

LANTIBIOTICS AND USES THEREOF

5

CONTINUING APPLICATION DATA

This application claims the benefit of U.S. Provisional Application Serial No. 60/961,374, filed July 20, 2007, which is incorporated by reference herein.

10

GOVERNMENT FUNDING

The present invention was made with government support under Grant No. DE-FG02-98ER82577 and DE-FG02-00ER83009, awarded by the Department of Energy. The Government has certain rights in this invention.

15

BACKGROUND

Recent molecular studies into the microbial diversity of the human intestine reveal a much greater diversity than previously recognized and very little is currently known of the contribution of individual groups to the human organism (Gill et al., 2006, *Science*, 312:1355-1359). One numerically dominant group of microbes, the bifidobacteria, is often suggested to be associated with good intestinal health given their overriding dominance in the feces of breast fed infants (Yoshioka et al., 1983, *Pediatrics*, 72:317-321). This phenomenon led to their discovery in 1899 by the pediatrician Henri Tissier and his subsequent use of these bacteria for the treatment of infantile diarrhea (Tissier, 1906, *Crit Rev Soc Biol*, 60:359-361).

25 The proposed beneficial effect of bifidobacteria is further supported by the decrease of these bacteria in geriatric individuals and the concomitant increase of other microbial groups, most notably clostridia and *E. coli* (Mitsuoka et al., 1973, *Zentralbl Bakteriol [Orig A]*, 223:333-342, Hopkins et al., 2001, *Gut*, 48:198-205, Ishibashi et al, 1997, *Mal J Nutr*, 3:149-159). This has led to the growing

30 worldwide interest of including bifidobacteria in foods specifically for their potential intestinal health benefits (O'Sullivan, Primary Sources of Probiotic Cultures, In: *Probiotics in food safety and human health*. Edited by Goktepe et al., Boca Raton: Taylor & Francis/CRC Press, 2006:91-107). However, clinical feeding studies with bifidobacteria show that while the strains can be detected in subject's feces during

35 feeding trials, they are rapidly lost upon cessation of the studies pointing to a

possible loss of competitive fitness of the strains for competition within the human intestinal environment (O'Sullivan, Primary Sources of Probiotic Cultures, In: *Probiotics in food safety and human health*. Edited by Goktepe et al., Boca Raton: Taylor & Francis/CRC Press, 2006:91-107, Fukushima et al., 1998, *Int J Food Microbiol*, 42:39-44, Su et al, 2005, *FEMS Microbiol Lett*, 244:99-103. This may be due to attenuation of the strains, as the fermentation environment is very different to the buffered and anaerobic environment of the human colon.

Bacteriocins are peptide based antimicrobial compounds produced by many types of bacteria and are inhibitory to closely related bacteria. Frequently, the inhibitory spectrum is within the genus of the producing bacterium. A lantibiotic is a type of bacteriocin that has a wide inhibitory spectrum and is also post-translationally modified. Specifically, modification enzymes modify some amino acids into lantionine residues. Nisin, which is produced by certain strains of the lactic acid bacterium *Lactococcus lactis*, is a lantibiotic with the widest inhibitory spectrum of any lantibiotic described to date that extends to most gram positive bacteria. Given its broad spectrum it is widely used as a preservative and a shelf life extender. Unfortunately, spoilage and pathogenic bacteria are not just gram positive. Many pathogens, such as *E. coli* and *Salmonella* are gram negative and many spoilage bacteria are also gram negative, such as *Pseudomonas* and *Klebsiella*.

20

SUMMARY OF THE INVENTION

The present invention provides a lantibiotic, entitled bisin, from a probiotic culture of *Bifidobacterium longum* that inhibits both gram positive and gram negative bacteria. This is the first bacteriocin described to date to have natural inhibitory action against both gram positive and gram negative bacteria. It therefore has potential to be an effective shelf life extender in dairy products, given that the enzymatic activities of gram negative bacteria, particularly *Pseudomonas*, are responsible for a lot of defects.

The potential to produce a lantibiotic was first recognized from the genome sequence of the *Bifidobacterium longum* strain described herein; however, initial attempts at detecting a lantibiotic produced by the strain were unsuccessful. Further experiments were required before growth conditions were found that caused a lantibiotic to be produced. Subsequently, bioassays were used to test its spectrum of

inhibition and clearly showed effective inhibition against both gram positive and gram negative indicators.

The present invention provides an isolated biologically active compound that includes an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity. The polypeptide sequence may include at least one conservative substitution of the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22. The compound has the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.

10 The Gram negative may be an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp. In some aspects it is preferably not a *P. aeruginosa*. The compound inhibits growth of a Gram positive microbe, such as a *Lactobacillus* spp., *Lactococcus* spp., a *Streptococcus* spp., a *Staphylococcus* spp., or a *Bacillus* spp. The compound may be produced by a *Bifidobacterium*. The present invention also includes a composition

15 having the isolated biologically active compound and a food product, and a composition having the isolated biologically active compound and a pharmaceutically acceptable carrier.

The present invention also provides an isolated polynucleotide including: (a) a nucleotide sequence encoding a polypeptide, wherein the amino acid sequence of the polypeptide and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity, or (b) the full complement of the nucleotide sequence of (a). The isolated polynucleotide may be operably linked to a heterologous regulatory sequence. The present invention also provides a vector containing the isolated polynucleotide, and a cell containing the isolated polynucleotide.

25 The present invention further provides isolated lantibiotic, wherein the lantibiotic inhibits growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe. The lantibiotic may include an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity. The Gram negative may be an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp. In some aspects it is preferably not a *P. aeruginosa*.

The present invention provides a composition with a lantibiotic and a food product, wherein the lantibiotic has the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram

negative microbe. The lantibiotic may be present on the surface of the food product, in the food product, or the combination. The lantibiotic may include an amino acid sequence, wherein the amino acid sequence of the lantibiotic and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity. The Gram negative may be an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp.

The present invention provides a composition with a lantibiotic and a pharmaceutically acceptable carrier, wherein the lantibiotic includes the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe. The lantibiotic may include an amino acid sequence, wherein the amino acid sequence of the lantibiotic and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity. The Gram negative may be an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp.

The present invention also provides methods for producing the compounds described herein. The methods may include growing an isolated *Bifidobacterium* under conditions suitable for producing a lantibiotic, wherein the *Bifidobacterium* produces a lantibiotic. The method may further include isolating the lantibiotic. The growing may include growing the *Bifidobacterium*, preferably *B. longum*, on a surface. The present invention also includes a lantibiotic produced by the method.

Method for producing a lantibiotic may include growing a microbe that includes a polynucleotide encoding a polypeptide, wherein the amino acid sequence of the polypeptide and the amino acid sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity, wherein the microbe is grown under conditions suitable for producing the polypeptide, and wherein the microbe produces the polypeptide. The microbe may further include a polynucleotide encoding a polypeptide selected from SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16, or a combination thereof. The growing may include growing the *Bifidobacterium*, preferably *B. longum*, on a surface. The present invention also includes a polypeptide produced by the method. The method may further include isolating the polypeptide, for instance by extraction with a composition that includes an alcohol, such as methanol.

Further provided by the present invention are methods for using lantibiotics. A method may include adding the lantibiotic to a food product, wherein the lantibiotic includes the characteristic of inhibiting growth of a Gram negative

microbe in conditions that do not damage the outer membrane of the Gram negative microbe. The method may include applying the lantibiotic to the surface of the food product, for instance, by bringing a surface of a casing, film, or packaging material comprising the lantibiotic into contact with the food product. The adding may
5 include adding the lantibiotic to the food product. The lantibiotic may act as a food preservative.

The present invention provides a dentifrice, such as a mouthwash or a toothpaste, that includes a biologically active compound with an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid
10 sequence of SEQ ID NO:21 or SEQ ID NO:22 have at least 80% identity, wherein the compound has the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.

Also provided by the present invention is a method for using a lantibiotic
15 that includes administering a composition with the lantibiotic to an animal, such as a human, wherein the subject has or is at risk of an infection by a microbe that is inhibited by the lantibiotic, and wherein the lantibiotic has the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe. The composition may include a
20 pharmaceutically acceptable carrier, and the composition may be administered topically.

The present invention also provides isolated biologically active polypeptides, wherein the amino acid sequence of the polypeptide and the amino acid sequence of
SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ
25 ID NO:14, or SEQ ID NO:16, have at least 80% identity. Also included in the invention are isolated polynucleotides encoding the polypeptides.

The present invention further provides a *Bifidobacterium* that produces a lantibiotic. The lantibiotic has the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram
30 negative microbe. The Gram negative may be an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp. The *Bifidobacterium* may be encapsulated or in tablet form, for instance, and may be present in a food product. The present invention also provides method that includes administering a *Bifidobacterium* to an animal in need thereof, wherein the *Bifidobacterium* will produce a lantibiotic that has the characteristic of

inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.

The term "and/or" means one or all of the listed elements or a combination of any two or more of the listed elements.

5 The words "preferred" and "preferably" refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful, and is not intended to exclude other
10 embodiments from the scope of the invention.

The terms "comprises" and variations thereof do not have a limiting meaning where these terms appear in the description and claims.

Unless otherwise specified, "a," "an," "the," and "at least one" are used interchangeably and mean one or more than one.

15 Also herein, the recitations of numerical ranges by endpoints include all numbers subsumed within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, 5, etc.).

For any method disclosed herein that includes discrete steps, the steps may be conducted in any feasible order. And, as appropriate, any combination of two or
20 more steps may be conducted simultaneously.

The above summary of the present invention is not intended to describe each disclosed embodiment or every implementation of the present invention. The description that follows more particularly exemplifies illustrative embodiments. In several places throughout the application, guidance is provided through lists of
25 examples, which examples can be used in various combinations. In each instance, the recited list serves only as a representative group and should not be interpreted as an exclusive list.

BRIEF DESCRIPTION OF THE FIGURES

30 Figure 1. Organization of mobile integrase cassettes (MIC) in *B. longum* DJO10A. (A) and NCC2705, (B). Orfs 1, 2 and 3 refer to three contiguous, but different *xerC* integrase genes. P, a conserved 20 bp palindrome (TTAAACCGACATCGGTTTAA (SEQ ID NO:24), which has an 11 bp extension in MIC III. IR, 96 bp inverted repeat (IR)

(GATTAAGCCGGGTTTGTGTTAAGCCGGGGAACGGTTCGGGGTCTTGGT
GGCTGGCCGTGTCCCATGTGGTTTCCCGGCTTAACGTTCCGGGTAT
(SEQ ID NO:25)), that has a 3 bp extension in MIC I and II, a 5 bp extension in
MIC III and a 1 bp extension in MIC 1, 2 and 3. IS, insertion sequence.

5 Figure 2. Genome unique regions. (A) Base deviation index (BDI) analysis
of the *B. longum* DJO10A and NCC2705 genomes. Unique regions of each genome
as defined in the text are numbered. The locations of oriC and terC are indicated by
green arrows. Letters refer to predicted gene phenotypes from regions with
definitive BDI peaks that are present in both genomes, a, GTPase, b, cation
10 transport ATPase, c, DNA partitioning protein, d, choloylglycine hydrolase, e,
glutamine synthase beta chain, f, alanyl-tRNA synthetase, g, pyruvate kinase, h,
cation transport ATPase, I, fibronectin type III, j, aminopeptidase C, k, subtilisin-
like serine protease, l, sortase, m, fatty acid synthase. (B) Organization of the
unique region 1 showing the location of a 361 bp DNA remnant, indicated by the
15 green bar, from the *ushA* gene remaining at the predicted deletion location in
NCC2705. Sky blue colored ORFs indicate common genes between both genomes.
a, mobile integrase cassette.

Figure 3. Comparison of oligosaccharide utilization gene cluster 7 between
two *B. longum* genomes. DJO10A-unique genes in unique region 10 are colored
20 dark grey, ISL3-type IS element is colored black and other matched genes are
colored white. *galA*, α -galactosidase; *lacI*, LacI-type repressor; *malEFG*, ABC-type
transport system; ISL3, ISL3-type IS element; *aglI*, glycosidase; *ilvA*, threonine
dehydratase; *SIR2*, NAD-dependent protein deacetylase; *glyH*, glycosyl hydrolase;
hyp, hypothetical protein.

25 Figure 4. Organization of genes involved in polyol metabolism in the unique
region 13 in strain DJO10A and comparison with an analogous region in *B.*
adolescentis ATCC 15703. Amino acid identities are indicated between homologous
genes. ORFs shaded black are from unique region 13 and corresponding homologs
in *B. adolescentis* ATCC 15703.

30 Figure 5. Arsenic resistance of selected bacteria. (A) Genetic organization of
arsenic resistance gene clusters compiled from the completed genome sequences of
Bifidobacterium longum DJO10A, *Bacillus subtilis* 168 (Kunst et al., 1997, *Nature*
1997, 390:249-256), *Bacteroides thetaiotamicron* VPI-5482 (Xu et al., 2003,
Science 2003, 299:2074-2076), *Lactobacillus brevis* ATCC 367 (Makarova et al.,

Proc Natl Acad Sci USA 103:15611-15616), *L. plantarum* WCFS1 (Kleerebezem et al., 2003, *Proc Natl Acad Sci USA* 2003, 100:1990-1995), *L. johnsonii* NCC 533 (Pridmore et al., 2004, *Proc Natl Acad Sci USA* 2004, 101:2512-2517) and *E. coli* K-12 (Sofia et al., 1994, *Nucleic Acids Res* 1994, 22:2576-2586). a, 48 kb element that is excised by the site-specific recombinase SpoIVCA during sporulation, b, indicates a plasmid sequence, *arsR*, repressor, *arsA*, arsenite stimulated ATPase, *arsB*, arsenite efflux pump, *arsC*, arsenate reductase, *arsD*, arsenic chaperone, *hyp*, hypothetical protein. (B) Comparison of arsenic resistance activity in *B. longum* DJO10A with fermentation adapted *B. animalis* subsp. *lactis* strains, *E. coli* and *Lactobacillus plantarum*. c, calculated from data presented in van Kranenburg et al., (van Kranenburg et al., 2005, *Appl Environ Microbiol* 2005, 71:1223-1230).

Figure 6. Lantibiotic production by *B. longum* DJO10A. (A) Organization of the lantibiotic encoding unique region 12 of *B. longum* DJO10A and the corresponding genome locations in strains NCC2705 and DJO10A-JH1. The A or B designator following IS30 refer to unique classes of IS30 elements that are only found at this location in the genome. The ' designator indicates a fragmented IS30 element. (B) Pulsed Field Gel Electrophoresis (PFGE) analysis of XbaI-digested total DNA from *B. longum* DJO10A and its fermentation adapted isolate, DJO10A-JH1. White arrows indicate bands missing from strain DJO10A-JH1. (C) Bioassay for lantibiotic production by *B. longum* DJO10A with strains DJO10A and DJO10A-JH1 as indicator bacteria.

Figure 7. IS30 'jumping' in the genome of *B. longum* DJO10A. (A) Genome positioning of the IS30 elements in the genome of *B. longum* DJO10A and the laboratory adapted strain DJO10A-JH1. The gray arrows indicate the five elements identified by direct sequencing of DJO10A genomic DNA. The white arrows indicate the location of elements that were detected in some sequencing clones prepared from DJO10A genomic DNA. The asterisk under A6 indicates this element was missing from some sequencing clones of DJO10A DNA. (B) *NruI* digested genomic DNA from DJO10A shown in the left gel and its Southern hybridization (right gel) using probes specific for four different IS element families. (1) refers to DJO10A and (2) refers to DJO10A-JH1. Arrows indicate bands in DJO10A corresponding to specific IS30 elements as illustrated in (A).

