr 1725	Thr 1735	Ala 1745	Asp 1755	Met 1765	Ala 1775	Ile 1785	Leu 1795	Cys 1805	Val 1815
Gly 1825	Phe 1835	Arg 1845	Pro 1855	Asn 1865	Thr 1875	Gly 1885	Leu 1895	Leu 1905	Lys 1915	Gly 1925	Lys 1935	Val 1945	Asp 1955	Met 1965	Asn 1975
Ala 1985	Asn 1995	Gly 2005	Ser 2015	Ile 2025	Lys 2035	Thr 2045	Asn 2055	Asp 2065	Tyr 2075	Met 2085	Gln 2095	Thr 2105	Ser 2115	Asp 2125	Pro 2135
Asp 2145	Ile 2155	Tyr 2165	Gly 2175	Ala 2185	Gly 2195	Asp 2205	Ser 2215	Val 2225	Ala 2235	Val 2245	His 2255	Tyr 2265	Asn 2275	Pro 2285	Thr 2295
Lys 2305	Lys 2315	Asp 2325	Ala 2335	Tyr 2345	Ile 2355	Pro 2365	Leu 2375	Ala 2385	Thr 2395	Asn 2405	Ala 2415	Val 2425	Arg 2435	Gln 2445	Gly 2455
Thr 2465	Leu 2475	Val 2485	Gly 2495	Leu 2505	Asn 2515	Ile 2525	Phe 2535	Lys 2545	Pro 2555	Thr 2565	Arg 2575	Lys 2585	Tyr 2595	Met 2605	Gly 2615
Thr 2625	Gln 2635	Ser 2645	Thr 2655	Ser 2665	Gly 2675	Leu 2685	Met 2695	Leu 2705	Phe 2715	Gly 2725	Gln 2735	Thr 2745	Ile 2755	Val 2765	Ser 2775
Ser 2785	Gly 2795	Met 2805	Thr 2815	Leu 2825	Glu 2835	His 2845	Ala 2855	Gln 2865	Ala 2875	Glu 2885	Asn 2895	Val 2905	Pro 2915	Ala 2925	Ala 2935
Ala 2945	Val 2955	Thr 2965	Phe 2975	Glu 2985	Asp 2995	Asn 3005	Tyr 3015	Arg 3025	Pro 3035	Glu 3045	Phe 3055	Met 3065	Pro 3075	Thr 3085	Thr 3095
Lys 3105	Pro 3115	Val 3125	Leu 3135	Met 3145	Gln 3155	Leu 3165	Val 3175	Tyr 3185	Asn 3195	Pro 3205	Glu 3215	Thr 3225	Arg 3235	Glu 3245	Ile 3255
Leu 3265	Gly 3275	Ala 3285	Gln 3295	Phe 3305	Met 3315	Ser 3325	Glu 3335	His 3345	Asp 3355	Val 3365	Ser 3375	Gln 3385	Ser 3395	Ala 3405	Asn 3415
Val 3425	Ile 3435	Ser 3445	Val 3455	Met 3465	Ile 3475	Gln 3485	Asn 3495	His 3505	Asn 3515	Thr 3525	Ile 3535	Asp 3545	Asp 3555	Leu 3565	

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<210> SEQ ID NO 7
 <211> LENGTH: 1353
 <212> TYPE: DNA
 <213> ORGANISM: *Lactobacillus plantarum*

<400> SEQUENCE: 7

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tctctgtgga tcgcacttta ccttgccggc caagttgctg atcctcaagg cctatattat      180
tccagtctcg aacagttagc taagttaggc gcaactgttc atatgcaaca tgatgtgacg      240
gatgtgaata ctgacaaaca tgaaattacg gttactgact taaagactgg tgaatctaag      300
actgatcact atgacaagtt agttgtcact actggttcac ggctgttat tccaccaatt      360
gacggcatcg atagtcccaa tgtctactta tgcaagaact ggacgcacgc tcagaattta      420
tggaagcag ccaaacaccg taagcgggtc attgtgatcg gtggcggtta tatcggtact      480
gaattagttg aagcttacca gaagcaaggt aaggaagtca cactaattga tggtaaacca      540
cggattttta ataaatactt agacaaagaa ttcactgacc gggttgaaca agactttgtt      600
gatcacggta tcaagatggc tttgaatcaa atggtgcaag gcttcagtga tgatggtaaa      660
gaagttacgg tcaagactga caagggcagc tacacagccg acatggcgat tctttgtgtt      720
ggcttcggcg caaataccgg cttactcaag ggcaaggctg atatgaacgc taatggctcg      780
atcaagacca atgactacat gcaaaacttc gatccagaca tttacggggc tggtgactcg      840
gttctgttgc actataaccc aactaagaaa gatgcttata tcccattagc aacgaatgcg      900
gttcgccaa gaaaccttagt tggtttgaac atcttcaagc caacgcggaa gtacatgggg      960
acacaatcaa cttctggggt aatgttgttc ggccaaacca tcgtttcatc tgggatgacc     1020
ctagaacatg cacaggccga aaatgttcg gcagccgctg tcacttttga agacaactac     1080
cggccagaat ttatgccaac cactaagcct gttttaatgc aattggttta caatcctgaa     1140
actcgcgaaa tcctaggtgc acaattcatg agtgaacatg atgtttcgca atcagccaat     1200
gtgatttcag tgatgattca aaatcacaat accattgacg acttaggggt cgtagatatg     1260
ttcttccaac caatttaaga ccggccattt aactatttga acttacttgg tcaagcagcg     1320
attgcccatg cggccgaagc tgtcactgaa taa                                     1353
  
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<210> SEQ ID NO 8
 <211> LENGTH: 450
 <212> TYPE: PRT
 <213> ORGANISM: *Lactobacillus plantarum*

<400> SEQUENCE: 8

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Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
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Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
20          25          30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
35          40          45

Gly Gly Gln Val Ala Asp Pro Gln Gly Leu Phe Tyr Ser Ser Pro Glu
50          55          60

Gln Leu Ala Lys Leu Gly Ala Thr Val His Met Gln His Asp Val Thr
65          70          75          80

Asp Val Asn Thr Asp Lys His Glu Ile Thr Val Thr Asp Leu Lys Thr
85          90          95