Figure 8. Simulated fecal competitive analysis of *B. longum* DJO10A and its *in vitro* adapted derivative, strain DJO10A-JH1, against *Clostridium difficile* and *E.*

coli. (A) Viable cell counts of *E. coli* DJOec1 at the beginning of the competitive study (black), following competition with *B. longum* DJO10A-JH1 (horizontal lines) and *B. longum* DJO10A (hatched). (B) Viable cell counts of *C. difficile* DJOcd1 at the beginning of the competitive study (black), following competition with *B. longum* DJO10A-JH1 (horizontal lines) and *B. longum* DJO10A (hatched). N = 3.

Figure 9. Conserved structure of the *oriC* region. This consists of three clusters, in the two *B. longum* genomes. The DnaA boxes consist of 7 types, designated A to G as follows: Type A (TTATCCACA), Type B (TTGTCCACA), Type C (TTTTCCACA), Type D (TTACCCACA), Type E (TTATCCACC), Type F (TTATTCACA), Type G (TTATGCACA).

Figure 10. Type I and II restriction modification (R-M) systems encoded by the *B. longum* genomes. (A) Alignment of the genomic locations encoding a type I R-M system between *B. longum* DJO10 and NCC2705. (B) Comparison of a Sau3AI-type II R-M system (recognition site, 5'-GATC-3') with analogous R-M systems in other bacteria and (C) comparison of a EcoRII-type II R-M system (recognition site, 5'-CCWGG-3') with analogous R-M systems in other bacteria. Percentage protein sequence identities compared to *B. longum* DJO10A are indicated.

Figure 11. Organization of the 11 different types of oligosaccharide utilization gene clusters (11 in DJO10A and 7 in NCC2705). Unique genes of strain DJO10A are indicated. IS, insertion sequence; Hyp, hypothetical protein; Arab, arabinosidase; E, malE; F, malF; G, malG; R, lacI-type repressor; K, ATPase of ABC transporter; α Gal, α -galactosidase; β Xyl, β -xylosidase; Est, esterase; LCFACS, long-chain fatty acid acetyl CoA synthetase; f, fragmented gene; XylT, D-xylose proton symporter; β Gal, β -galactosidase; Arab- β Gal, arabinogalactan endo-1,4- β -galactosidase; O157, ORF with homolog only in *E. coli* O157; α Man, α -mannosidase; GlycH, glycosyl hydrolase; NAc-Glc, N-acetyl glucosaminidase; UhpB, histidine kinase; RfbA, dTDP-glucose pyrophosphorylase; RfbB, dTDP-D-glucose 4,6-dehydratase; RfbC, dTDP-4-dehydrorhamnose 3,5-epimerase; RgpF, lipopolysaccharide biosynthesis protein; TagG, ABC-type polysaccharide/polyol phosphate export systems, permease component; TagH, ABC-type polysaccharide/polyol phosphate transport system, ATPase component; MdoB, phosphoglycerol transferase; ProP, permease; Acyl-Est, acyl esterase. It should be

noted that the glycosyl hydrolase gene in cluster 7 was annotated as isomaltase in the NCC2705 genome annotation.

Figure 12. Nucleotide substitution analysis of all gene homologs between *B. longum* DJO10A and NCC2705, according to the dN:dS ratio.

5 Figure 13. Organization of four predicted LPXTG-type, cell surface anchor proteins in *B. longum* DJO10A. The numbers below the signal peptide boxes indicate the location of signal peptides. The size of the respective proteins is indicated in amino acids.

Figure 14. Loss of the lantibiotic gene cluster from *B. longum* DJO10A-JH1.
 10 (A) Detection of DJO10A specific gene clusters in *B. longum* DJO10A and its fermentation adapted isolate DJO10A-JH1 by PCR. M, 1 kb DNA ladder (Invitrogen); lane 1, unique region 15; lane 2, unique region 6; lane 3, unique region 9; lane 4, unique region 11; lane 5, unique region 5; lane 6, unique region 7; lane 7, unique region 12; lane 8, 16S rRNA partial gene. The arrow indicates the lantibiotic
 15 encoded unique region 12 that is missing from strain DJO10A-JH1. (B) Southern blot analysis using a lanM probe and the EcoRI-digested genomes of *B. longum* strains DJO10A and DJO10A-JH1. The 1.7 kb EcoRI band containing lanM is indicated with an arrow.

Figure 15. Growth curves in RCM medium of the four bacteria used in the
 20 fecal competitive growth experiments. All bacteria were inoculated at 1% from freshly grown cultures. Squares, *E. coli* DJOec1; triangles, *Clostridium difficile* DJOcd1; circles, *B. longum* DJO10A-JH1; and diamonds, *B. longum* DJO10A.

Figure 16. Portion of genomic sequence of *B. longum* DJO10A (Genbank Accession No. CP000605) including the lantibiotic-encoding gene cluster (SEQ ID
 25 NO:23). Present within SEQ ID NO:23: nucleotides 1979049 - 1979753 (SEQ ID NO:1) and the polypeptide encoded thereby (SEQ ID NO:2); nucleotides 1979747 - 1980907 (SEQ ID NO:3) and the polypeptide encoded thereby (SEQ ID NO:4); nucleotides 1981217 - 1981417 (SEQ ID NO:5) and the polypeptide encoded
 30 thereby (SEQ ID NO:6); nucleotides 1981501 - 1982160 (SEQ ID NO:7) and the polypeptide encoded thereby (SEQ ID NO:8); nucleotides 1982200 - 1982937 (SEQ ID NO:9) and the polypeptide encoded thereby (SEQ ID NO:10); nucleotides 1983009 - 1986110 (SEQ ID NO:11) and the polypeptide encoded thereby (SEQ ID NO:12); nucleotides 1986161 - 1986979 (SEQ ID NO:13) and the polypeptide

encoded thereby (SEQ ID NO:14); nucleotides 1986976 - 1989213 (SEQ ID NO:15) and the polypeptide encoded thereby (SEQ ID NO:16).

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

5 The present invention provides compounds that inhibit the growth of certain microbes. A compound of the present invention includes a polypeptide. As used herein, the term "polypeptide" refers broadly to a polymer of two or more amino acids joined together by peptide bonds. The term "polypeptide" also includes molecules which contain more than one polypeptide joined by a disulfide bond, or
10 complexes of polypeptides that are joined together, covalently or noncovalently, as multimers (e.g., dimers, tetramers). Thus, the terms peptide, oligopeptide, and protein are all included within the definition of polypeptide and these terms are used interchangeably. It should be understood that these terms do not connote a specific length of a polymer of amino acids, nor are they intended to imply or distinguish
15 whether the polypeptide is produced using recombinant techniques, chemical or enzymatic synthesis, or is naturally occurring. A compound of the present invention can be referred to herein as a lantibiotic. Preferably, a compound of the present invention is isolated. As used herein, an "isolated" polypeptide, such as a lantibiotic, or polynucleotide refers to a polypeptide or polynucleotide that has been either
20 removed from its natural environment, produced using recombinant techniques, or chemically or enzymatically synthesized. Preferably, a polypeptide or polynucleotide of this invention is purified, i.e., essentially free from any other polypeptide or polynucleotide and associated cellular products or other impurities.

 Without intending to be limiting, during production of a compound of the
25 present invention by a microbe, such as a *Bifidobacterium*, a prepeptide is produced and subsequently processed in three steps; dehydration of certain amino acids, formation of thioether linkages between certain amino acids, and cleavage by a signal peptidase. The initial prepeptide may have the amino acid sequence SEQ ID NO:6.

30 The prepeptide is processed by dehydration to result in an intermediate. Serine residues may be dehydrated to form didehydroalanine. Thus, with reference to SEQ ID NO:6, the serine amino acids at position 36, 38, 42, 45, 47, 49, 52, 61 or a combination thereof, may be dehydrated to form didehydroalanine. Preferably, the serine amino acids at positions 47, 49, and 61 are dehydrated to form

didehydroalanine. Threonine amino acids may be dehydrated to form didehydrobutyrine. Thus, with reference to SEQ ID NO:6, the threonine amino acids at positions 54, 57 or a combination thereof, may be dehydrated to form didehydrobutyrine. Preferably, the threonines at both positions 54 and 57 are
 5 dehydrated to form didehydrobutyrine.

Thus, an intermediate polypeptide resulting from the dehydration amino acids may have the following structure:

Methionine-Serine-Isoleucine-Aspartic acid-Glutamic acid-Lysine-Serine-
 10 Isoleucine-Valine-Glycine-Glutamic acid-Serine-Phenylalanine-Glutamic acid-Aspartic acid-Leucine-Serine-Alanine-Alanine-Aspartic acid-Methionine-Alanine-Methionine-Leucine-Threonine-Glycine-Arginine-Asparagine-Aspartic acid-Aspartic acid-Glycine-Valine-Alanine-proline-alanine-Xaa1-leucine- Xaa2-phenylalanine-alanine-valine- Xaa3-valine-leucine- Xaa4-valine- Xaa5-phenylalanine- Xaa6-alanine- cysteine- Xaa7-valine- Xaa8-valine-valine- Xaa9-
 15 arginine-leucine-alanine- Xaa10- cysteine-glycine-asparagine- cysteine-lysine (SEQ ID NO:19)

where Xaa1, 2, 3, 4, 5, 6, 7, and 10 are each independently serine or
 20 didehydroalanine; and Xaa8 and 9 are each independently threonine or didehydrobutyrine. A preferred example of an intermediate polypeptide resulting from the dehydration of certain amino acids is

Methionine-Serine-Isoleucine-Asparagine-Glutamic acid-Lysine-Serine-Isoleucine-
 25 Valline-Glycine-Glutamic acid-Serine-Phenylalanine-Glutamic acid-Aspartic acid-Leucine-Serine-Alanine-Alanine-Aspartic acid-Methionine-Alanine-Methionine-Leucine-Threonine-Glycine-Arginine-Asparagine-Aspartic acid-Aspartic acid-Glycine-Valine-Alanine-proline-alanine-serine-leucine-serine-phenylalanine-alanine-valine-serine-valine-leucine-serine-valine-didehydroalanine-phenylalanine-
 30 didehydroalanine-alanine-cysteine-serine-valine-didehydrobutyrine-valine-valine-didehydrobutyrine-arginine-leucine-alanine-didehydroalanine-cysteine-glycine-asparagine-cysteine-lysine (SEQ ID NO:20).

The polypeptide resulting from the dehydration of certain amino acids is further processed to form thioether linkages between certain amino acids.

Didehydrobutyrine residues may be processed to form 2-aminobutyric acid (Abu) when used to form a thioether linkage with another amino acid, didehydroalanine residues may be processed to form alanine when used to form a thioether linkage with another amino acid, and cysteine residues may be processed to form alanine when used to form a thioether linkage with another amino acid. As has been observed in lantibiotics, lanthionine and 3-methylanthionine residues result from the formation of thioether linkages between different amino acids.

The processed polypeptide is further processed by cleavage between two amino acids. The expected cleavage site is between amino acids 33 and 34. Other cleavage sites in SEQ ID NO:6 may be used to result in a processed peptide.

Thus, a compound of the present invention may have the following sequence:

proline-alanine-Xaa1-leucine- Xaa2-phenylalanine-alanine-valine- Xaa3-valine-leucine- Xaa4-valine- Xaa5-phenylalanine- Xaa6-alanine- Xaa7- Xaa8-valine- Xaa9-valine-valine- Xaa10-arginine-leucine-alanine- Xaa11- Xaa12-glycine-asparagine- Xaa13-lysine (SEQ ID NO:21)

where Xaa1, 2, 3, 4, 5, 6, 8, and 11 are each independently serine, didehydroalanine, or alanine; Xaa7, 12, and 13 are each independently cysteine or alanine, and Xaa9 and 10 are each independently threonine, didehydrobutyrine, or 2-aminobutyric acid. A preferred example of a compound of the present invention is

proline-alanine-serine-leucine-serine-phenylalanine-alanine-valine-serine-valine-leucine-serine-valine-alanine-phenylalanine-didehydroalanine-alanine-alanine-serine-valine-didehydrobutyrine-valine-valine-2-aminobutyric acid-arginine-leucine-alanine-alanine-alanine-glycine-asparagine-alanine-lysine (SEQ ID NO:22).

A compound may have at least 1, at least 2, at least 3, at least 4, at least 5, at least 6 thioether cross links. Preferably, a compound of the present invention has at least 1, more preferably at least 2, most preferably 3 cross links. The cross links can be between any two residues at positions Xaa 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and

13 of SEQ ID NO:21, in any combination. Preferably, each cross link includes one cysteine residue, i.e., Xaa 7, 12, or 13 of SEQ ID NO:21. A preferred example of a compound of the present invention is SEQ ID NO:22 with thioether cross links between the amino acids at positions 14 (Xaa 5) and 18 (Xaa 7), positions 24 (Xaa 10) and 29 (Xaa 12), and positions 28 (Xaa 11) and 32 (Xaa 13).

A compound of the present invention may include polypeptides other than those depicted at SEQ ID NOs: 19, 20, 21, or 22, preferably, SEQ ID NO:21. For instance, a compound of the present invention may include those having structural similarity with another amino acid sequence. The similarity is referred to as structural similarity and is generally determined by aligning the residues of the two amino acid sequences (i.e., a candidate amino acid sequence and the amino acid sequence of SEQ ID NOs: 19, 20, 21, or 22) to optimize the number of identical amino acids along the lengths of their sequences; gaps in either or both sequences are permitted in making the alignment in order to optimize the number of identical amino acids, although the amino acids in each sequence must nonetheless remain in their proper order. A candidate amino acid sequence is the amino acid sequence being compared to an amino acid sequence present in an amino acid sequence, such as SEQ ID NO:21. A candidate amino acid sequence may be isolated from a *Bifidobacterium*, or may be produced using recombinant techniques, or chemically or enzymatically synthesized. Preferably, two amino acid sequences are compared using the BESTFIT algorithm in the GCG package (version 10.2, Madison WI), or the the Blastp program of the BLAST 2 search algorithm, as described by Tatusova, et al. (*FEMS Microbiol Lett* 1999, 174:247-250), and available through the World Wide Web, for instance at the internet site maintained by the National Center for Biotechnology Information, National Institutes of Health. Preferably, the default values for all BLAST 2 search parameters are used, including matrix = BLOSUM62; open gap penalty = 11, extension gap penalty = 1, gap x_dropoff = 50, expect = 10, wordsize = 3, and optionally, filter on. In the comparison of two amino acid sequences using the BLAST search algorithm, structural similarity is referred to as "identities." Preferably, a compound of the present invention also includes polypeptides with an amino acid sequence having at least 80% amino acid identity, at least 81% amino acid identity, at least 82% amino acid identity, at least 83% amino acid identity, at least 84% amino acid identity, at least 85% amino acid identity, at least 86% amino acid identity, at least 87% amino acid identity, at least

88% amino acid identity, at least 89% amino acid identity, at least 90% amino acid identity, at least 91% amino acid identity, at least 92% amino acid identity, at least 93% amino acid identity, at least 94% amino acid identity, at least 95% amino acid identity, at least 96% amino acid identity, at least 97% amino acid identity, at least
5 98% amino acid identity, or at least 99% amino acid identity to SEQ ID NOs: 19, 20, 21, or 22, preferably SEQ ID NO:21.