Gly Glu Ser Lys Thr Asp His Tyr Asp Lys Leu Val Val Thr Thr Gly
  
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100						105						110					
Ser	Trp	Pro	Val	Ile	Pro	Pro	Ile	Asp	Gly	Ile	Asp	Ser	Pro	Asn	Val		
115						120						125					
Tyr	Leu	Cys	Lys	Asn	Trp	Thr	His	Ala	Gln	Asn	Leu	Trp	Glu	Ala	Ala		
130						135						140					
Lys	Pro	Ala	Lys	Arg	Val	Ile	Val	Ile	Gly	Gly	Gly	Tyr	Ile	Gly	Thr		
145						150						155					
Glu	Leu	Val	Glu	Ala	Tyr	Gln	Lys	Gln	Gly	Lys	Glu	Val	Thr	Leu	Ile		
165						170						175					
Asp	Gly	Arg	Pro	Arg	Ile	Leu	Asn	Lys	Tyr	Leu	Asp	Lys	Glu	Phe	Thr		
180						185						190					
Asp	Arg	Val	Glu	Gln	Asp	Phe	Val	Asp	His	Gly	Ile	Lys	Met	Ala	Leu		
195						200						205					
Asn	Gln	Met	Val	Gln	Gly	Phe	Ser	Asp	Asp	Gly	Lys	Glu	Val	Thr	Val		
210						215						220					
Lys	Thr	Asp	Lys	Gly	Ser	Tyr	Thr	Ala	Asp	Met	Ala	Ile	Leu	Cys	Val		
225						230						235					
Gly	Phe	Arg	Pro	Asn	Thr	Gly	Leu	Leu	Lys	Gly	Lys	Val	Asp	Met	Asn		
245						250						255					
Ala	Asn	Gly	Ser	Ile	Lys	Thr	Asn	Asp	Tyr	Met	Gln	Thr	Ser	Asp	Pro		
260						265						270					
Asp	Ile	Tyr	Gly	Ala	Gly	Asp	Ser	Val	Ala	Val	His	Tyr	Asn	Pro	Thr		
275						280						285					
Lys	Lys	Asp	Ala	Tyr	Ile	Pro	Leu	Ala	Thr	Asn	Ala	Val	Arg	Gln	Gly		
290						295						300					
Thr	Leu	Val	Gly	Leu	Asn	Ile	Phe	Lys	Pro	Thr	Arg	Lys	Tyr	Met	Gly		
305						310						315					
Thr	Gln	Ser	Thr	Ser	Gly	Leu	Met	Leu	Phe	Gly	Gln	Thr	Ile	Val	Ser		
325						330						335					
Ser	Gly	Met	Thr	Leu	Glu	His	Ala	Gln	Ala	Glu	Asn	Val	Pro	Ala	Ala		
340						345						350					
Ala	Val	Thr	Phe	Glu	Asp	Asn	Tyr	Arg	Pro	Glu	Phe	Met	Pro	Thr	Thr		
355						360						365					
Lys	Pro	Val	Leu	Met	Gln	Leu	Val	Tyr	Asn	Pro	Glu	Thr	Arg	Glu	Ile		
370						375						380					
Leu	Gly	Ala	Gln	Phe	Met	Ser	Glu	His	Asp	Val	Ser	Gln	Ser	Ala	Asn		
385						390						395					
Val	Ile	Ser	Val	Met	Ile	Gln	Asn	His	Asn	Thr	Ile	Asp	Asp	Leu	Gly		
405						410						415					
Phe	Val	Asp	Met	Phe	Phe	Gln	Pro	Ile	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr		
420						425						430					
Leu	Asn	Leu	Leu	Gly	Gln	Ala	Ala	Ile	Ala	His	Ala	Ala	Glu	Ala	Val		
435						440						445					
Thr	Glu																
450																	

<210> SEQ ID NO 9

<211> LENGTH: 450

<212> TYPE: PRT

<213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 9

Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Val
 1 5 10 15

Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu

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20							25					30				
Arg	Asn	Asp	Asn	Val	Ser	Phe	Leu	Ser	Cys	Gly	Ile	Ala	Leu	Tyr	Leu	
	35						40					45				
Gly	Gly	Gln	Val	Ala	Asp	Pro	Gln	Gly	Leu	Phe	Tyr	Ser	Ser	Pro	Glu	
	50					55					60					
Gln	Leu	Ala	Lys	Leu	Gly	Ala	Thr	Val	His	Met	Gln	His	Asp	Val	Thr	
65					70					75				80		
Asp	Val	Asn	Thr	Asp	Lys	His	Glu	Ile	Thr	Val	Thr	Asp	Leu	Lys	Thr	
				85					90					95		
Gly	Glu	Ser	Lys	Thr	Asp	His	Tyr	Asp	Lys	Leu	Val	Val	Thr	Thr	Gly	
			100					105					110			
Ser	Trp	Pro	Val	Ile	Pro	Pro	Ile	Asp	Gly	Ile	Asp	Ser	Pro	Asn	Val	
		115					120					125				
Tyr	Leu	Cys	Lys	Asn	Trp	Thr	His	Ala	Gln	Asn	Leu	Trp	Glu	Ala	Ala	
	130					135					140					
Lys	Pro	Ala	Lys	Arg	Val	Ile	Val	Ile	Gly	Gly	Gly	Tyr	Ile	Gly	Thr	
145					150					155					160	
Glu	Leu	Val	Glu	Ala	Tyr	Gln	Lys	Gln	Gly	Lys	Glu	Val	Thr	Leu	Ile	
				165					170					175		
Asp	Gly	His	Pro	Arg	Ile	Leu	Asn	Lys	Tyr	Leu	Asp	Lys	Glu	Phe	Thr	
			180					185					190			
Asp	Arg	Val	Glu	Gln	Asp	Phe	Val	Asp	His	Gly	Ile	Lys	Met	Ala	Leu	
		195					200					205				
Asn	Gln	Met	Val	Gln	Gly	Phe	Ser	Asp	Asp	Gly	Lys	Glu	Val	Thr	Val	
	210					215					220					
Lys	Thr	Asp	Lys	Gly	Ser	Tyr	Thr	Ala	Asp	Met	Ala	Ile	Leu	Cys	Val	
225					230					235					240	
Gly	Phe	Arg	Pro	Asn	Thr	Gly	Leu	Leu	Lys	Gly	Lys	Val	Asp	Met	Asn	
				245					250					255		
Ala	Asn	Gly	Ser	Ile	Lys	Thr	Asn	Asp	Tyr	Met	Gln	Thr	Ser	Asp	Pro	
			260					265					270			
Asp	Ile	Tyr	Gly	Ala	Gly	Asp	Ser	Val	Ala	Val	His	Tyr	Asn	Pro	Thr	
		275					280					285				
Lys	Lys	Asp	Ala	Tyr	Ile	Pro	Leu	Ala	Thr	Asn	Ala	Val	Arg	Gln	Gly	
	290					295					300					
Thr	Leu	Val	Gly	Leu	Asn	Ile	Phe	Lys	Pro	Thr	Arg	Lys	Tyr	Met	Gly	
305					310					315					320	
Thr	Gln	Ser	Thr	Ser	Gly	Leu	Met	Leu	Phe	Gly	Gln	Thr	Ile	Val	Ser	
				325					330					335		
Ser	Gly	Met	Thr	Leu	Glu	His	Ala	Gln	Ala	Glu	Asn	Val	Pro	Ala	Ala	
			340				345						350			
Ala	Val	Thr	Phe	Glu	Asp	Asn	Tyr	Arg	Pro	Glu	Phe	Met	Pro	Thr	Thr	
		355					360					365				
Lys	Pro	Val	Leu	Met	Gln	Leu	Val	Tyr	Asn	Pro	Glu	Thr	Arg	Glu	Ile	
	370					375					380					
Leu	Gly	Ala	Gln	Phe	Met	Ser	Glu	His	Asp	Val	Ser	Gln	Ser	Ala	Asn	
385					390					395					400	
Val	Ile	Ser	Val	Met	Ile	Gln	Asn	His	Asn	Thr	Ile	Asp	Asp	Leu	Gly	
				405					410					415		
Phe	Val	Asp	Met	Phe	Phe	Gln	Pro	Ile	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr	
		420						425					430			
Leu	Asn	Leu	Leu	Gly	Gln	Ala	Ala	Ile	Ala	His	Ala	Ala	Glu	Ala	Val	
	435						440					445				

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Thr Glu
450

<210> SEQ ID NO 10
<211> LENGTH: 1353
<212> TYPE: DNA
<213> ORGANISM: *Lactobacillus plantarum*

<400> SEQUENCE: 10

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tcctgtggga tcgcacttta ccttgccggc caagttgctg atcctcaagg cctattttat    180
tccagtctcg aacagtttagc taagtttaggc gcaactgttc atatgcaaca tgatgtgacg    240
gatgtgaata ctgacaaaca tgaaattacg gttactgact taaagactgg tgaatctaag    300
actgatcact atgacaagtt agttgtcact actggttcat ggctgttat tccaccaatt    360
gacggcatcg atagtcccaa tgtctactta tgcaagaact ggacgcacgc tcagaattta    420
tgggaagcag ccaaaccagc taagcgggtc attgtgatcg gtggcggtta tateggtact    480
gaattagttg aagcttacca gaagcaaggt aaggaagtca cactaattga tggtcrycca    540
cggattttta ataaatactt agacaaagaa ttcactgacc gggttgaaca agactttgtt    600
gatcacggtg tcaagatggc ttgaaatcaa atggtgcaag gcttcagtga tgatggtaaa    660
gaagttacgg tcaagactga caagggcagc tacacagccg acatggcgat tctttgtgtt    720
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atcaagacca atgactacat gcaaaactct gatccagaca ttacggggc tggtgactcg    840
gttgctgttc actatacccc aactaagaaa gatgcttata tcccattagc aacgaatgcg    900
gttcgccaa gaaaccttagt tggtttgaa atcttcaagc caacgcggaa gtacatgggg    960
acacaatcaa cttctggggt aatgttgttc ggccaaacca tcgtttcatc tgggatgacc   1020
ctagaacatg cacaggccga aaatgttcg gcagccgctg tcacttttga agacaactac   1080
cggccagaat ttatgccaac cactaagcct gttttaatgc aattggttta caatcctgaa   1140
actcgcgaaa tcctaggtgc acaattcatg agtgaacatg atgtttcgca atcagccaat   1200
gtgatttcag tgatgattca aaatcacaat accattgacg acttaggggt cgtagatatg   1260
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<210> SEQ ID NO 11
<211> LENGTH: 450
<212> TYPE: PRT
<213> ORGANISM: *Lactobacillus plantarum*

<400> SEQUENCE: 11

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Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
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Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
 20            25            30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
 35            40            45

Gly Gly Gln Val Ala Asp Pro Gln Gly Leu Phe Tyr Ser Ser Pro Glu
 50            55            60

Gln Leu Ala Lys Leu Gly Ala Thr Val His Met Gln His Asp Val Thr
 65            70            75            80