A compound of the present invention having structural similarity to SEQ ID NOs: 19, 20, 21, or 22, preferably SEQ ID NO:21, may include one or more conservative substitutions of the sequence disclosed at SEQ ID NOs: 19, 20, 21, or
10 22. A conservative substitution is typically the substitution of one amino acid for another that is a member of the same class. For example, it is well known in the art of protein biochemistry that an amino acid belonging to a grouping of amino acids having a particular size or characteristic (such as charge, hydrophobicity, and/or hydrophilicity) can generally be substituted for another amino acid without
15 substantially altering the secondary and/or tertiary structure of a polypeptide. For the purposes of this invention, conservative amino acid substitutions are defined to result from exchange of amino acids residues from within one of the following classes of residues: Class I: Gly, Ala, Val, Leu, and Ile (representing aliphatic side chains); Class II: Gly, Ala, Val, Leu, Ile, Ser, and Thr (representing aliphatic and
20 aliphatic hydroxyl side chains); Class III: Tyr, Ser, and Thr (representing hydroxyl side chains); Class IV: Cys and Met (representing sulfur-containing side chains); Class V: Glu, Asp, Asn and Gln (carboxyl or amide group containing side chains); Class VI: His, Arg and Lys (representing basic side chains); Class VII: Gly, Ala, Pro, Trp, Tyr, Ile, Val, Leu, Phe and Met (representing hydrophobic side chains);
25 Class VIII: Phe, Trp, and Tyr (representing aromatic side chains); and Class IX: Asn and Gln (representing amide side chains). The classes are not limited to naturally occurring amino acids, including amino acids not coded for in the standard genetic code and resulting from, for instance, post-translational modification of an amino acid, but also include artificial amino acids. A conservative substitution may be
30 present at any location, preferably, at position 1, 2, 4, 6, 7, 8, 10, 11, 13, 15, 17, 20, 22, 23, 25, 26, 27, 30, 31, 33, or a combination thereof of SEQ ID NO:21.

Guidance concerning how to make phenotypically silent amino acid substitutions is provided in Bowie et al. (1990, Science, 247:1306-1310), wherein the authors indicate proteins are surprisingly tolerant of amino acid substitutions.

For example, Bowie et al. disclose that there are two main approaches for studying the tolerance of a polypeptide sequence to change. The first method relies on the process of evolution, in which mutations are either accepted or rejected by natural selection. The second approach uses genetic engineering to introduce amino acid changes at specific positions of a cloned gene and selects or screens to identify sequences that maintain functionality. As stated by the authors, these studies have revealed that proteins are surprisingly tolerant of amino acid substitutions. The authors further indicate which changes are likely to be permissive at a certain position of the protein. For example, most buried amino acid residues require non-polar side chains, whereas few features of surface side chains are generally conserved. Other such phenotypically silent substitutions are described in Bowie et al, and the references cited therein.

Preferably, a compound of the present invention is biologically active. As used herein, a "biologically active" compound or a compound having "biological activity" is one that inhibits growth of an indicator microbe. When the lantibiotic to be tested for biological activity is being produced by a microbe, preferably a *Bifidobacterium*, the microbe may be used to inoculate the center of an agar plate and incubated for a period of time, for instance, 2 days, to allow for replication of the microbe and production of the lantibiotic. Preferably, the agar plate is MRS or BLIM. Next, an indicator strain, previously grown on a different plate or in broth, is suspended in a molten top agar, for instance, 0.5% agar, and poured over the plate that contains the microbe producing the lantibiotic to be tested. The amount of indicator strain used can vary, but is typically added at a concentration that will yield visible growth in 1 to 2 days in the absence of a lantibiotic-producing microbe. The top agar is allowed to cool and harden, and the plate is incubated under conditions to allow growth of the indicator strain. The absence of the indicator strain around the microbe inoculated in the middle of the plate indicates the microbe is producing a lantibiotic with biological activity. The plate may be completely devoid of growth of the indicator strain, or there may be a halo of no indicator strain in the center of the plate.

When the lantibiotic to be tested for biological activity is isolated or purified, a hole may be cut in the center of an agar plate, and a solution containing an isolated or purified lantibiotic may be added to the hole and allowed to diffuse into the agar. Next, an indicator strain, previously grown on a different plate or in broth, is

suspended in a molten top agar, for instance, 0.5% agar, and poured over the plate that contains the isolated or purified lantibiotic. The top agar is allowed to cool and harden, and the plate is incubated under conditions to allow growth of the indicator strain. The absence of the indicator strain around the microbe inoculated in the
5 middle of the plate indicates the microbe is producing a lantibiotic with biological activity. The plate may be completely devoid of growth of the indicator strain, or there may be a halo of no indicator strain in the center of the plate.

Some lantibiotics are known to have some biological activity against gram negative microbes, but typically the biological activity exists only if the outer
10 membrane of the gram negative microbe is damaged before exposure to the lantibiotic. The lantibiotic of the present invention has biological activity against gram negative microbes in the absence of damage to the outer membrane. Accordingly, testing whether a lantibiotic has biological activity is preferably done under conditions that do not damage the outer membrane of a gram negative
15 microbe. Such conditions include, for instance, inclusion of a chelator in the medium, subjecting the indicator microbe to conditions of osmotic shock, heat, hydrostatic pressure, exposure to sub-lethal antimicrobials that effect the lipopolysaccharide of the outer membrane, sub-lethal microwave exposure, and sublethal sonication. Likewise, some lantibiotics are known to have some biological
20 activity against gram negative microbes, but typically the biological activity exists only if the gram negative microbe is exposed to higher concentrations of the lantibiotic than are used to inhibit a gram positive microbe (Hillman, U.S. Patent Application 20020128186. The lantibiotic of the present invention has biological activity against gram negative microbes and gram positive microbes when used at
25 the same concentration.

Preferred indicator strains include, for instance, *Micrococcus leuteus*, *Lactococcus lactis*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *E. coli*, *Serratia marcescens*, and *Proteus vulgaris*.

A compound of the present invention also has the characteristics of being
30 resistant to heating to 100°C for 10 minutes, inactivated by proteolytic digestion with pepsin at pH 2 and pronase E at pH7.5, and not inactivated by proteolytic digestion with α -Chymotrypsin, proteinase K, trypsin, and thermolysin. The compound is predicted to have an isoelectric point of 9.5, and a molecular weight of 3291.8 Daltons.

The present invention also provides other isolated polypeptides. Without intending to be limiting, production of a compound of the present invention, for instance, SEQ ID NO:22, by a microbe such as a *Bifidobacterium*, is facilitated by 7 other polypeptides. The naturally occurring versions of these 7 polypeptides are
5 encoded by a set of coding regions including the coding region encoding the naturally occurring preprotein SEQ ID NO:6, and the expression of each of these 7 polypeptide results in the production of a compound, for instance, SEQ ID NO:22.

These 7 polypeptides are a response regulator of two component system (SEQ ID NO:2), a signal transduction histidine kinase (SEQ ID NO:4), a response
10 regulator (SEQ ID NO:8), a prepeptide modification polypeptide (SEQ ID NO:10), a modifying enzyme (SEQ ID NO:12), an immunity polypeptide (SEQ ID NO:14), and a transporter polypeptide (SEQ ID NO:16). The transporter polypeptide is predicted to include protease capability to cleave the prepeptide. Also included in the invention are polypeptides having structural similarity with the amino acid
15 sequence of SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16. The similarity is referred to as structural similarity and is generally determined by aligning the residues of the two amino acid sequences (i.e., a candidate amino acid sequence and the amino acid sequence of
SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ
20 ID NO:14, or SEQ ID NO:16) as described above. Preferably, a polypeptide of this aspect of the invention also includes polypeptides with an amino acid sequence having at least 80% amino acid identity, at least 81% amino acid identity, at least 82% amino acid identity, at least 83% amino acid identity, at least 84% amino acid identity, at least 85% amino acid identity, at least 86% amino acid identity, at least
25 87% amino acid identity, at least 88% amino acid identity, at least 89% amino acid identity, at least 90% amino acid identity, at least 91% amino acid identity, at least 92% amino acid identity, at least 93% amino acid identity, at least 94% amino acid identity, at least 95% amino acid identity, at least 96% amino acid identity, at least 97% amino acid identity, at least 98% amino acid identity, or at least 99% amino
30 acid identity to SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16. A polypeptide the present invention having structural similarity to SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16 may include one or more conservative substitutions of the sequence disclosed at SEQ ID NO:2, SEQ ID

NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16.

5 A polypeptide having structural similarity to SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16 preferably has activity of producing a biologically active compound of SEQ ID NO:22. Whether a polypeptide having structural similarity to SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16 has activity can be determined by expressing one of the polypeptides with an altered amino acid sequence in a microbe, preferably a *Bifidobacterium*, with the
10 other naturally occurring polypeptides, and determining whether a biologically active compound of the present invention is produced. For instance, if a polypeptide having structural similarity to SEQ ID NO:2 is to be tested for activity, it may be expressed in a cell with SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, and SEQ ID NO:16, and the cell grown
15 under conditions suitable for the production of a compound of the present invention. If the cell produces a compound having biological activity, then the tested polypeptide, i.e., the polypeptide having structural similarity to SEQ ID NO:2, is active.

20 *Polynucleotides*

The present invention also provides polynucleotides, preferably isolated polynucleotides. As used herein, the term "polynucleotide" refers to a polymeric form of nucleotides of any length, either ribonucleotides or deoxynucleotides, and includes both double- and single-stranded DNA and RNA. A polynucleotide may
25 include nucleotide sequences having different functions, including for instance coding sequences, and non-coding sequences such as regulatory sequences. Coding sequence, non-coding sequence, and regulatory sequence are defined below. A polynucleotide can be obtained directly from a natural source, or can be prepared with the aid of recombinant, enzymatic, or chemical techniques. A polynucleotide
30 can be linear or circular in topology. A polynucleotide can be, for example, a portion of a vector, such as an expression or cloning vector, or a fragment.

One polynucleotide of the present invention includes SEQ ID NO:17 (nucleotides 1981316 - 1981417 of SEQ ID NO:23), which encodes the polypeptide depicted at amino acids 34-66 of SEQ ID NO:6. It should be understood that a

polynucleotide encoding a polypeptide represented by amino acids 34-66 of SEQ ID NO:6 is not limited to the nucleotide sequence disclosed at SEQ ID NO:17, but also includes the class of polynucleotides encoding such a polypeptide as a result of the degeneracy of the genetic code. For example, the naturally occurring nucleotide
5 sequence SEQ ID NO:17 is but one member of the class of nucleotide sequences encoding a polypeptide having the amino acid sequence depicted at amino acids 34-66 of SEQ ID NO:6.

Other polynucleotides encoding a biologically active polypeptide of the present invention include those having structural similarity with the nucleotide
10 sequence of SEQ ID NO:17. The similarity is referred to as structural similarity and is determined by aligning the residues of the two polynucleotides (i.e., the nucleotide sequence of the candidate sequence and the nucleotide sequence of SEQ ID NO:17) to optimize the number of identical nucleotides along the lengths of their sequences; gaps in either or both sequences are permitted in making the alignment in order to
15 optimize the number of shared nucleotides, although the nucleotides in each sequence must nonetheless remain in their proper order. A candidate sequence is the sequence being compared to SEQ ID NO:17. A candidate nucleotide sequence may be isolated from a *Bifidobacterium*, or may be produced using recombinant techniques, or chemically or enzymatically synthesized. Preferably, two nucleotide
20 sequences are compared using the BESTFIT algorithm in the GCG package (version 10.2, Madison WI), or the the Blastn program of the BLAST 2 search algorithm, as described by Tatusova, et al. (*FEMS Microbiol Lett* 1999, 174:247-250), and available through the World Wide Web, for instance at the internet site maintained by the National Center for Biotechnology Information, National Institutes of Health.
25 Preferably, the default values for all BLAST 2 search parameters are used, including reward for match = 1, penalty for mismatch = -2, open gap penalty = 5, extension gap penalty = 2, gap x_dropoff = 50, expect = 10, wordsize = 11, and optionally, filter on. In the comparison of two nucleotide sequences using the BLAST search algorithm, structural similarity is referred to as "identities." Preferably, a
30 polynucleotide includes a nucleotide sequence having at least 80% nucleotide identity, at least 81% nucleotide identity, at least 82% nucleotide identity, at least 83% nucleotide identity, at least 84% nucleotide identity, at least 85% nucleotide identity, at least 86% nucleotide identity, at least 87% nucleotide identity, at least 88% nucleotide identity, at least 89% nucleotide identity, at least 90% nucleotide

identity, at least 91% nucleotide identity, at least 92% nucleotide identity, at least 93% nucleotide identity, at least 94% nucleotide identity, at least 95% nucleotide identity, at least 96% nucleotide identity, at least 97% nucleotide identity, at least 98% nucleotide identity, or at least 99% nucleotide identity to SEQ ID NO:17.

- 5 Preferably, a nucleotide sequence having structural similarity to SEQ ID NO:17 encodes a compound of the present invention having biological activity.

Optionally, a polynucleotide identical to, or having structural similarity with SEQ ID NO:17 includes an additional nucleotide sequence located immediately 5' or upstream of SEQ ID NO:17. This optional sequence encodes a polypeptide
10 corresponding to the amino terminal region of the prepeptide that is removed during processing, i.e., amino acids 1-33 of SEQ ID NO:6. These nucleotides are disclosed at nucleotides 1 - 99 of SEQ ID NO:5. It should be understood that a polynucleotide encoding a polypeptide represented by amino acids 1-33 of SEQ ID NO:6 is not limited to the nucleotide sequence disclosed at nucleotides 1 - 99 of SEQ ID NO:5,
15 but also includes the class of polynucleotides encoding such a polypeptide as a result of the degeneracy of the genetic code.

Other isolated polynucleotides encoding the amino terminal region of the prepeptide include those having structural similarity with the nucleotide sequence of nucleotides 1 - 99 of SEQ ID NO:5. The similarity is referred to as structural
20 similarity and is determined by aligning the residues of the two polynucleotides (i.e., the nucleotide sequence of the candidate sequence and nucleotides 1 - 99 of SEQ ID NO:5) as described above. Preferably, such a polynucleotide includes a nucleotide sequence having at least 80% nucleotide identity, at least 81% nucleotide identity, at least 82% nucleotide identity, at least 83% nucleotide identity, at least 84%
25 nucleotide identity, at least 85% nucleotide identity, at least 86% nucleotide identity, at least 87% nucleotide identity, at least 88% nucleotide identity, at least 89% nucleotide identity, at least 90% nucleotide identity, at least 91% nucleotide identity, at least 92% nucleotide identity, at least 93% nucleotide identity, at least 94% nucleotide identity, at least 95% nucleotide identity, at least 96% nucleotide identity,
30 at least 97% nucleotide identity, at least 98% nucleotide identity, or at least 99% nucleotide identity to nucleotides 1 - 99 of SEQ ID NO:5.