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Asp	Val	Asn	Thr	Asp	Lys	His	Glu	Ile	Thr	Val	Thr	Asp	Leu	Lys	Thr
				85					90					95	
Gly	Glu	Ser	Lys	Thr	Asp	His	Tyr	Asp	Lys	Leu	Val	Val	Thr	Thr	Gly
			100					105					110		
Ser	Trp	Pro	Val	Ile	Pro	Pro	Ile	Asp	Gly	Ile	Asp	Ser	Pro	Asn	Val
		115					120					125			
Tyr	Leu	Cys	Lys	Asn	Trp	Thr	His	Ala	Gln	Asn	Leu	Trp	Glu	Ala	Ala
	130					135					140				
Lys	Pro	Ala	Lys	Arg	Val	Ile	Val	Ile	Gly	Gly	Gly	Tyr	Ile	Gly	Thr
145					150					155					160
Glu	Leu	Val	Glu	Ala	Tyr	Gln	Lys	Gln	Gly	Lys	Glu	Val	Thr	Leu	Ile
			165						170					175	
Asp	Lys	Lys	Pro	Arg	Ile	Leu	Asn	Lys	Tyr	Leu	Asp	Lys	Glu	Phe	Thr
			180					185					190		
Asp	Arg	Val	Glu	Gln	Asp	Phe	Val	Asp	His	Gly	Ile	Lys	Met	Ala	Leu
		195					200					205			
Asn	Gln	Met	Val	Gln	Gly	Phe	Ser	Asp	Asp	Gly	Lys	Glu	Val	Thr	Val
	210					215					220				
Lys	Thr	Asp	Lys	Gly	Ser	Tyr	Thr	Ala	Asp	Met	Ala	Ile	Leu	Cys	Val
225					230					235					240
Gly	Phe	Arg	Pro	Asn	Thr	Gly	Leu	Leu	Lys	Gly	Lys	Val	Asp	Met	Asn
			245						250					255	
Ala	Asn	Gly	Ser	Ile	Lys	Thr	Asn	Asp	Tyr	Met	Gln	Thr	Ser	Asp	Pro
			260					265					270		
Asp	Ile	Tyr	Gly	Ala	Gly	Asp	Ser	Val	Ala	Val	His	Tyr	Asn	Pro	Thr
		275					280					285			
Lys	Lys	Asp	Ala	Tyr	Ile	Pro	Leu	Ala	Thr	Asn	Ala	Val	Arg	Gln	Gly
	290					295					300				
Thr	Leu	Val	Gly	Leu	Asn	Ile	Phe	Lys	Pro	Thr	Arg	Lys	Tyr	Met	Gly
305					310					315					320
Thr	Gln	Ser	Thr	Ser	Gly	Leu	Met	Leu	Phe	Gly	Gln	Thr	Ile	Val	Ser
			325						330					335	
Ser	Gly	Met	Thr	Leu	Glu	His	Ala	Gln	Ala	Glu	Asn	Val	Pro	Ala	Ala
			340					345					350		
Ala	Val	Thr	Phe	Glu	Asp	Asn	Tyr	Arg	Pro	Glu	Phe	Met	Pro	Thr	Thr
		355					360					365			
Lys	Pro	Val	Leu	Met	Gln	Leu	Val	Tyr	Asn	Pro	Glu	Thr	Arg	Glu	Ile
	370					375					380				
Leu	Gly	Ala	Gln	Phe	Met	Ser	Glu	His	Asp	Val	Ser	Gln	Ser	Ala	Asn
385					390					395					400
Val	Ile	Ser	Val	Met	Ile	Gln	Asn	His	Asn	Thr	Ile	Asp	Asp	Leu	Gly
			405						410					415	
Phe	Val	Asp	Met	Phe	Phe	Gln	Pro	Ile	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr
		420						425					430		
Leu	Asn	Leu	Leu	Gly	Gln	Ala	Ala	Ile	Ala	His	Ala	Ala	Glu	Ala	Val
	435					440						445			
Thr	Glu														
	450														

<210> SEQ ID NO 12

<211> LENGTH: 450

<212> TYPE: PRT

<213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 12

Met 1	Lys	Val	Ile	Val 5	Ile	Gly	Cys	Thr	His 10	Ala	Gly	Thr	Ala	Ala 15	Val
Asn	Gln	Ile	Leu 20	Ala	Ser	Asn	Pro	Asp 25	Thr	Glu	Val	Thr	Ile 30	Tyr	Glu
Arg	Asn	Asp 35	Asn	Val	Ser	Phe	Leu 40	Ser	Cys	Gly	Ile	Ala 45	Leu	Tyr	Leu
Gly	Gly 50	Gln	Val	Ala	Asp 55	Pro	Gln	Gly	Leu	Phe	Tyr 60	Ser	Ser	Pro	Glu
Gln 65	Leu	Ala	Lys	Leu	Gly 70	Ala	Thr	Val	His	Met 75	Gln	His	Asp	Val	Thr 80
Asp	Val	Asn	Thr 85	Asp	Lys	His	Glu	Ile	Thr 90	Val	Thr	Asp	Leu	Lys 95	Thr
Gly	Glu	Ser	Lys 100	Thr	Asp	His	Tyr	Asp 105	Lys	Leu	Val	Val	Thr 110	Thr	Gly
Ser	Trp	Pro 115	Val	Ile	Pro	Pro	Ile 120	Asp	Gly	Ile	Asp	Ser 125	Pro	Asn	Val
Tyr	Leu 130	Cys	Lys	Asn	Trp	Thr 135	His	Ala	Gln	Asn	Leu 140	Trp	Glu	Ala	Ala
Lys 145	Pro	Ala	Lys	Arg	Val 150	Ile	Val	Ile	Gly	Gly 155	Gly	Tyr	Ile	Gly	Thr 160
Glu	Leu	Val	Glu	Ala 165	Tyr	Gln	Lys	Gln	Gly 170	Lys	Glu	Val	Thr	Leu	Ile 175
Asp	Arg	Lys	Pro 180	Arg	Ile	Leu	Asn	Lys 185	Tyr	Leu	Asp	Lys 190	Glu	Phe	Thr
Asp	Arg	Val 195	Glu	Gln	Asp	Phe	Val 200	Asp	His	Gly	Ile	Lys 205	Met	Ala	Leu
Asn 210	Gln	Met	Val	Gln	Gly	Phe 215	Ser	Asp	Asp	Gly	Lys 220	Glu	Val	Thr	Val
Lys 225	Thr	Asp	Lys	Gly	Ser 230	Tyr	Thr	Ala	Asp	Met 235	Ala	Ile	Leu	Cys	Val 240
Gly	Phe	Arg	Pro 245	Asn	Thr	Gly	Leu	Leu	Lys 250	Gly	Lys	Val	Asp	Met	Asn 255
Ala	Asn	Gly	Ser 260	Ile	Lys	Thr	Asn	Asp 265	Tyr	Met	Gln	Thr	Ser 270	Asp	Pro
Asp	Ile	Tyr 275	Gly	Ala	Gly	Asp	Ser 280	Val	Ala	Val	His	Tyr 285	Asn	Pro	Thr
Lys 290	Lys	Asp	Ala	Tyr	Ile	Pro 295	Leu	Ala	Thr	Asn	Ala 300	Val	Arg	Gln	Gly
Thr 305	Leu	Val	Gly	Leu	Asn 310	Ile	Phe	Lys	Pro	Thr 315	Arg	Lys	Tyr	Met	Gly 320
Thr	Gln	Ser	Thr 325	Ser	Gly	Leu	Met	Leu	Phe 330	Gly	Gln	Thr	Ile	Val 335	Ser
Ser	Gly	Met	Thr 340	Leu	Glu	His	Ala	Gln 345	Ala	Glu	Asn	Val 350	Pro	Ala	Ala
Ala	Val	Thr 355	Phe	Glu	Asp	Asn	Tyr 360	Arg	Pro	Glu	Phe	Met 365	Pro	Thr	Thr
Lys	Pro 370	Val	Leu	Met	Gln 375	Leu	Val	Tyr	Asn	Pro	Glu 380	Thr	Arg	Glu	Ile
Leu 385	Gly	Ala	Gln	Phe	Met 390	Ser	Glu	His	Asp	Val 395	Ser	Gln	Ser	Ala	Asn 400
Val	Ile	Ser	Val 405	Met	Ile	Gln	Asn	His 410	Asn	Thr	Ile	Asp	Leu 415	Gly	
Phe	Val	Asp 420	Met	Phe	Phe	Gln	Pro	Ile 425	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr

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Leu Asn Leu Leu Gly Gln Ala Ala Ile Ala His Ala Ala Glu Ala Val
 435 440 445

Thr Glu
 450

<210> SEQ ID NO 13
 <211> LENGTH: 1353
 <212> TYPE: DNA
 <213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 13

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atgaaagtta ttgtaattgg ttgtacccat gccggcactg ctgctgttaa tcagatttta    60
gcatcaaatc cagatactga agtgacgatt tatgaaagaa atgacaatgt ctcgttccta    120
tcctgtggga tcgcacttta ccttgccggc caagttgctg atcctcaagg cctattttat    180
tccagtccctg aacagttagc taagttaggc gcaactgttc atatgcaaca tgatgtgacg    240
gatgtgaata ctgacaaaca tgaaattacg gttactgact taaagactgg tgaatctaag    300
actgatcact atgacaagtt agttgtcact actggttcac ggctgttat tccaccaatt    360
gacggcatcg atagtcccaa tgtctactta tgcaagaact ggacgcacgc tcagaattta    420
tgggaagcag ccaaacaccg taagcgggtc attgtgatcg gtggcggtta ttcgggtact    480
gaattagttg aagcttacca gaagcaaggt aaggaagtca cactaattga tarraaacca    540
cggattttta ataaataact agacaaagaa ttcactgacc gggttgaaca agactttgtt    600
gatcacggta tcaagatggc tttgaatcaa atggtgcaag gcttcagtga tgatggtaaa    660
gaagttacgg tcaagactga caagggcagc tacacagccg acatggcgat tctttgtgtt    720
ggcttcgggc caaataccgg cttactcaag ggcaaggctg atatgaacgc taatggctcg    780
atcaagacca atgactacat gcaaaacttc gatccagaca tttacggggc tggtgactcg    840
gttgctgttc actatacccc aactaagaaa gatgcttata tcccattagc aacgaatgcg    900
gttcgccaa gaaacctagt tggtttgaac atcttcaagc caacgcggaa gtacatgggg    960
acacaatcaa cttctggggt aatgttggtc ggccaaacca tcgtttcatc tgggatgacc   1020
ctagaacatg cacaggccga aaatgttccg gcagccgctg tcaactttga agacaactac   1080
cggccagaat ttatgccaac cactaagcct gttttaatgc aattggttta caatcctgaa   1140
actcgcgaaa tcctaggtgc acaattcatg agtgaacatg atgtttcgca atcagccaat   1200
gtgatttcag tgatgattca aaatcacaat accattgacg acttaggggt cgtagatatg   1260
ttcttccaac caatttacga ccggccattt aactatttga acttacttgg tcaagcagcg   1320
attgcccatg cggccgaagc tgctactgaa taa                                     1353

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<210> SEQ ID NO 14
 <211> LENGTH: 450
 <212> TYPE: PRT
 <213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 14

Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
 1 5 10 15

Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
 20 25 30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
 35 40 45

Gly Gly Gln Val Ala Asp Pro Gln Gly Leu Phe Tyr Ser Ser Pro Glu
 50 55 60

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Gln Leu Ala Lys Leu Gly Ala Thr Val His Met Gln His Asp Val Thr
 65 70 75 80
 Asp Val Asn Thr Asp Lys His Glu Ile Thr Val Thr Asp Leu Lys Thr
 85 90 95
 Gly Glu Ser Lys Thr Asp His Tyr Asp Lys Leu Val Val Thr Thr Gly
 100 105 110
 Ser Trp Pro Val Ile Pro Pro Ile Asp Gly Ile Asp Ser Pro Asn Val
 115 120 125
 Tyr Leu Cys Lys Asn Trp Thr His Ala Gln Asn Leu Trp Glu Ala Ala
 130 135 140
 Lys Pro Ala Lys Arg Val Ile Val Ile Gly Gly Gly Tyr Ile Gly Thr
 145 150 155 160
 Glu Leu Val Glu Ala Tyr Gln Lys Gln Gly Lys Glu Val Thr Leu Ile
 165 170 175
 Asp Lys Arg Pro Arg Ile Leu Asn Lys Tyr Leu Asp Lys Glu Phe Thr
 180 185 190
 Asp Arg Val Glu Gln Asp Phe Val Asp His Gly Ile Lys Met Ala Leu
 195 200 205
 Asn Gln Met Val Gln Gly Phe Ser Asp Asp Gly Lys Glu Val Thr Val
 210 215 220
 Lys Thr Asp Lys Gly Ser Tyr Thr Ala Asp Met Ala Ile Leu Cys Val
 225 230 235 240
 Gly Phe Arg Pro Asn Thr Gly Leu Leu Lys Gly Lys Val Asp Met Asn
 245 250 255
 Ala Asn Gly Ser Ile Lys Thr Asn Asp Tyr Met Gln Thr Ser Asp Pro
 260 265 270
 Asp Ile Tyr Gly Ala Gly Asp Ser Val Ala Val His Tyr Asn Pro Thr
 275 280 285
 Lys Lys Asp Ala Tyr Ile Pro Leu Ala Thr Asn Ala Val Arg Gln Gly
 290 295 300
 Thr Leu Val Gly Leu Asn Ile Phe Lys Pro Thr Arg Lys Tyr Met Gly
 305 310 315 320
 Thr Gln Ser Thr Ser Gly Leu Met Leu Phe Gly Gln Thr Ile Val Ser
 325 330 335
 Ser Gly Met Thr Leu Glu His Ala Gln Ala Glu Asn Val Pro Ala Ala
 340 345 350
 Ala Val Thr Phe Glu Asp Asn Tyr Arg Pro Glu Phe Met Pro Thr Thr
 355 360 365
 Lys Pro Val Leu Met Gln Leu Val Tyr Asn Pro Glu Thr Arg Glu Ile
 370 375 380
 Leu Gly Ala Gln Phe Met Ser Glu His Asp Val Ser Gln Ser Ala Asn
 385 390 395 400
 Val Ile Ser Val Met Ile Gln Asn His Asn Thr Ile Asp Asp Leu Gly
 405 410 415
 Phe Val Asp Met Phe Phe Gln Pro Ile Tyr Asp Arg Pro Phe Asn Tyr
 420 425 430
 Leu Asn Leu Leu Gly Gln Ala Ala Ile Ala His Ala Ala Glu Ala Val
 435 440 445
 Thr Glu
 450