The present invention also includes isolated polynucleotides encoding the 7 polypeptides that facilitate production of a compound of the present invention. These polynucleotides include SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:7, SEQ

ID NO:9, SEQ ID NO:11, SEQ ID NO:13, and SEQ ID NO:15. These polynucleotides encode SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, and SEQ ID NO:16, respectively. It should be understood that a polynucleotide encoding a polypeptide represented by SEQ ID
5 NO:2, SEQ ID NO:4, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, or SEQ ID NO:16 is not limited to the nucleotide sequence disclosed at SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:7, SEQ ID NO:9, SEQ ID NO:11, SEQ ID NO:13, or SEQ ID NO:15, but also includes the class of polynucleotides encoding such a polypeptide as a result of the degeneracy of the genetic code.

10 Other polynucleotides encoding one of the 7 polypeptides that facilitate expression of a compound of the present invention include those having structural similarity with the nucleotide sequence of SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:7, SEQ ID NO:9, SEQ ID NO:11, SEQ ID NO:13, or SEQ ID NO:15. The similarity is referred to as structural similarity and is determined by aligning the
15 residues of the two polynucleotides (e.g., the nucleotide sequence of the candidate sequence and the nucleotide sequence of SEQ ID NO:1) as described above. Preferably, a polynucleotide includes a nucleotide sequence having at least 80% nucleotide identity, at least 81% nucleotide identity, at least 82% nucleotide identity, at least 83% nucleotide identity, at least 84% nucleotide identity, at least 85%
20 nucleotide identity, at least 86% nucleotide identity, at least 87% nucleotide identity, at least 88% nucleotide identity, at least 89% nucleotide identity, at least 90% nucleotide identity, at least 91% nucleotide identity, at least 92% nucleotide identity, at least 93% nucleotide identity, at least 94% nucleotide identity, at least 95% nucleotide identity, at least 96% nucleotide identity, at least 97% nucleotide identity,
25 at least 98% nucleotide identity, or at least 99% nucleotide identity to SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:7, SEQ ID NO:9, SEQ ID NO:11, SEQ ID NO:13, or SEQ ID NO:15. Preferably, a nucleotide sequence having structural similarity to SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:7, SEQ ID NO:9, SEQ ID NO:11, SEQ ID NO:13, or SEQ ID NO:15 having the activity of producing a compound of SEQ
30 ID NO:22. Testing for such activity is described above.

A polynucleotide of the present invention may be present in a vector. A vector is a replicating polynucleotide, such as a plasmid, phage, cosmid, or artificial chromosome, to which another polynucleotide may be attached so as to bring about the replication of the attached polynucleotide. When present in a vector, a

polynucleotide of the invention may be referred to as a recombinant polynucleotide. As used herein, a "recombinant polynucleotide" refers to a polynucleotide having sequences that are not naturally joined together. The sequences may be joined by the artificial manipulation of different polynucleotide sequences using recombinant techniques, or may be chemically or enzymatically synthesized. A recombinant polynucleotide may be included in a suitable vector. Construction of vectors containing a polynucleotide of the invention employs standard ligation techniques known in the art. See, e.g., Sambrook et al, *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press (1989).

10 A vector can provide for further cloning (amplification of the polynucleotide), i.e., a cloning vector, or for expression of the polypeptide encoded by the coding region, i.e., an expression vector. Suitable expression vectors include those that can be used to produce amounts of polypeptide, preferably a compound of the present invention that can be used in a composition of the present invention and, 15 for instance, administered to a subject. Vectors may include a coding region encoding a polypeptide of the present invention or a fragment thereof. As used herein, a "coding region" refers to a nucleotide sequence that encodes a polypeptide and, when placed under the control of appropriate regulatory sequences expresses the encoded polypeptide. The boundaries of a coding region are generally 20 determined by a translation start codon at its 5' end and a translation stop codon at its 3' end

Selection of a vector depends upon a variety of desired characteristics in the resulting construct, such as a selection marker, vector replication rate, and the like. Suitable host cells for cloning or expressing the vectors herein are prokaryote or 25 eukaryotic cells.

An expression vector optionally includes regulatory sequences operably linked to the coding region. A regulatory sequence is a nucleotide sequence that regulates expression of a coding region to which it is operably linked. Nonlimiting examples of regulatory sequences include promoters, transcription initiation sites, 30 translation start sites, translation stop sites, and terminators. "Operably linked" refers to a juxtaposition wherein the components so described are in a relationship permitting them to function in their intended manner. A regulatory sequence is "operably linked" to a coding region when it is joined in such a way that expression of the coding region is achieved under conditions compatible with the regulatory

sequence. The invention is not limited by the use of any particular promoter, and a wide variety of promoters are known. Promoters act as regulatory signals that bind RNA polymerase in a cell to initiate transcription of a downstream (3' direction) coding region. The promoter used may be a constitutive or an inducible promoter. It may be, but need not be, heterologous with respect to the host cell. As used herein, a "heterologous" regulatory sequence is a regulatory sequence operably linked to a coding region to which it is not normally operably linked.

An expression vector may optionally include a ribosome binding site and a start site (e.g., the codon ATG) to initiate translation of the transcribed message to produce the polypeptide. It may also include a termination sequence to end translation. A termination sequence is typically a codon for which there exists no corresponding aminoacyl-tRNA, thus ending polypeptide synthesis. The polynucleotide used to transform the host cell may optionally further include a transcription termination sequence.

A vector may include more than one polynucleotide of the present invention. When more than one polynucleotide of the present invention is present in one vector, the polynucleotides may be organized in an operon, and operably linked to the same promoter located upstream of the first coding region in the operon. Alternatively, more than one promoter may drive expression of the polynucleotides. For instance,

The vector introduced into a host cell optionally includes one or more marker sequences, which typically encode a molecule that inactivates or otherwise detects or is detected by a compound in the growth medium. For example, the inclusion of a marker sequence may render the transformed cell resistant to an antibiotic, or it may confer compound-specific metabolism on the transformed cell. Examples of a marker sequence are sequences that confer resistance to kanamycin, ampicillin, chloramphenicol, tetracycline, neomycin, and erythromycin.

Methods of making

The present invention is also directed to methods for making compounds of the present invention. A method for producing a compound of the present invention may include growing a *Bifidobacterium* under conditions suitable for producing the compound. Typically, such conditions may include growing the *Bifidobacterium* on a surface. Suitable components that can be used to for a solid medium include, but

are not limited to, agar, gelatin, and gums such as alginate, xanthan, and the like. The medium may be complete or minimal, preferably complete. Examples of suitable media include, but are not limited to, complex media that include a fermentable sugar, such as MRS, BLIM, and Brain Heart Infusion.

5 Bifidobacteria that may produce a compound of the present invention can be obtained from an individual, or laboratory strains can be used. Examples of bifidobacteria that may be used as a source of a compound of the present invention include *B. adolescentis*, *B. aerophilum*, *B. angulatum*, *B. animalis*, *B. asteroides*, *B. bifidum*, *B. boum*, *B. breve*, *B. catenulatum*, *B. choerinum*, *B. coryneforme*, *B.*
 10 *cuniculi*, *B. denticolens*, *B. dentium*, *B. gallicum*, *B. gallinarum*, *B. indicum*, *B. infantis*, *B. inopinatum*, *B. longum*, *B. magnum*, *B. merycicum*, *B. minimum*, *B. pseudocatenulatum*, *B. pseudolongum*, *B. psychraerophilum*, *B. pullorum*, *B. ruminantium*, *B. saeculare*, *B. scardovii*, *B. subtile*, *B. thermacidophilum*, and *B. thermophilum*. Preferably, the *Bifidobacterium* is *B. breve*, *B. infantis*, or *B. longum*,
 15 more preferably, *B. longum*.

Since bifidobacteria are believed to lose the ability to produce lantibiotics after prolonged *in vitro* culture in liquid medium, a *Bifidobacterium* is preferably obtained from an individual. Methods for obtaining a *Bifidobacterium* from an individual are routine and known in the art (see, for instance, Kullen et al., 1997,
 20 *FEMS Microbiol. Lett.*, 154:377-383; O'Sullivan, U.S. Patent 6,746,672). For instance, fresh fecal samples may be collected from an individual and immediately homogenized in an appropriate amount of a sterile solution such as sterile peptone water (0.1%). Preferably, an individual has no history of gastrointestinal disorders and has not used antibiotics in the previous year. The homogenate may be
 25 transferred to an anaerobic chamber, where it may be serially diluted and plated on, for instance, BIM-25 (Muñoz et al., 1988, *Appl. Environ. Microbiol.*, 54:1715-1718). After anaerobic incubation at 37°C, red colonies can be randomly selected. The authenticity of the colonies appearing on the BIM-25 plates can be verified by routine methods, such as assessing the activity of fructose-6-phosphate
 30 phosphoketolase, a diagnostic enzyme for bifidobacteria, or by molecular analysis of the 16s rRNA gene or the *recA* gene as described by Kullen et al. (1997, *FEMS Microbiol Lett.*, 154:377-383).

Once a microbe such as a *Bifidobacterium* is growing in conditions that permit lantibiotic production it is expected to be able to continue to do so. However,

a *Bifidobacterium* that produces a compound of the present invention should not be grown for extended periods under conditions that do not favor lantibiotic production, such as in broth, as they can lose the gene cluster encoding the compound. As the gene cluster also encodes the immunity genes, it cannot be lost if the lantibiotic is in the environment.

A *Bifidobacterium* can be screened to determine if it produces a compound of the present invention. Screening methods include culturing a *Bifidobacterium* under conditions suitable for expression of a lantibiotic and testing for the presence of a lantibiotic. Conditions that are "suitable" for an event to occur, or conditions that "allow" an event to occur, such as production of a lantibiotic by a *Bifidobacterium*, or "suitable" conditions are conditions that do not prevent such events from occurring. Thus, these conditions permit, enhance, facilitate, and/or are conducive to the event. Methods for determining whether a *Bifidobacterium* expresses a compound of the present invention are described above.

Screening methods may include determining if a *Bifidobacterium* has one or more of the polynucleotides involved in the synthesis of a compound of the present invention. For instance, the presence of a polynucleotide of the present invention can be determined by amplification. Preferably, a polynucleotide is amplified by the polymerase chain reaction (PCR). In PCR, a molar excess of a primer pair is added to a sample that includes polynucleotides from the test *Bifidobacterium*, preferably the chromosomal DNA. The primers are extended to form complementary primer extension products which act as templates for synthesizing the desired amplified polynucleotides. The presence of an amplified polynucleotide of the expected size indicates the test *Bifidobacterium* may produce a compound of the present invention.

Suitable polynucleotides that can be amplified include coding regions present in SEQ ID NOs: 1, 3, 5, 7, 9, 11, 13, and 15. Preferably, the polynucleotide amplified is a portion of the nucleotide sequence (SEQ ID NO:5) encoding the polypeptide SEQ ID NO:6. Primers that amplify a portion of a polynucleotide of the present invention can be designed using readily available computer programs, such as OMIGA program, (Oxford Molecular, Ltd., Oxford, UK). Factors that can be considered in designing primers include, but are not limited to, melting temperatures, primer length, size of the amplification product, and specificity. Primer length is generally between 15 and 30 nucleotides, but can be shorter or longer if desired. The conditions for amplifying a polynucleotide by PCR vary

depending on the nucleotide sequence of primers used, and methods for determining such conditions are routine in the art. Examples of primer pairs include, for instance, LANR1-F (ATGAAGGCGATTCTGTTC, SEQ ID NO:38) and LANR1-R (TCACAGCTCGATATTGGTG, SEQ ID NO:39), which result in an amplified
5 product of 676 bp, and LANT1-F (GAGCATCAATGAGAAGTCC, SEQ ID NO:56) and LANT1-R (GCAATCAACACCAAAACC, SEQ ID NO:57), which result in an amplified product of 788 bp.

In another aspect the presence of a polynucleotide of the present invention can be determined with polynucleotide probes designed to hybridize to a
10 polynucleotide present in the test *Bifidobacterium*. As used herein, "hybridizes," "hybridizing," and "hybridization" refers to noncovalent interaction forms between a probe and a target polynucleotide under standard conditions. Standard hybridizing conditions are those conditions that allow a probe to hybridize to a target polynucleotide. Such conditions are readily determined for a probe and the target
15 polynucleotide using techniques well known to the art, for example see Sambrook et al. *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory: New York (1989). Suitable polynucleotides that can be identified by hybridization include coding regions present in SEQ ID NOs: 1, 3, 5, 7, 9, 11, 13, and 15. Preferably, the polynucleotide identified by hybridization is the nucleotide sequence
20 encoding the polypeptide SEQ ID NO:6. A probe may be less than 20 nucleotides, at least 20 nucleotides, at least 50 nucleotides, or at least 100 nucleotides in length.

In another aspect, a method for producing a compound of the present invention may include growing a microbe that includes a recombinant polynucleotide encoding a polypeptide that includes an amino acid sequence having
25 structural similarity to SEQ ID NO:19, SEQ ID NO:20, SEQ ID NO:21, or SEQ ID NO:22, preferably SEQ ID NO:22. A microbe may include a coding region encoding a *lanA* of the present invention, and optionally may include a coding region encoding a *lanR2* of the present invention, a *lanK* of the present invention, a *lanR1* of the present invention, a *lanD* of the present invention, a *lanM* of the present
30 invention, a *lanI* of the present invention, a *lanT* of the present invention, or a combination thereof. Preferably, microbe may include a coding region encoding SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16, or a combination thereof. A compound

of the present invention may also be produced *in vivo* (Xie et al., 2004, Science, 303:679-681).

A microbe that includes a recombinant polynucleotide encoding a compound of the present invention may be an Archae, Eukarya or a Eubacteria, preferably a Eubacteria, such as a gram negative or a gram positive microbe. Examples of gram negative microbes include, but are not limited to, *E. coli* and *Salmonella* spp. Examples of gram poositve microbes include, but are not limited to, *Bacillus* spp. such as *B. subtilis*, *Enterococcus* spp. such as *E. faecium*, *E. faecalis*, lactic acid bacteria such as *Lactococcus lactis*, *L. sakei*, and *Streptomyces*. Other microbes include yeast such as, but not limited to, *Saccharomyces cerevisiae* and *Pichia pastoris*.

A compound of the present invention may be isolated. For instance, a microbe producing a compound of the present invention, preferably a *Bifidobacterium*, can be grown in conditions suitable for the production of a lantibiotic, and the culture, including the medium, exposed to conditions suitable for isolating the compound. In one aspect, a compound of the present invention may be isolated by drying the cells and, optionally, the solid medium on which the cells are grown. Optionally, the culture may be further treated to sterilize it. For example, the culture can be treated by exposure to conditions to kill the bifidobacteria present in the culture. Examples of conditions useful for sterilization include heat or ultraviolet radiation. The culture may be dried until essentially all moisture is removed and a powder containing the compound remains. Methods for drying cultures are known to the art and include, for instance, spray drying, freeze drying, tunnel drying, vacuum drying, and air drying. The result of such methods is a mixture that includes a large number of components, including the compound of the present invention. Such a mixture may be added to food products. The mixture added to food products may be sterile.

In another aspect, a lantibiotic of the present invention may be isolated by methanol extraction. Additional methods may be used for further isolation and/or purification using methods known in the art for isolating and/or purifying lantibiotics. Such methods typically include, but are not limited to, column chromatography, including hydrophobic interaction chromatography, and high performance liquid chromatography (HPLC), such as reverse phase HPLC using, for instance, a C18 column. The optimum conditions to be used can be determined by

routine experimentation. A purified compound of the present invention may be made using known synthetic chemistry techniques.

Compositions

5 The present invention also provides compositions. A composition may include a compound of the present invention. Such compositions may optionally include a pharmaceutically acceptable carrier. As used herein "pharmaceutically acceptable carrier" includes saline, solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like, compatible with pharmaceutical
10 administration and not deleterious to a recipient thereof. The compound present in the composition may be isolated or purified. An isolated compound may be one that is isolated by drying the cells. Additional active compounds can also be incorporated into the compositions.

 Compositions of the present invention may further include at least one
15 component that damages the outer membrane of a gram negative microbe. For instance, a composition may include at least one chelator, preferably a metal chelator. The use of chelators such as ethylenediaminetetraacetic acid (EDTA) with lantibiotics is known to result in expanding the activity of some lantibiotics, such as nisin, from just gram positive microbes to include gram negative microbes
20 (Blackburn et al., U.S. Patent 5,691,301). The use of a chelator with a compound of the present invention is not required for the compound to be active against gram negative microbes. Examples of metal chelators include natural and synthetic compounds. Examples of natural compounds include plant phenolic compounds, such as flavonoids. Examples of flavinoids include the copper chelators catechin and
25 naringenin, and the iron chelators myricetin and quercetin. Examples of synthetic copper chelators include, for instance, tetrathiomolybdate, and examples of synthetic zinc chelators include, for instance, N,N,N',N' -Tetrakis (2-pyridylmethyl)-ethylene diamine. Examples of synthetic iron chelators include 2,2'-dipyridyl, 8-hydroxyquinoline, EDTA, ethylenediamine-di-O-hydroxyphenylacetic acid
30 (EDDHA), desferrioxamine methanesulphonate (desferol), transferrin, lactoferrin, ovotransferrin, biological siderophores, such as xcatecholates and hydroxamates, and citric acid. Preferably, the chelator is EDTA.

 Compositions of the present invention may further include at least one surfactant, preferably a non-ionic surfactant. Examples of non-ionic surfactants

include glycerol monolaurate, sucrose esters such as sucrose palmitate, polysorbate 20, TRITON X-100, Isoceteth-20, ARLASOLVE 200L, Lauramine oxide, Decylpolyglucose, Phospholipid PTC, MEROXAPOL 105, and the like.

Compositions of the present invention may include other agents having bacteriostatic and/or bacteriocidal activity. Examples include, but are not limited to, lysostaphin, bacitracin, neomycin, polymixin, beta-lactams, including penicillin, methicillin, moxalactam and cephalosporins, such as cefaclor, cefadroxil, cefamandole nafate, cefazolin, cefixime, cefinetazole, cefoniod, cefoperazone, ceforanide, cefotanme, cefotaxime, cefotetan, cefoxitin, cefpodoxime proxetil, ceftazidime, ceftizoxime, ceftriaxone, cefriaxone, cefuroxime, cephalixin, cephalosporin C, cephalosporin C sodium salt, cephalothin, cephalothin sodium salt, cephalothin dihydrate, cephapirin, cephradine, cefuroximeaxetil, loracarbef, and the like, glycopeptides, anti-bacterial enzymes, including anti-staphylococcal enzymes such as mutanolysin, lysozyme or cellosyl muramidase, anti-bacterial antibodies, other anti-bacterial peptides such as defensins, and bacteriocins, including other lantibiotics such as nisin, subtilin, epidermin, cinnamycin, duramycin, ancovenin and Pep 5. In some aspects these agents may be particularly preferred when the composition is to be applied topically.

A composition may contain organic acids acceptable for use in food products or salts of these acids. A composition may contain individual acids or salts, or mixtures thereof. Preferred organic acids or salts for use in compositions include acetic acid, sodium acetate, sodium diacetate, potassium acetate, lactic acid, sodium lactate, potassium lactate, propionic acid, propionates, including, but not limited to, sodium propionate and potassium propionate, citric acid or its salts such as sodium citrate or potassium citrate, or combinations thereof.

A composition for administration to a subject may be prepared by methods known in the art of pharmacy. In general, a composition can be formulated in a dosage form to be compatible with its intended route of administration. Examples of routes of administration include, but are not limited to, perfusion; parenteral, e.g., intravenous, intradermal, intramuscular, subcutaneous; topical, e.g., mucosal (such as nasal, sublingual, vaginal, buccal, or rectal) and transdermal; otic; and oral. Solutions or suspensions can include the following components: a sterile diluent such as water for administration, saline solution, fixed oils, polyethylene glycols, glycerine, propylene glycol or other synthetic solvents; antibacterial agents such as

benzyl alcohol or methyl parabens; antioxidants such as ascorbic acid or sodium bisulfite; buffers such as acetates, citrates or phosphates; electrolytes, such as sodium ion, chloride ion, potassium ion, calcium ion, and magnesium ion, and agents for the adjustment of tonicity such as sodium chloride or dextrose. pH can be adjusted with acids or bases, such as hydrochloric acid or sodium hydroxide. A composition can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic.

Compositions can include sterile aqueous solutions (where water soluble) or dispersions and sterile powders for the extemporaneous preparation of sterile solutions or dispersions. For intravenous administration, suitable carriers include physiological saline, bacteriostatic water, or phosphate buffered saline (PBS). A composition is typically sterile and, when suitable for injectable use, should be fluid to the extent that easy syringability exists. It should be stable under the conditions of manufacture and storage and optionally preserved against the contaminating action of microorganisms such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. Prevention of the action of microorganisms can be achieved by various optional antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent which delays absorption, for example, aluminum monostearate and gelatin.

Sterile solutions can be prepared by incorporating the active compound (i.e., a compound of the present invention) in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the active compound into a sterile vehicle, which contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying which yields

a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

Oral compositions generally include an inert diluent or an edible carrier. For the purpose of oral therapeutic administration, the active compound can be incorporated with excipients and used in the form of tablets or capsules, e.g., gelatin capsules. Oral compositions can also be prepared using a fluid carrier for use as a dentifrice. A dentifrice may be a liquid, paste, or powder, such as a mouthwash or a toothpaste. Pharmaceutically compatible binding agents may be included as part of the composition. The tablets, pills, capsules, and the like can contain any of the following ingredients, or compounds of a similar nature: a binder such as microcrystalline cellulose, gum tragacanth or gelatin; an excipient such as starch or lactose, a disintegrating agent such as alginic acid, Primogel, or corn starch; a lubricant such as magnesium stearate or Sterotes; a glidant such as colloidal silicon dioxide; a sweetening agent such as sucrose or saccharin; or a flavoring agent such as peppermint, methyl salicylate, or orange flavoring. In another aspect, a composition may be a transgenic plant expressing a compound of the present invention.

For administration by inhalation, the active compounds may be delivered in the form of an aerosol spray from a pressured container or dispenser which contains a suitable propellant, e.g., a gas such as a hydrofluoroalkane, or a nebulizer.

For topical administration compositions of the invention may include various mixtures and combinations that can be applied topically and to permit even spreading and absorption into cutaneous and mucosal surfaces. Examples include sprays, mists, aerosols, lotions, creams, aqueous and non-aqueous solutions or liquids, oils, gels, powders, ointments, pastes, unguents, emulsions and suspensions. Topical formulations may be prepared by combining a compound of the present invention with conventional pharmaceutical or cosmeceutical diluents or carriers commonly used in topical dry, liquid, cream and aerosol formulations. Both liquids and powders can be delivered as sprays, mists or aerosols.

Powders may be formed with the aid of any suitable powder base, e.g., talc, lactose, starch, and the like. Solutions can be formulated with an aqueous or non-aqueous base, and can also include one or more dispersing agents, suspending agents, solubilizing agents, and the like. Topical gels may be prepared using polymers having a molecular weight and level of concentration effective to form a

viscous solution or colloidal gel of an aqueous or non-aqueous solution or suspension of the active compound. Polymers from which topical gels may be prepared include polyphosphoesters, polyethylene glycols, high molecular weight poly(lactic) acids, hydroxypropyl celluloses, chitosan, polystyrene sulfonates, and
5 the like.

Ointments, creams and lotions may be formulated, for example, with an aqueous or oily base and addition of a suitable thickening agent, gelling agent, stabilizing agent, emulsifying agent, dispersing agent, suspending agent, or consistency regulating agent, and the like. Bases include water, an alcohol or an oil,
10 such as liquid paraffin, mineral oil, or a vegetable oil, such as peanut or castor oil. Thickening agents that can be used according to the nature of the base include soft paraffin, aluminum stearate, cetostearyl alcohol, propylene glycol, polyethylene glycols, polyphosphoesters, poly(lactic acids), hydroxyethyl celluloses, hydroxypropyl celluloses, cellulose gums, acrylate polymers, hydrophilic gelling
15 agents, chitosan, polystyrene sulfonate, petrolatum, woolfat, hydrogenated lanolin, beeswax, and the like.

The ointments, pastes, creams, gels, and lotions can also contain excipients, such as animal and vegetable fats, oils, waxes, paraffins, starch, tragacanth, cellulose derivatives, polyethylene glycols, silicones, bentonites, silicic acid, talc, zinc oxide,
20 and mixtures thereof. Powders and sprays can also contain excipients such as silicic acid, aluminum hydroxide, calcium silicates and polyamide powder, or mixtures of these substances. Solutions, suspensions or dispersions can be converted into aerosols or sprays by any of the known means routinely used for making aerosols for topical application. In general, such methods include pressurizing or providing a
25 means of pressurizing a container of a solution, suspension or dispersion, usually with an inert carrier gas, and passing the pressured gas through a small orifice. Sprays and aerosols can also contain customary propellants, e.g., chlorofluorohydrocarbons or volatile unsubstituted hydrocarbons, such as butane and propane.

30 Excipients may include compounds that promote skin absorption, such as dimethyl sulfoxide (DMSO), partial glycerides of fatty acids, and the like. Examples of partial fatty acid glycerides include, but are not limited to IMWITOR 742 and IMWITOR 308. The topical formulations may also optionally include inactive

ingredients to improve cosmetic acceptability, including but not limited to, humectants, surfactants, fragrances, coloring agents, emollients, fillers, and the like.

A composition may be administered directly by the dusting of a powder, spraying of an aerosol or by spreading a film of an ointment, cream, lotion, solution
5 or gel to the desired area of the skin using the fingertips of the patient or a healthcare provider or other conventional application such as a swab or wipe. The product may be first applied to the skin and spread with the fingertips or an applicator or applied to the fingertips and spread over the skin. The compositions may also optionally first be coated on the surface of a topical applicator, such as a bandage, swab, moist
10 woven or non-woven wipe and the like, which is then applied to the portion of the skin to receive the composition.

The active compounds can also be prepared in the form of suppositories (e.g., with conventional suppository bases such as cocoa butter and other glycerides) or retention enemas for rectal delivery.

15 The active compounds may be prepared with carriers that will protect the active compound against rapid elimination from the body, such as a controlled release formulation, including implants. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid. The materials can also be obtained
20 commercially. Liposomal suspensions can also be used as pharmaceutically acceptable carriers. These can be prepared according to methods known to those skilled in the art.

Since the lantibiotic described in the examples is expressed by bifidobacteria while present in animals, it is expected the compounds of the present invention are
25 safe and suitable for use in animals, including use in foods eaten by an animal. However, toxicity and therapeutic efficacy of such active compounds may be determined by standard pharmaceutical procedures in cell cultures or experimental animals, e.g., for determining the LD₅₀ (the dose lethal to 50% of the population) and the ED₅₀ (the dose therapeutically effective in 50% of the population). The dose
30 ratio between toxic and therapeutic effects is the therapeutic index and it can be expressed as the ratio LD₅₀/ED₅₀. Compounds which exhibit high therapeutic indices are preferred. Methods for evaluating the toxicity of lantibiotics are known in the art and are routine.

The data obtained from cell culture assays and animal studies can be used in formulating a range of dosage for use in animals, including humans. The dosage of such compounds lies preferably within a range of circulating concentrations that include the ED₅₀ with little or no toxicity. The dosage may vary within this range depending upon the dosage form employed and the route of administration utilized. For a compound used in the methods of the invention, the therapeutically effective dose can be estimated initially from cell culture assays. A dose may be formulated in animal models to achieve a concentration range that includes the IC₅₀ (i.e., the concentration of the test compound which achieves a half-maximal inhibition of signs) as determined in cell culture. Such information can be used to more accurately determine useful doses.

In those aspects where a composition is being administered to an animal for a pharmaceutical application or a personal care application, the composition can be administered one or more times per day to one or more times per week, including once every other day. The skilled artisan will appreciate that certain factors may influence the dosage and timing required to effectively treat a subject, including but not limited to the severity of the disease or disorder, previous treatments, the general health and/or age of the subject, and other diseases present. Moreover, treatment of a subject with an effective amount of a compound of the present invention can include a single treatment or, preferably, can include a series of treatments.

The present invention includes both patient-specific dosage forms, as well as non-patient-specific multi-dosage forms that can be used to decontaminate populations exposed to pathogens as a consequence of a bioterrorism attack.

A composition of the present invention may include a microbe, such as a *Bifidobacterium*, that expresses a compound of the present invention. A composition including a microbe that expresses a compound of the present invention may be encapsulated in, for example, a sugar matrix, a fat matrix, a polysaccharide matrix, or a protein matrix. It may also be coated and/or incorporated into tablet form. For instance, encapsulation, coating, and incorporation into tablet form may allow better survival of the microbe in the composition, or may allow better delivery of the microbe to the large intestine.

Such compositions that include a microbe that expresses a compound of the present invention are often orally administered to an animal. It is known in the art that bifidobacteria can be incorporated into different types of food products. In

particular, the bifidobacteria of the present invention can be incorporated into solid and semi-solid dairy products, including fermented dairy products, for instance yogurt. Other examples of dairy products include cottage cheese, cheese, and powdered milk. Bifidobacteria can also be incorporated into baby foods. Beverages to which bifidobacteria can be added include milk, vegetable juice, fruit juice, soy milk, soybean milk, fermented soybean milk, and fruit flavored dairy beverages.

Methods of Use

The present invention is also directed to methods of using the compositions described herein. The methods include, for instance, pharmaceutical applications, food applications, personal care applications, and probiotic applications. The methods may include preventing microbial growth. The prevention of growth may be due to a bacteriostatic activity or a bacteriocidal activity of a compound of the present invention. The microbe may be gram positive or gram negative. Examples of gram positive microbes that may be sensitive to a lantibiotic of the present invention and inhibited include, but are not limited to, *Streptococcus* spp., such as *S. agalactiae*; *Enterococcus* spp., such as *E. faecalis* and *E. faecium*; *Bacillus* spp., such as *B. anthracis*, *B. cereus*, *B. coagulans*, and *B. licheniformis*; *Listeria* spp., such as *L. monocytogenes*; *Staphylococcus* spp., such as *S. aureus*; *Streptococcus* spp., such as *S. agalactiae*, *S. mutans*, *S. viridans*, *S. thermophilus*, *S. constellatus*, and *S. zooepidemicus*; *Clostridium* spp., such as *C. botulinum*, *C. difficile*, *C. perfringens*, *C. sordellii*, *C. tetani*, *C. sordellii*, *C. sporogenes*, *C. tyrobutyricum*, and *C. putrefasciens*; *Actinomyces* spp., such as *A. israelii* and *A. naeslundii*; *Leuconostoc* spp.; *Lactobacillus* spp.; *Micrococcus* spp.; *Mycobacterium* spp., *Corynebacterium* spp., *Propionibacterium* spp., *Pediococcus* spp., *Peptostreptococcus* spp., *Sporolactobacillus* spp., *Brevibacterium* spp., and *Sporolactobacillus* spp.