<210> SEQ ID NO 15

<211> LENGTH: 450

<212> TYPE: PRT

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<213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 15

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Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
 1           5           10           15

Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
 20           25           30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
 35           40           45

Gly Gly Gln Val Ala Asp Pro Gln Gly Leu Phe Tyr Ser Ser Pro Glu
 50           55           60

Gln Leu Ala Lys Leu Gly Ala Thr Val His Met Gln His Asp Val Thr
 65           70           75           80

Asp Val Asn Thr Asp Lys His Glu Ile Thr Val Thr Asp Leu Lys Thr
 85           90           95

Gly Glu Ser Lys Thr Asp His Tyr Asp Lys Leu Val Val Thr Thr Gly
100           105           110

Ser Trp Pro Val Ile Pro Pro Ile Asp Gly Ile Asp Ser Pro Asn Val
115           120           125

Tyr Leu Cys Lys Asn Trp Thr His Ala Gln Asn Leu Trp Glu Ala Ala
130           135           140

Lys Pro Ala Lys Arg Val Ile Val Ile Gly Gly Gly Tyr Ile Gly Thr
145           150           155           160

Glu Leu Val Glu Ala Tyr Gln Lys Gln Gly Lys Glu Val Thr Leu Ile
165           170           175

Asp Lys His Pro Arg Ile Leu Asn Lys Tyr Leu Asp Lys Glu Phe Thr
180           185           190

Asp Arg Val Glu Gln Asp Phe Val Asp His Gly Ile Lys Met Ala Leu
195           200           205

Asn Gln Met Val Gln Gly Phe Ser Asp Asp Gly Lys Glu Val Thr Val
210           215           220

Lys Thr Asp Lys Gly Ser Tyr Thr Ala Asp Met Ala Ile Leu Cys Val
225           230           235           240

Gly Phe Arg Pro Asn Thr Gly Leu Leu Lys Gly Lys Val Asp Met Asn
245           250           255

Ala Asn Gly Ser Ile Lys Thr Asn Asp Tyr Met Gln Thr Ser Asp Pro
260           265           270

Asp Ile Tyr Gly Ala Gly Asp Ser Val Ala Val His Tyr Asn Pro Thr
275           280           285

Lys Lys Asp Ala Tyr Ile Pro Leu Ala Thr Asn Ala Val Arg Gln Gly
290           295           300

Thr Leu Val Gly Leu Asn Ile Phe Lys Pro Thr Arg Lys Tyr Met Gly
305           310           315           320

Thr Gln Ser Thr Ser Gly Leu Met Leu Phe Gly Gln Thr Ile Val Ser
325           330           335

Ser Gly Met Thr Leu Glu His Ala Gln Ala Glu Asn Val Pro Ala Ala
340           345           350

Ala Val Thr Phe Glu Asp Asn Tyr Arg Pro Glu Phe Met Pro Thr Thr
355           360           365

Lys Pro Val Leu Met Gln Leu Val Tyr Asn Pro Glu Thr Arg Glu Ile
370           375           380

Leu Gly Ala Gln Phe Met Ser Glu His Asp Val Ser Gln Ser Ala Asn
385           390           395           400