Examples of gram negative microbes that may be sensitive to a lantibiotic of the present invention and inhibited include, but are not limited to, members of the family Enterobacteriaceae, such as *Citrobacter* spp., *Edwardsiella* spp., *Enterobacter* spp., *Erwinia* spp., *Escherichia*, such as *E. coli* (e.g., H7:O157), *Ewingella* spp., *Klebsiella*, such as *K. pneumoniae* spp., *Plesiomonas*, such as *P. shigelloides* spp., *Proteus*, such as *P. vulgaris* spp., *Providencia* spp., *Salmonella* spp., *Serratia*, such as *S. marcescens* spp., *Shigella* spp., and *Yersinia*, such as *Y.*

enterocolitica and *Y. pestis*; members of the family Vibrionaceae, such as *Vibrio alginolyticus*, *V. cholerae*, *V. parahaemolyticus*, and *V. vulnificus*; and members of the family Pseudomonadaceae, such as *Pseudomonas aeruginosa*, *P. anguilliseptica*, *P. oryzihabitans*, *P. plecoglossicida*, *P. fluorescens* and *P. syringae*. Other

5 examples of gram negative microbes that may be inhibited include, but are not limited to, *Helicobacter pylori*; *Campylobacter* spp., such as *C. jejuni*, *C. coli*, and *C. upsaliensis*; *Bacteroides* spp., such as *B. fragilis*; *Fusobacterium* spp., such as *F. necrophorum*, *F. ulcerans*, *F. russi*, and *F. varium*; *Leptospira* spp.; *Pectobacterium* spp., such as *P. carotovorum*; *Pasteurella* spp., such as *P.*

10 *multocida*, *Borrelia* spp., *Legionella* spp., *Neisseria* spp., *Fusobacterium* spp., and *Agrobacterium* spp.

Pharmaceutical and personal care applications include, for instance, methods of treating an animal to inhibit, preferably prevent microbial growth. As used herein, "treatment" and "treating" refer to the use of a composition of the present invention

15 to prevent, cure, retard, or reduce the severity of signs in a subject resulting from the presence of a microbe, and/or result in no worsening of signs over a specified period of time in an subject which has already been exposed to a microbe that can cause the signs. Treatment may be prophylactic or, alternatively, may be initiated after the exposure of an animal to a microbe. Prophylactic treatment refers to the use of a

20 composition of the present invention to inhibit, preferably prevent microbial growth, thereby preventing or reducing signs of a condition if the subject is later exposed to a microbe. Treatment that is prophylactic, for instance, initiated before a subject manifests signs of a condition, is referred to herein as treatment of a subject that is "at risk" of developing a condition. Treatment initiated after the exposure of a

25 subject to a microbe causing a condition may result in decreasing the severity of the signs, or completely removing the signs.

As used herein, the term "signs" refers to objective evidence in a subject of a condition caused by the presence of a microbe. Signs can vary depending upon the microbe. Signs of conditions caused by the presence of a microbe and the evaluation

30 of such signs are routine and known in the art. Accordingly, the present invention is also directed to methods for treating a microbial infection in an animal, and methods for treating a condition caused by a microbe. As used herein, a "microbial infection" refers to a detrimental colonization of an animal by a microbe.

The methods include administering an effective amount of the composition of the present invention to an animal having an infection and/or signs of a condition caused by a microbe, and determining whether the infection and/or signs of the condition have decreased. Conditions include, but are not limited to, wound
5 infections, halitosis, caries, systemic infections, and skin infections.

The methods may include administering a composition of the present invention to an animal. The animal may be any animal susceptible to a condition caused by a microbe including, but not limited to, a vertebrate, more preferably a mammal, or an avian. Examples of mammals include, but are not limited to, a
10 human; a member of the subfamily Bovinae, such as cattle and bison; a member of the subfamily Caprinae, such as sheep and goats; a member of the genus *Sus*, such as pigs and hogs; companion animals, such as cats and dogs; and a member of the genus *Equus*, such as horses and donkeys. Examples of birds include, but are not limited to, domesticated birds such as turkeys, chickens, ducks, and geese. Another
15 example of a vertebrate is a fish. A composition of the present invention may be delivered to an animal by methods described herein and known in the art, thereby providing an effective amount to the animal. In this aspect of the invention, an "effective amount" is an amount effective to inhibit growth of a microbe, prevent the manifestation of signs of the condition, decrease the severity of the signs of the
20 condition, and/or complete remove the signs. It is not required that any composition of the present invention completely inhibit growth of all microbes, or completely cure or eliminate all signs of a condition being treated.

Food applications include, for instance, food preservation by inhibiting microbes that spoil food. The term "food" or "food product" encompasses all edible
25 nutritive substances and compositions, including those intended for human consumption as well as consumption by, for instance, livestock. "Food" and "food product" includes unprocessed, as well as processed, e.g., cooked, nutritive substances and compositions, such as beverages. The expression "present in food" refers to portions of a food that may be resident to harmful bacteria, such as external
30 surfaces, interior surfaces, or the combination thereof.

A composition of the present invention may be used in connection with a food product that is susceptible to bacterial growth or degradation. These include, but are not limited to, dairy foods, fruits and vegetables, fruit and vegetable derived products, grains and grain derived products, meats, poultry, and seafood. Examples

of dairy foods include, but are not limited to, cheese, milk, cream, and fermented dairy foods such as yogurt. Examples of meats include, for instance, ham, beef, salami, chicken, and turkey, including whole parts or processed meat products made therefrom. Other food products include processed food products including ready to eat meals, entrees, and meats, deli salads, mayonnaise, dressings (including salad dressings), sauces and condiments, pastas, soups, edible oils, fish and fish products, egg products, beverages, aseptically packaged foods, as well as mixtures of the foregoing.

A composition of the present invention may be used by mixing with and/or applying on a blendable food product, but may be applied to a surface of solid food products by a dip, rinse, or spray, or by application to the interior of such products, e.g. by injection. The composition may be applied as a marinade, breading, seasoning rub, glaze, colorant mixture, and the like, or as an ingredient to be mixed with and incorporated into the food product. In still other aspects, the composition may be indirectly placed into contact with the food surface by applying the composition to food packaging materials, such as a casing or a film, and thereafter applying the packaging to the food surface such that the composition comes into contact with the external food surface. The optimum amount to be used will depend upon the particular food product to be treated and the method used to apply the composition to the food and/or the food surface, but can be determined by routine experimentation.

Probiotic applications of compositions of the present invention include, for instance, use of a microbe, preferably a *Bifidobacterium*, expressing a compound of the present invention, as a dietary supplement or as a food ingredient. The uses of bifidobacteria as dietary supplements is known in the art and routine. Typically, a *Bifidobacterium* expressing a compound of the present invention is administered to an animal in need thereof. The *Bifidobacterium* can be administered as a biologically pure culture, or as a mixed culture. As used herein, a "mixed" culture is one containing a *Bifidobacterium* and at least one other microbe, preferably a prokaryotic microbe, more preferably a second *Bifidobacterium*.

One method of the present invention provides inhibiting the replication of microbes in the gastrointestinal tract, preferably the large intestine, of an animal by administering to an animal a *Bifidobacterium* that expresses a compound of the present invention. The method may include measuring the presence in the

gastrointestinal tract of the microbe to be inhibited, where a decrease in the presence of the microbe in the animal after administration of the *Bifidobacterium* indicates inhibition of the replication of the microbe in the gastrointestinal tract of the animal.

5 The types of microbes whose replication can be inhibited include those present in the gastrointestinal tract of an animal when the *Bifidobacterium* is administered, and microbes that are introduced to the gastrointestinal tract after the *Bifidobacterium* is administered. Thus, a *Bifidobacterium* expressing a compound of the present invention can also be used in a method for inhibiting the establishment of a microbe in the gastrointestinal tract of an animal.

10 Another probiotic application includes methods for establishing a *Bifidobacterium* flora in an animal. Such a flora is expected to competitively inhibit the ability of other microbes to establish themselves as a flora in the gastrointestinal tract. The method includes administering to an animal a *Bifidobacterium* that expresses a compound of the present invention. The method also includes measuring
15 the presence in the gastrointestinal tract of the *Bifidobacterium* over a period of time following the administration. A *Bifidobacterium* flora is considered to be established in an animal when there is at least about 10^6 of the *Bifidobacterium* present per gram of feces. Preferably, the animal is an adolescent or adult human or an infant, including an immature, premature, or mature infant. The present method can be
20 used to establish a *Bifidobacterium* flora in a healthy human, and in humans that have had their normal intestinal flora modified by, for instance, diarrhea or by drug treatment including antibiotic therapy or chemotherapy.

The present invention is illustrated by the following examples. It is to be
25 understood that the particular examples, materials, amounts, and procedures are to be interpreted broadly in accordance with the scope and spirit of the invention as set forth herein.

EXAMPLES

30

Example 1

Bifidobacteria are frequently proposed to be associated with good intestinal health primarily because of their overriding dominance in the feces of breast fed infants. However, clinical feeding studies with exogenous bifidobacteria show they

don't remain in the intestine, suggesting they may lose competitive fitness when grown outside the gut.

To further the understanding of genetic attenuation that may be occurring in bifidobacteria cultures, we obtained the complete genome sequence of an intestinal isolate, *Bifidobacterium longum* DJO10A that was minimally cultured in the laboratory (less than 20 generations), and compared it to that of a culture collection strain, *B. longum* NCC2705. This comparison revealed colinear genomes that exhibited high sequence identity, except for the presence of 17 unique DNA regions in strain DJO10A and six in strain NCC2705. While the majority of these unique regions encoded proteins of diverse function, eight from the DJO10A genome and one from NCC2705, encoded gene clusters predicted to be involved in diverse traits pertinent to the human intestinal environment, specifically oligosaccharide and polyol utilization, arsenic resistance and lantibiotic production. Seven of these unique regions were suggested by a base deviation index analysis to have been precisely deleted from strain NCC2705 and this is substantiated by a DNA remnant from within one of the regions still remaining in the genome of NCC2705 at the same locus. This targeted loss of genomic regions was experimentally validated when growth of the intestinal *B. longum* in the laboratory for 1,000 generations resulted in two large deletions, one in a lantibiotic encoding region, analogous to a predicted deletion event for NCC2705. A simulated fecal growth study showed a significant reduced competitive ability of this deletion strain against *Clostridium difficile* and *E. coli*. The deleted region was between two IS30 elements which were experimentally demonstrated to be hyperactive within the genome. The other deleted region bordered a novel class of mobile elements, termed mobile integrase cassettes (MIC) substantiating the likely role of these elements in genome deletion events.

Deletion of genomic regions, often facilitated by mobile elements, allows bifidobacteria to adapt to fermentation environments in a very rapid manner (2 genome deletions per 1,000 generations) and the concomitant loss of possible competitive abilities in the gut.

Results and Discussion

Genomic sequencing of a minimally cultured *B. longum* strain. The power of comparative genomics can provide insights into features that are important for a species to survive and compete in its habitat. The genome sequence of the culture

collection strain, *B. longum* NCC2705 (Schell et al., 2002, *Proc Natl Acad Sci USA*, 99:14422-14427, is available and the ability to compare this genome with one from a strain that was deliberately minimally cultured in vitro may provide new insights to features that may be important for this prominent species from the human large

5 gut. Newly isolated and minimally cultured *B. longum* strains were characterized and strain DJO10A was selected based on its prominent ability to bacteriostatically inhibit other bacteria through the production of siderophores (O'Sullivan, US Patent No. 6,746,672), a characteristic that appeared attenuated in all culture collection and commercial bifidobacteria analyzed. It was therefore selected for genomic

10 sequencing as an isolate that likely had minimal attenuation from its origin in the intestine. The complete genome sequence of this strain was deciphered and consisted of one circular chromosome and two cryptic plasmids, pDOJH10L and pDOJH10S that were described previously (Lee and O'Sullivan, 2006, *Appl Environ Microbiol* 2006, 72:527-535).

15 General characteristics of the *B. longum* DJO10A genome. The chromosome of *B. longum* DJO10A contained 2,375,792 bp, with 60.15% G+C content and 1,990 encoded genes containing four rRNA operons, 58 tRNAs, 6 insertion sequence (IS) families as well as one prophage (Table 1). Its genomic characteristics were analogous to strain NCC2705, except it contained an extra tRNA_Ser: GCT encoded

20 on its prophage (Ventura et al, 2005, *Appl Environ Microbiol* 2005, 71:8692-8705). Codon usage analysis showed that this tRNA is the most frequently used tRNA_Ser in the prophage, while it is not the most used tRNA_Ser for the *B. longum* DJO10A genome (Table 2), pointing to an evolutionary selective pressure for its presence on the prophage. While both genomes contained tRNA's for every amino acid, the

25 corresponding genes for aminoacyl-tRNA synthetases for both asparagine and glutamine are missing, suggesting a reliance on alternative pathways for translation with these amino acids, similar to many other bacteria (Skouloubris et al.2003, *Proc Natl Acad Sci USA* 2003, 100:11297-11302, Min et al., 2002, *Proc Natl Acad Sci USA* 2002, 99:2678-2683). Both these alternative pathways involve gatABC, which

30 is present in both genomes as well as *gltX* and *aspS* involved in the glutamine and asparagine alternative translation pathways respectively, substantiating this proposed translation route. Interestingly, the *B. longum* genome contains novel mobile integrase cassettes (MIC) consisting of three different contiguous integrases flanked by an inverted repeat and a palindrome structure sandwiched by two IS3-type IS

elements (Fig. 1). Analysis of the genome of *B. longum* NCC2705 revealed three analogous MIC elements, located in a non-linear fashion relative to strain DJO10A indicating these elements are indeed mobile (Fig. 9). Interestingly, analysis of the genome sequences of another Bifidobacterium species, *B. adolescentis* (GeneBank
 5 AP009256), as well as other intestinal bacteria, *Bacteroides* (AE015928), *Lactobacillus* (CP000033), and *E. coli* (U00096), did not reveal MIC elements, suggesting these structures may be unique to a subset of closely related bifidobacteria.

10 Table 1. Overall characteristics of the genomes of *B. longum* strains DJO10A and NCC2705.

	DJO10A	NCC2705
Size of chromosome (bp)	2,375,792	2,256,640
Overall G+C %	60.15	60.12
Number of plasmids	2 (10 and 3.6 kb)	1 (3.6 kb)
Genes		
Total genes	1990	1727
Average gene length (bp)	1031	1115
Gene density (genes/kb)	0.838	0.765
Gene coding percentage (%)	86.4	85.3
Gene G+C %	61.13	60.86
Unique Sequences		
Strain-specific unique genes	269	117
Number of unique regions ^a	17	6
Number of genes in unique regions	218	84
Prophage	1	1
Number of genes in prophage region	57	19
RNAs and Repeat Sequences		
rRNA operons	4	4
tRNAs	58	57
Tandem repeats	22	23
Mobile Elements ^b		
Mobile integrase cassette (MIC)	4	3
IS3 family	13	14
IS21 family	10	7
IS30 family	9	5
IS256 family	4	7
ISL3 family	7	12
IS200/605 family	1	1

^a, refers to unique regions that encode functional or hypothetical genes in DNA regions > 3 kb, ^b, includes fragmented elements

Table 2. Comparison of serine codon usage between chromosomal and prophage genes in strain DJO10A.

Amino acid	Codon	Non-prophage genes		Prophage genes	
		Number	Frequency	Number	Frequency
Serine	UCU	2416	0.35	20	0.18
	UCC^a	16802	2.45	169	1.53
	UCA	2277	0.33	33	0.30
	UCG	9031	1.32	97	0.88
	AGU	1837	0.27	19	0.17
	AGC^b	8769	1.28	324	2.94

^a, bold indicates the most frequent codon; ^b, AGC is compatible to the extra tRNA_{Ser} in the prophage genome.

5

Organization of the origin and terminus of replication. An *oriC* and *terC* were found in identical locations in the genome of strain DJO10A and the updated genome sequence of strain NCC2705 (Fig. 9). These regions are extremely highly conserved in both genomes (> 99.9% identity) and consist of three *oriC* clusters and a *terC*, which is consistent with the predicted replication regions from other bacterial genomes (Mackiewicz et al., 2004, *Nucleic Acids Res* 2004, 32:3781-3791). However, the location of the observed *oriC* region in both genomes is slightly different from the predicted location based on genome asymmetry, a feature that has previously been seen in the *Helicobacter pylori* 26695 genome (Mackiewicz et al., 2004, *Nucleic Acids Res* 2004, 32:3781-3791, Zawilak et al., 2001, *Nucleic Acids Res* 2001, 29:2251-2259). As well as the multiple *oriC* clusters, there are 7 different types of DnaA boxes, consistent with the majority of sequenced genomes and are proposed to be involved in controlling initiation of chromosome replication (Mackiewicz et al., 2004, *Nucleic Acids Res* 2004, 32:3781-3791).

20 Restriction and modification (R-M) systems. The protective role that R-M systems impart on bacteria has been compared to the immune system of higher organisms (Price and Bickle, 1986, *Microbiol Sci* 1986, 3:296-299). The presence of these systems in numerous bacteria demonstrates their important role for bacterial survival in nature. Both of the *B. longum* genomes encode type I and two type II R-M systems that are highly conserved (Fig. 10). They also contain an Mrr system that is predicted to restrict methylated DNA (usually HhaII or PstI methylated DNA) that is 100% conserved between both strains (Fig. 10A). The clustering of Mrr with the type I R-M system is similar to *E. coli* K12 (GenBank U00096). The low identity (40%) between the HsdS proteins in the two strains likely reflects the independent

25

evolution of this type I R-M system in these strains following their evolutionary divergence, as these systems evolve by changing their specificity components (HsdS) to enable it to recognize different sequences. This is substantiated by the existence of an *hsdS* gene that was inactivated by an IS256 insertion event and both parts of this disrupted gene exhibit much higher conservation, suggesting the insertion event occurred before their evolutionary divergence (Fig. 10A). Upstream from this locus in strain DJO10A there is another restriction gene, McrA (restricts DNA methylated by HpaII or SssI), that is not present in NCC2705. The conserved type II R-M systems in both strains are isoschizomers of Sau3AI and EcoRII which restrict DNA at very frequently occurring sites (Fig. 10B and 10C). This, together with the range of restriction systems present, may be a factor in limiting the incursion of foreign DNA into these bacteria thus explaining the very low electroporation frequencies reported for bifidobacteria to date.

Unique genome regions in the *B. longum* strains. Alignment of the genome sequence of *B. longum* DJO10A with that of strain NCC2705 illustrates that they are highly conserved and collinear, except for the mobile IS and MIC elements (Fig. 9). There is also an apparent genome reduction in strain NCC2705, consistent with previous observations for microbes growing in a stable environment without horizontal gene transfer opportunities and redundant genes accumulating mutations before subsequent deletion (Nilsson et al., 2005, *Proc Natl Acad Sci USA* 2005, 102:12112-12116). There are 248 unique sequences of > 10 bp between the two genomes, with the majority of them being short and encoding few if any genes. This high number of unique sequences between the two strains was surprising given that the genomes of a clinical isolate of *Mycobacterium tuberculosis* and one that was extensively passaged for decades in the laboratory display only 86 of such regions in genomes twice the size (Fleischmann et al., 2002, *J Bacteriol* 2002, 184:5479-5490). There are 23 larger unique regions that encode functional or hypothetical genes and range in size from 3.0 to 48.6 kb, with 17 of these unique regions present in strain DJO10A encoding 219 predicted genes, and 6 unique regions in NCC2705 encoding 84 genes (Fig. 2A). These unique regions are not clustered around the *oriC* and *terC* which have previously been associated with regions of intraspecies variation (Berger et al, 2007, *J Bacteriol* 2007, 189:1311-1321, Molenaar et al., 2005, *J Bacteriol* 2005, 187:6119-6127).

One unique region in each genome corresponds to a prophage. The prophage in strain NCC2705, which is truncated, appears to be a longtime resident of the genome as it does not correspond with a Base Deviation Index (BDI) peak (Fig. 2A), as this analysis predicts recent horizontal gene transfer (HGT) events. This appears to have been replaced in the genome of strain DJO10A with a different prophage, that is complete and inducible (Lee and O'Sullivan, 2006, *Appl Environ Microbiol* 2006, 72:527-535) and corresponds with a significant BDI peak substantiating this recent HGT event. The other five unique regions in strain NCC2705 contain largely hypothetical genes or genes of diverse functions without any significant gene clusters. However one of these regions (unique region 4') does encode putative xylan degradation genes, which is a function predicted to be important for competition in the large intestine. As this region corresponds to a BDI peak, it suggests it may be a recent acquisition by this strain and its evolution in the large intestine would provide the selective pressure for acquiring this unique region. Of the other 16 unique regions in the strain DJO10A, eight encode significant gene clusters involved in functions predicted to be important for competition in the large intestine, specifically oligosaccharide and polyol utilization, arsenic resistance and lantibiotic production.

Oligosaccharide and polyol utilization. According to a COG functional classification (Tatusov et al., 2000, *Nucleic Acids Res* 2000, 28:33-36), the highest number of unique genes in strain DJO10A with a predicted function belongs to the carbohydrate metabolism [G] category (Table 3). Interestingly, most of the unique genes in the carbohydrate metabolism category are involved in oligosaccharide utilization, which is the major carbohydrate source available to microbes in the large intestine. In all there are 11 oligosaccharide utilization gene clusters in strain DJO10A, of which 5 are fully present and 2 are partially present in strain NCC2705 (Fig. 11). It is noteworthy that one of these clusters (Cluster 7 in Fig. 11) contains an ISL3 element in the NCC2705 genome at the precise location of the extra oligosaccharide utilization genes in strain DJO10A (Fig. 3). A BDI analysis suggested that the extra oligosaccharide gene clusters in strain DJO10A were not acquired following evolutionary divergence from strain NCC2705, as neither corresponds with a BDI peak (Fig. 2A). The majority of BDI peaks suggesting recent HGT events were the same in both genomes substantiating this analysis. This would suggest the six unique regions 6, 9, 10, 11, 15 and 17 encoding

oligosaccharide utilization genes were likely lost from strain NCC2705 during its adaptation to a fermentation environment. Further evidence for the loss of these unique regions from strain NCC2705 comes from a DNA remnant of 361 bp (98% identity) from the *ushA* gene within the unique region 1 that was left remaining at this locus in NCC2705 (Fig. 2B).

Table 3. COG categories for all genes in both *B. longum* genomes.

Function class	Individual function categories	<i>B. longum</i> DJO10A	<i>B. longum</i> NCC2705
Information	J: Translation, ribosomal structure and biogenesis	133 (2) ^a	130
	K: Transcription	129 (18)	115 (9)
Cellular processes	L: DNA replication, recombination, and repair	150 (20)	96 (1)
	D: Cell division and chromosome partitioning	22 (2)	23 (1)
	V: Defense mechanisms	48 (5)	48 (3)
	O: Posttranslational modification, protein turnover	51 (2)	50 (2)
	M: Cell envelope biogenesis, outer membrane	68 (8)	67 (10)
	P: Inorganic ion transport and metabolism	56 (2)	54
	U: Intracellular trafficking, secretion	16 (1)	14
Metabolism	N: Cell motility	3	4
	T: Signal transduction mechanisms	53 (6)	41 (1)
	F: Nucleotide transport and metabolism	70 (2)	65 (1)
	G: Carbohydrate transport and metabolism	188 (32)	167 (7)
	E: Amino acid transport and metabolism	171 (6)	153
	H: Coenzyme metabolism	44	44 (1)
	I: Lipid metabolism	41 (1)	36 (1)
	C: Energy production and conversion	50 (1)	50 (2)
	Q: Secondary metabolites transport and metabolism	6	4
	R: General function prediction only	167 (20)	161 (15)
Poorly characterized	S: Function unknown	525 (142)	405 (63)
Total		1991 (270)	1727 (117)

^a, refers to the number of genes in the unique regions of each genome as defined in the text

Polyols are not digestible by humans and their metabolism is believed to be important for bacterial competition in the human large intestine and their ingestion has been implicated in increased bifidobacteria numbers (Gostner et al., 2006, *Br J Nutr*, 95:40-50.). While strain NCC2705 does not contain genes involved in polyol metabolism, unique region 13 of strain DJO10A is dedicated to this (Fig. 4), containing genes involved in polyol recognition, transport and dehydration, and there are also some polyol metabolism genes in unique region 11. Given that unique region 13 does coincide with a BDI peak (Fig. 2A), it may represent gene acquisition by strain DJO10A. Interestingly, a similar polyol locus was found in *B. adolescentis* ATCC 15703 at a similar genome location (Fig. 4).

Arsenic resistance. Other unique regions in strain DJO10A encode gene clusters predicted to be involved in characteristics that would be important for survival and competition in the human intestine. Two operons encoding ATP-dependent arsenic resistance genes are in unique regions 5 and 7 and may be
5 important for intestinal survival as the human intestine contains low concentrations of arsenic from the diet (Ratnaike 2003, *Postgrad Med J* 2003, 79:391-396). Many intestinal bacteria such as *E. coli*, *Lactobacillus* and *Bacteroides* contain arsenic resistance genes (Fig. 5A), substantiating the competitive advantage for having this ability in the intestine. As the unique regions, 5 and 7, containing these arsenic
10 resistance genes do not correspond to BDI peaks (Fig. 2A), it suggests they may not be recently acquired by strain DJO10A, but rather lost from strain NCC2705. This theory, that adaptation to a pure-culture fermentation environment can result in loss of arsenic resistance, was further substantiated by the exceptional arsenate resistance of strain DJO10A which was 2,000% greater than a fermentation adapted
15 Bifidobacterium isolate (*B. animalis* subsp. *lactis* BB12) and 100% greater than *E. coli* K12 (Fig. 5B). This would suggest that this phenotype is a competitive advantage to intestinal isolates, but not of significance for pure-culture fermentation environments.

Lantibiotic production. The production of antimicrobial peptides, or
20 bacteriocins, is an important characteristic for bacterial competition in natural environments. One exceptionally broad spectrum class of bacteriocins is the lantibiotics, which are post-translationally modified to form lanthionine residues and to date none have been isolated from any bifidobacteria. A 10.2 kb gene cluster encoding all the genes indicative of a lantibiotic was detected in the unique region
25 12 of strain DJO10A (Fig. 6A). It was also noted that this unique region did not correspond to a BDI peak, suggesting a likely loss of this region from strain NCC2705. As lantibiotic production would be very advantageous for microbial competition in the intestine, but of no value to a microbe in pure culture, it provides the selective pressure for the loss of this unique region 12 from strain NCC2705.

30 Genome attenuation of *B. longum* in fermentation environments. Given the large number of unique DNA regions in the genome of strain DJO10A, that are predicted to have been lost from strain NCC2705, it suggests that deletion of DNA regions that are not useful may reflect the rapid adaptation of *B. longum* to a new and very different environment than exists in the human large gut. This would

suggest an elevated mutation frequency. A comparative nucleotide substitution analysis between strains DJO10A and NCC2705 shows the majority of genes are highly conserved (Fig. 12), which is to be expected with two closely related strains. However, analysis of the 52 least conserved genes (listed as ‘positive selection’ in Fig. 12) indicates that of the mutations that can be attributed to one strain or the other (frameshifts, deletions, insertions and stop mutations), 11 are from strain NCC2705 and three from strain DJO10A (Table 4). Further substantiation of an increased mutation frequency in strain NCC2705 comes from comparing genes encoding surface protein homologs between the two strains. A search of the DJO10A genome for LPXTG motifs, which is a signature of one class of cell surface anchoring proteins found four potential proteins and SignalP analysis of these proteins (BLD1468, BLD1511, BLD1637 and BLD1638) confirmed the presence of a signal sequence in each case (Fig. 13 Additional file 10). In addition, BLASTP analysis of these four proteins showed that they are very similar to other known surface proteins containing the LPXTG motif. The NCC2705 showed three of these gene homologs (BLD1468, BLD1637 and BLD1638), and had a predicted protein exhibiting 99% amino acid identity to BLD1511, but was missing the LPXTG motif due to an ISL3 insertion in the 3’ end of the gene. This further highlights the rapid evolutionary status of bifidobacteria when they are removed from the human gut into pure-culture fermentation environments.

Table 4. Substitution ratios of the 52 genes in the positive selection category.