Val Ile Ser Val Met Ile Gln Asn His Asn Thr Ile Asp Asp Leu Gly

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405					410					415					
Phe	Val	Asp	Met	Phe	Phe	Gln	Pro	Ile	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr
			420					425					430		
Leu	Asn	Leu	Leu	Gly	Gln	Ala	Ala	Ile	Ala	His	Ala	Ala	Glu	Ala	Val
		435					440					445			
Thr	Glu														
	450														
<210> SEQ ID NO 16															
<211> LENGTH: 450															
<212> TYPE: PRT															
<213> ORGANISM: Lactobacillus plantarum															
<400> SEQUENCE: 16															
Met	Lys	Val	Ile	Val	Ile	Gly	Cys	Thr	His	Ala	Gly	Thr	Ala	Ala	Val
1				5					10					15	
Asn	Gln	Ile	Leu	Ala	Ser	Asn	Pro	Asp	Thr	Glu	Val	Thr	Ile	Tyr	Glu
			20				25						30		
Arg	Asn	Asp	Asn	Val	Ser	Phe	Leu	Ser	Cys	Gly	Ile	Ala	Leu	Tyr	Leu
		35					40					45			
Gly	Gly	Gln	Val	Ala	Asp	Pro	Gln	Gly	Leu	Phe	Tyr	Ser	Ser	Pro	Glu
		50				55					60				
Gln	Leu	Ala	Lys	Leu	Gly	Ala	Thr	Val	His	Met	Gln	His	Asp	Val	Thr
	65			70					75					80	
Asp	Val	Asn	Thr	Asp	Lys	His	Glu	Ile	Thr	Val	Thr	Asp	Leu	Lys	Thr
			85					90						95	
Gly	Glu	Ser	Lys	Thr	Asp	His	Tyr	Asp	Lys	Leu	Val	Val	Thr	Thr	Gly
			100					105					110		
Ser	Trp	Pro	Val	Ile	Pro	Pro	Ile	Asp	Gly	Ile	Asp	Ser	Pro	Asn	Val
		115					120					125			
Tyr	Leu	Cys	Lys	Asn	Trp	Thr	His	Ala	Gln	Asn	Leu	Trp	Glu	Ala	Ala
	130					135					140				
Lys	Pro	Ala	Lys	Arg	Val	Ile	Val	Ile	Gly	Gly	Gly	Tyr	Ile	Gly	Thr
	145			150					155					160	
Glu	Leu	Val	Glu	Ala	Tyr	Gln	Lys	Gln	Gly	Lys	Glu	Val	Thr	Leu	Ile
			165					170						175	
Asp	Arg	Arg	Pro	Arg	Ile	Leu	Asn	Lys	Tyr	Leu	Asp	Lys	Glu	Phe	Thr
			180				185						190		
Asp	Arg	Val	Glu	Gln	Asp	Phe	Val	Asp	His	Gly	Ile	Lys	Met	Ala	Leu
		195					200					205			
Asn	Gln	Met	Val	Gln	Gly	Phe	Ser	Asp	Asp	Gly	Lys	Glu	Val	Thr	Val
	210					215					220				
Lys	Thr	Asp	Lys	Gly	Ser	Tyr	Thr	Ala	Asp	Met	Ala	Ile	Leu	Cys	Val
	225			230					235					240	
Gly	Phe	Arg	Pro	Asn	Thr	Gly	Leu	Leu	Lys	Gly	Lys	Val	Asp	Met	Asn
			245					250						255	
Ala	Asn	Gly	Ser	Ile	Lys	Thr	Asn	Asp	Tyr	Met	Gln	Thr	Ser	Asp	Pro
		260					265						270		
Asp	Ile	Tyr	Gly	Ala	Gly	Asp	Ser	Val	Ala	Val	His	Tyr	Asn	Pro	Thr
	275						280					285			
Lys	Lys	Asp	Ala	Tyr	Ile	Pro	Leu	Ala	Thr	Asn	Ala	Val	Arg	Gln	Gly
	290					295			300						
Thr	Leu	Val	Gly	Leu	Asn	Ile	Phe	Lys	Pro	Thr	Arg	Lys	Tyr	Met	Gly
	305			310					315					320	
Thr	Gln	Ser	Thr	Ser	Gly	Leu	Met	Leu	Phe	Gly	Gln	Thr	Ile	Val	Ser

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      325              330              335
Ser Gly Met Thr Leu Glu His Ala Gln Ala Glu Asn Val Pro Ala Ala
      340              345              350

Ala Val Thr Phe Glu Asp Asn Tyr Arg Pro Glu Phe Met Pro Thr Thr
      355              360              365

Lys Pro Val Leu Met Gln Leu Val Tyr Asn Pro Glu Thr Arg Glu Ile
      370              375              380

Leu Gly Ala Gln Phe Met Ser Glu His Asp Val Ser Gln Ser Ala Asn
      385              390              395

Val Ile Ser Val Met Ile Gln Asn His Asn Thr Ile Asp Asp Leu Gly
      405              410              415

Phe Val Asp Met Phe Phe Gln Pro Ile Tyr Asp Arg Pro Phe Asn Tyr
      420              425              430

Leu Asn Leu Leu Gly Gln Ala Ala Ile Ala His Ala Ala Glu Ala Val
      435              440              445

Thr Glu
      450

<210> SEQ ID NO 17
<211> LENGTH: 450
<212> TYPE: PRT
<213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 17

Met Lys Val Ile Val Ile Gly Cys Thr His Ala Gly Thr Ala Ala Val
 1      5      10      15

Asn Gln Ile Leu Ala Ser Asn Pro Asp Thr Glu Val Thr Ile Tyr Glu
 20      25      30

Arg Asn Asp Asn Val Ser Phe Leu Ser Cys Gly Ile Ala Leu Tyr Leu
 35      40      45

Gly Gly Gln Val Ala Asp Pro Gln Gly Leu Phe Tyr Ser Ser Pro Glu
 50      55      60

Gln Leu Ala Lys Leu Gly Ala Thr Val His Met Gln His Asp Val Thr
 65      70      75      80

Asp Val Asn Thr Asp Lys His Glu Ile Thr Val Thr Asp Leu Lys Thr
 85      90      95

Gly Glu Ser Lys Thr Asp His Tyr Asp Lys Leu Val Val Thr Thr Gly
100      105      110

Ser Trp Pro Val Ile Pro Pro Ile Asp Gly Ile Asp Ser Pro Asn Val
115      120      125

Tyr Leu Cys Lys Asn Trp Thr His Ala Gln Asn Leu Trp Glu Ala Ala
130      135      140

Lys Pro Ala Lys Arg Val Ile Val Ile Gly Gly Gly Tyr Ile Gly Thr
145      150      155      160

Glu Leu Val Glu Ala Tyr Gln Lys Gln Gly Lys Glu Val Thr Leu Ile
165      170      175

Asp Arg His Pro Arg Ile Leu Asn Lys Tyr Leu Asp Lys Glu Phe Thr
180      185      190

Asp Arg Val Glu Gln Asp Phe Val Asp His Gly Ile Lys Met Ala Leu
195      200      205

Asn Gln Met Val Gln Gly Phe Ser Asp Asp Gly Lys Glu Val Thr Val
210      215      220

Lys Thr Asp Lys Gly Ser Tyr Thr Ala Asp Met Ala Ile Leu Cys Val
225      230      235      240

Gly Phe Arg Pro Asn Thr Gly Leu Leu Lys Gly Lys Val Asp Met Asn

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245							250					255				
Ala	Asn	Gly	Ser	Ile	Lys	Thr	Asn	Asp	Tyr	Met	Gln	Thr	Ser	Asp	Pro	
			260					265						270		
Asp	Ile	Tyr	Gly	Ala	Gly	Asp	Ser	Val	Ala	Val	His	Tyr	Asn	Pro	Thr	
		275					280					285				
Lys	Lys	Asp	Ala	Tyr	Ile	Pro	Leu	Ala	Thr	Asn	Ala	Val	Arg	Gln	Gly	
	290					295					300					
Thr	Leu	Val	Gly	Leu	Asn	Ile	Phe	Lys	Pro	Thr	Arg	Lys	Tyr	Met	Gly	
305					310					315					320	
Thr	Gln	Ser	Thr	Ser	Gly	Leu	Met	Leu	Phe	Gly	Gln	Thr	Ile	Val	Ser	
				325					330					335		
Ser	Gly	Met	Thr	Leu	Glu	His	Ala	Gln	Ala	Glu	Asn	Val	Pro	Ala	Ala	
			340					345					350			
Ala	Val	Thr	Phe	Glu	Asp	Asn	Tyr	Arg	Pro	Glu	Phe	Met	Pro	Thr	Thr	
		355					360					365				
Lys	Pro	Val	Leu	Met	Gln	Leu	Val	Tyr	Asn	Pro	Glu	Thr	Arg	Glu	Ile	
	370					375					380					
Leu	Gly	Ala	Gln	Phe	Met	Ser	Glu	His	Asp	Val	Ser	Gln	Ser	Ala	Asn	
385					390					395					400	
Val	Ile	Ser	Val	Met	Ile	Gln	Asn	His	Asn	Thr	Ile	Asp	Asp	Leu	Gly	
				405					410					415		
Phe	Val	Asp	Met	Phe	Phe	Gln	Pro	Ile	Tyr	Asp	Arg	Pro	Phe	Asn	Tyr	
		420						425					430			
Leu	Asn	Leu	Leu	Gly	Gln	Ala	Ala	Ile	Ala	His	Ala	Ala	Glu	Ala	Val	
		435					440					445				
Thr	Glu															
	450															

<210> SEQ ID NO 18

<211> LENGTH: 1353

<212> TYPE: DNA

<213> ORGANISM: Lactobacillus plantarum

<400> SEQUENCE: 18

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gcatcaaadc cagatactga agtgacgatt tatgaaagaa atgacaatgt ctcgttccta      120
tctgtgggga tcgcacttta ccttgccggc caagttgctg atcctcaagg cctattttat      180
tccagtctcg aacagttagc taagttaggc gcaactgttc atatgcaaca tgatgtgacg      240
gatgtgaata ctgacaaaaca tgaaattacg gttactgact taaagactgg tgaatctaag      300
actgatcact atgacaagtt agttgtcact actggttcac ggctgttat tccaccaatt      360
gacggcatcg atagtcccaa tgtctactta tgcaagaact ggacgcacgc tcagaattta      420
tggaagcag ccaaaccagc taagcgggtc attgtgatcg gtggcggtta tatcggtact      480
gaattagtgg aagcttacca gaagcaaggt aaggaagtca cactaattga tarrcrycca      540
cggattttta ataaatactt agacaagaa ttcactgacc ggggtgaaca agactttgtt      600
gatcacggta tcaagatggc tttgaatcaa atggtgcaag gcttcagtga tgatggtaaa      660
gaagttacgg tcaagactga caagggcagc tacacagccg acatggcgat tctttgtgtt      720
ggcttcgggc caaataccgg cttactcaag ggcaaggctg atatgaacgc taatggctcg      780
atcaagacca atgactacat gcaaaacttc gatccagaca tttacggggc tgggtgactcg      840
gttgcgttgc actataaacc aactaagaaa gatgcttata tcccattagc aacgaatgcg      900
gttcgccaaag gaaccttagt tggtttgaac atcttcaagc caacgcggaa gtacatgggg      960

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acacaatcaa cttctggggtt aatgttggtc ggccaaacca tcgtttcatc tgggatgacc 1020
ctagaacatg cacaggccga aaatgttccg gcagccgctg tcaactttga agacaactac 1080
cggccagaat ttatgccaac cactaagcct gttttaatgc aattgggtta caatcctgaa 1140
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60

caaaa

64

15

What is claimed is:

1. An isolated bacterial NADH oxidase, which is obtained from *Lactobacillus plantarum*, and regenerates NADP⁺ and NAD⁺, comprising

at least one amino acid mutation that facilitates enzymatic activity towards NADPH and comprises an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, and SEQ ID NO: 17.

2. The isolated bacterial NADH oxidase of claim 1, encoded by a nucleic acid sequence, which hybridizes under stringent conditions to the nucleic acid selected from the group consisting of SEQ ID NO: 5, SEQ ID NO: 7, SEQ ID NO: 10, SEQ ID NO: 13, and SEQ ID NO: 18.

3. The isolated bacterial NADH oxidase of claim 1, which comprises SEQ ID NO: 8.

4. The isolated bacterial NADH oxidase of claim 3, encoded by a nucleic acid sequence comprising SEQ ID NO: 10.

5. The isolated bacterial NADH oxidase of claim 1, which comprises SEQ ID NO: 16.

6. The isolated bacterial NADH oxidase of claim 5, encoded by a nucleic acid sequence comprising SEQ ID NO: 18.

7. A method of producing an enantiomer-enriched organic compound, comprising:

reacting a substrate with a first enzyme selective for producing an enantiomer, wherein the first enzyme requires a oxidized nicotinamide-based cofactor for catalytic activity;

producing the enantiomer, its oxidized counterpart, and a reduced nicotinamide-based cofactor; and

oxidizing the reduced nicotinamide-based cofactor with a second enzyme selective for a nicotinamide-based cofactor,

wherein the second enzyme selective for a nicotinamide-based cofactor comprises an amino acid sequence selected from the group consisting of SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 6, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, or SEQ ID NO: 17.

8. The method of producing an enantiomer-enriched organic compound of claim 7, wherein the enantiomer comprises an L-nucleoside, and wherein the second enzyme selective for a nicotinamide-based cofactor comprises a NADH oxidase obtained from *Lactobacillus plantarum*.

9. The method of producing an enantiomer-enriched organic compound of claim 7, wherein the second enzyme selective for a nicotinamide-based cofactor can oxidize NADPH and NADH.

10. The method of producing an enantiomer-enriched organic compound of claim 9, wherein the second enzyme selective for a nicotinamide-based cofactor comprises SEQ ID NO: 8.

11. The method of producing an enantiomer-enriched organic compound of claim 9, wherein the second enzyme selective for a nicotinamide-based cofactor comprises SEQ ID NO: 18.

12. The method of producing an enantiomer-enriched organic compound of claim 7, wherein the second enzyme selective for a nicotinamide-based cofactor can catalyze more than 113,000 turnovers per active site.

13. The method of producing an enantiomer-enriched organic compound of claim 7, wherein the second enzyme selective for a nicotinamide-based cofactor can catalyze more than 100,000 turnovers per active site in the absence of an externally added reducing agent.

* * * * *