DJO10A	NCC2705	dN:dS	Annotation	Mutation
BLD1991	BL1813	20.0673	Hypothetical protein	Frameshift (NCC2705)
BLD1477	BL1511	14.3257	Hypothetical protein	Frameshift and insertion (NCC2705)
<i>PyrH</i>	<i>pyrH</i>	12.9880	Uridylate kinase	Frameshift (NCC2705)
BLD0511	BL0781	12.7529	Hypothetical protein	Frameshift (NCC2705)
BLD0760	BL1007	10.5700	Predicted glycosyltransferase	Frameshift (NCC2705)
<i>ruvB</i>	<i>ruvB</i>	9.3214	Holliday junction resolvase, helicase subunit	
<i>citB</i>	BL1402	7.5024	Response regulator	Deletion (DJO10A)
<i>ppa</i>	<i>ppa</i>	6.2668	Inorganic pyrophosphatase	Deletion (NCC2705)
BLD0382	BL1490	6.1532	Hypothetical protein	Frameshift (NCC2705)
BLD1282	BL0491	4.2133	Hypothetical protein	
BLD0801	BL1050	4.0425	Hypothetical protein	
<i>soj</i>	BL1492	3.8930	ATPase involved in chromosome partitioning	
BLD1365	BL0571	3.7661	Predicted esterase	Deletion (NCC2705)
<i>ardA</i>	BL1465	3.6056	Antirestriction protein	
<i>cbiO</i>	BL0049	3.4507	ABC-type cobalt transport system, ATPase component	
BLD0038	BL0026	3.3177	Hypothetical protein	
BLD0376	BL1489	3.2395	Hypothetical protein	Deletion (DJO10A)
<i>dppD</i>	<i>oppD</i>	3.1112	ABC-type dipeptide/oligopeptide transport system	
BLD0144	BL0126	3.0474	Hypothetical protein	
BLD1389	BL0595	2.4181	Hypothetical protein	
BLD0109	BL0091	2.3769	Predicted aminoglycoside phosphotransferase	
<i>srtA</i>	BL0676	2.3202	Sortase (surface protein transpeptidase)	Deletion (NCC2705)
BLD0716	BL0962	1.9561	Predicted acyltransferase	
<i>metK</i>	<i>metK</i>	1.9085	S-adenosylmethionine synthetase	Frameshift (NCC2705)
BLD1580	BL1246	1.7926	Hypothetical protein	
BLD1774	BL1650	1.7408	Hypothetical protein	
<i>lytE</i>	BL1311	1.7363	LysM repeat	
<i>azlC</i>	BL1669	1.6564	Predicted branched-chain amino acid permease	
<i>glgP</i>	<i>glgP</i>	1.5354	Glucan phosphorylase	
BLD1672	BL1553	1.5276	Flagellar basal body P-ring biosynthesis protein	
BLD1399	BL0605	1.5179	Hypothetical protein	
<i>ftsW</i>	<i>ftsW</i>	1.4969	Uridylate kinase	
BLD1753	BL1627	1.4775	Predicted transcriptional regulator	
<i>nagA</i>	<i>nagA</i>	1.3702	N-acetylglucosamine-6-phosphate deacetylase	
BLD0620	BL0885	1.3620	Predicted acyltransferase	Stop mutation (DJO10A)
DAP2	BL1649	1.3497	Dipeptidyl aminopeptidase/acylaminoacyl-peptidase	
BLD1741	BL1614	1.3341	Hypothetical protein	
<i>topB</i>	<i>topB</i>	1.3066	Topoisomerase III	Annotation difference ^a (NCC2705)
<i>topA</i>	<i>topA</i>	1.2608	Topoisomerase I	
BLD0571	BL0837	1.2585	Hypothetical protein	
BLD0397	BL1498	1.2350	Hypothetical protein	
<i>wecD</i>	BL1151	1.2166	Histone acetyltransferase HPA2	
<i>pepC</i>	<i>pepC2</i>	1.1349	Aminopeptidase C	
<i>sdrC</i>	BL0094	1.1037	Predicted secreted protein containing a PDZ domain	
BLD1612	BL1278	1.0894	ABC-type transport system	
BLD1568	<i>rmlB1</i>	1.0865	dTDP-D-glucose 4,6-dehydratase	
BLD0548	BL0810	1.0694	Hypothetical protein	
BLD1455	BL0660	1.0642	Serine/Threonine protein kinase	
BLD0375	BL1488	1.0557	Hypothetical protein	Deletion (NCC2705)
BLD1772	BL1648	1.0402	Hypothetical protein	
BLD1401	BL0607	1.0338	Hypothetical protein	
BLD1983	BL1815	1.0056	Hypothetical protein	

^a, An N-terminal extension in the annotation of TopB in strain NCC2705 does not map to any other TopB sequence.

5 IS30 'jumping' in the *B. longum* genome. The dynamic environment within the *B. longum* cell in a fermentation environment is further substantiated by the intriguing observation during genome sequencing from different batches of DNA that everything was identical except for the location of some IS30 elements (Fig. 7A). This very rapid movement of an IS element within a cell has not been observed previously. The movement of IS30 within the genome occurred only at specific

10

sites, consistent with its insertion target specificity (Olasz et al., 1998, *Mol Microbiol* 1998, 28:691-704).

Adaptation of *B. longum* DJO10A to a pure-culture environment. To test the hypothesis that the switch from a variable and complex environment like the gut to a relatively stable and simplified, pure-culture one, results in hyper IS30 activity and rapid DNA loss of regions that are no longer beneficial to the new environment, strain DJO10A was grown in a typical laboratory medium without pH control for ~ 1,000 generations. Isolated colonies were then screened for seven unique regions encoding functions predicted to be useful for survival in the human gut. One of these regions (no. 12) involved in the lantibiotic production was found to be missing from 40% of the isolates (Fig. 14) substantiating this hypothesis. Analysis of this adapted strain, DJO10A-JH1, shows the deletion extended over the full lantibiotic region very similar to strain NCC2705 (Fig. 6A). It is further noted using Pulsed Field Gel Electrophoresis (PFGE) that the 39.9 kb XbaI band containing this region is missing from strain DJO10A-JH1 (Fig. 6B). The loss of the complete lantibiotic gene cluster from 40% of the culture was intriguing as the cluster also encodes the immunity gene to protect cells from the lantibiotic activity. However, analysis of lantibiotic production by strain DJO10A showed that none occurred during growth in broth media, and a solid surface such as agar, was needed for production (Fig. 6C) similar to streptin production from *Streptococcus pyogenes* (Wescombe and Tagg, 2003, *Appl Environ Microbiol* 2003, 69:2737-2747). The loss of the complete lantibiotic gene cluster renders strain DJO10A-JH1 sensitive to this pronase-E sensitive lantibiotic, which is also active against a wide spectrum of bacteria (Fig. 6C). Interestingly, the lantibiotic genome region that was deleted during the adaptation of strain DJO10A to the pure-culture environment was located between two IS30 elements, suggesting its role in genome deletion events.

It was also noted that the pure-culture adapted strain, DJO10A-JH1, was also missing a 140.7 kb XbaI band (Fig. 6B). It is intriguing that this band contains one of the four MIC elements, suggesting it may have been involved. PCR analysis of the loci immediately bordering this MIC element revealed the deletion extended between 10 and 50 kb directly downstream from this element substantiating its likely role in this deletion event. This further substantiated the rapid loss of DNA, and the prominent role of mobile elements, during evolutionary adaptation by these bacteria.

Southern hybridization of strains DJO10A and DJO10A-JH1 substantiate the IS30 'jumping' during growth in a pure-culture environment, while the positions of the other IS elements (IS21, IS256 and ISL3) remained stable (Fig. 7B). This IS30 hyperactivity in *B. longum* genomes may play an important role in deletion events and genome reduction during adaptation to new environments.

Competitive 'fitness' of the adapted *B. longum* strain DJO1A-JH1. The rapid genome reduction experienced by *B. longum* DJO10A during pure-culture growth in fermentation conditions suggested that the genomic regions lost may have been important for competition in the intestine. To test if this in vitro adaptation affected the 'fitness' of the strain, a simulated fecal competitive approach was developed. Bifidobacteria are frequently proposed to successfully compete against members of the clostridia and the enterobacteriae in the intestinal environment. A member of both of these bacterial groups was selected to test the relative competitive abilities of *B. longum* DJO10A and its in vitro adapted derivative, strain DJO10A-JH1. To ensure that the selected competitor strains were not attenuated in any way, new isolates were obtained from fresh feces by plating on selective media and speciated using a sequence analysis of the 16S rRNA gene. This resulted in the isolation of *Clostridium difficile* DJOcd1 and *E. coli* DJOec1, which were minimally cultured prior to undergoing fecal competitive experiments with the *B. longum* strains. An in vitro growth rate analysis established that *E. coli* DJOec1 had the fastest growth rate, followed by *C. difficile* DJOcd1, *B. longum* DJO10A-JH1 and *B. longum* DJO10A (Fig. 15). The noticeable increased growth rate of *B. longum* DJO10A-JH1 compared to strain DJO10A substantiated that the genome reduction of strain DJO10A-JH1 favored the in vitro growth environment.

Competitive growth experiments with both *E. coli* DJOec1 and *C. difficile* DJOcd1 in a simulated anaerobic fecal environment revealed that *B. longum* DJO10A had a significantly greater ability to compete against both *E. coli* and *C. difficile* (Fig 8). The significantly greater reduction in both these groups of bacteria by *B. longum* DJO10A supports the genome analysis hypothesis that the genome reduction exhibited in pure-culture growth may compromise a bacterium's ability to compete in its original environment.

While the simulated fecal competition studies suggested that the lantibiotic encoding genome region was important for competition in the human intestine, in vivo studies in an intestinal model would be necessary to verify this hypothesis.

Methods

Bacterial strains and growth conditions. *Bifidobacterium longum* strain DJO10A was isolated from a healthy young adult's feces (Islam, 2006, *MS thesis*. University of Minnesota, Department of Food Science and Nutrition) and *B. animalis* subsp. *lactis* BB12 was obtained from Chr. Hansen (Denmark). *B. animalis* subsp. *lactis* strains S1, S2, and S14 are genetically distinct isolates from fermented foods. *Clostridium difficile* DJOcd1 was isolated from fresh feces by plating on Clostridium difficile Selective Agar (BD Diagnostics) and speciated using a sequence analysis of its 16S rRNA gene. *E. coli* DJOec1 was obtained from fresh feces by plating on MacConkey agar (Difco) and speciated using a sequence analysis of its 16S rRNA gene. *E. coli* K12 was obtained from the American Type Culture Collection (ATCC). Bifidobacteria were cultivated at 37°C in MRS (Difco) supplemented with 0.05% L-cysteine·HCl (Sigma), Bifidobacteria Low-Iron Medium (BLIM) (Islam, 2006, *MS thesis*. University of Minnesota, Department of Food Science and Nutrition) or Bifidobacteria Fermentation Medium (BFM) (2% proteose peptone, 0.15% K₂HPO₄, 0.15% MgSO₄·7H₂O, 0.5% D-glucose) under anaerobic conditions using either the BBL Anaerobic system (BBL) or the Bactron II Anaerobic/Environmental Chamber (Sheldon Manufacturing).

Genome sequencing and assembly. Whole-genome shotgun sequencing was carried out at the US Department of Energy Joint Genome Institute (JGI). Sequences were assembled into 227 contigs using the Phred/Phrep/Consed software and the sequence coverage was 9.2-fold. Gap closure and genome sequence finishing was carried out at Fidelity Systems using ThermoFidelase-Fimer direct genome sequencing technology (Slesarev et al., 2002, *Proc Natl Acad Sci USA*, 99:4644-4649). Shotgun reads with and without IS30 elements covering A5, A6 and A7 loci were identified and assembled separately. The presence and location of long repeated sequences in genomic DNA samples were verified by direct genomic sequencing of the unique/repeat junctions. The resolution of the most complex high GC-rich repeats was achieved by sequencing of PCR products amplified with a hybrid TopoTaq DNA polymerase with increased strand displacement capacity.

Bioinformatic analysis. Annotation of all open reading frames (ORFs) was carried out using Glimmer, GeneMark, JGI annotation tools and GAMOLA (Altermann et al., 2003, *OMICS* 2003, 7:161-169), before manual checking of all

predicted genes. A comparative analysis of the two *B. longum* genomes was conducted using MUMmer3, ACT4 and ClustalX. The origin of replication and terminus were predicted using OriLoc (Frank and Lobry, 2000, *Bioinformatics* 2000, 16:560-561). Codon usage was analyzed using the General Codon Usage Analysis (GCUA) program (McInerney 1998, *Bioinformatics* 1998, 14:372-373). The base-deviation index (BDI) was performed by scaled χ^2 analysis of Artemis8. To predict gene functions, the two conserved protein domain databases of GAMOLA and InterProScan were used. COG functional categories were used for functional classification of all genes in both *B. longum* genome sequences.

10 Molecular techniques. General sequencing was conducted using a Big-Dye terminator and ABI Prism 3730xl Auto sequencer (Applied Biosystems). All PCR primers are listed in Table 5. For Southern blot analysis of unique region 12, a 646 bp probe from the lanM gene was obtained using PCR with LANT-F and LANT-R primers. Probes for IS elements were also PCR amplified. Probes were DIG-labeled
15 and hybridized with digested genomic DNA according to the manufacturer's instructions (Roche). Pulsed field gel electrophoresis of XbaI-digested *B. longum* genomes was performed using a CHEF-DR III Variable Angle Pulsed Field Electrophoresis System according to manufacturer's instructions (Bio-Rad).

Table 5. Primers used.

Target region	Primer	Sequence ^b	Size	Reference
Unique region no. ^a				
Oligo cluster				
15	OLIGO15-F OLIGO15-R	5'-GAAATCCCGAAANACNACC-3' 5'-GTTGCCGATGTTYTGNC-3'	1,793 bp	This study
6	OLIGO6-F OLIGO6-R	5'-GTATGTGATGAGCGGNAGY-3' 5'-ACCAACGGATTTYTGNGG-3'	1,840 bp	This study
9	OLIGO9-F OLIGO9-R	5'-AAGTTCACCGATGARACN-3' 5'-GTAACGCAACGARTAYTCC-3'	2,001 bp	This study
11	OLIGO11-F OLIGO11-R	5'-TCCCCAACTACATTATHGTNG-3' 5'-TCAACACCATCNGCNACC-3'	1,419 bp	This study
Arsenic cluster				
5	ARS5-F ARS5-R	5'-ATTGGCTTATTGCTNACN-3' 5'-GACTGCTTCAACTGNAGDATCC-3'	736 bp	This study
7	ARS7-F ARS7-R	5'-ACAGTCCCAATACAGTAARACN-3' 5'-CTCAAAGAAATTAGANGCNCC-3'	1,125 bp	This study
Lantibiotic				
12	LANT-F LANT-R	5'-CGCTATTACACCAGATACG -3' 5'-GGTAGACATACAGGTTCTCC -3'	646 bp	This study
Positive control (16S rRNA gene)				
	16S-F 16S-R	5'-CAGCWGCCGCGTAATWC-3' 5'-ACGGGCGGTGTGTRC-3'	890 bp	(Lane et al., 1985)
Deletion of lantibiotic operon				
Forward	F3	5'-ATCCAACGAGCAAGAACC-3'		This study
Reverse	R3	5'-GTGAAATCACCCTACCACC-3'		
Deletion of MIC III region				
Upstream	MIC-F1 MIC-R1	5'-CACATCTTGGAAGTCTTGG-3' 5'-CGTACACCGATGAATGACC-3'		This study
Downstream	MIC-F2 MIC-R2	5'-GTTCTTCGTACCTCCACC-3' 5'-AGTAATGTCCCGAATCCTCC-3'		
IS elements				
IS30	IS30-F IS30-R	5'-GACAAACCCAAGACCCTCC-3' 5'-CGTGCATATCCCCATTATCC -3'	352 bp	This study
IS21	IS21-F IS21-R	5'-GCCCCAAGTACAGTCTATCC-3' 5'-CAGAACGAACAATCGAACC-3'	681 bp	This study
IS256	IS256-F IS256-R	5'-TGTCACAGCAGATTCTACAGG-3' 5'-CAGCAATTCGTTACAGC -3'	719 bp	This study
ISL3	ISL3-F ISL3-R	5'-CGAGATCGTCGAGCTTTCC -3' 5'-ATCAGGGCGATGAGGTTGG -3'	169 bp	This study

a, as defined in the text ; b, Y (C/T), R (A/G), H (A/C/T), D (A/G/T), N (A/T/G/C), W (A/T)
SEQ ID NOs:26-55

Lane et al., 1985. Proc. Natl. Acad. Sci. USA 82: 6955-6959.

Identification of gene homologs between the two *B. longum* genomes.

Comparative nucleotide substitution analysis by Nei and Gojobori's algorithm (Nei and Gojobori, 1986, *Mol Biol Evol* 1986, 3:418-426) was used to identify gene homologs. The predicted genes of both genome sequences were compared using the
5 local BlastN program in the NCBI toolkit and 1,590 aligned genes were used for the nucleotide substitution analysis by Nei's unweighted method I (Nei and Gojobori, 1986, *Mol Biol Evol* 1986, 3:418-426). According to the ratio of dN:dS, all matched genes were categorized into three groups, highly conserved (< 0.035), normal, and positive selection (> 1).

10 Minimal inhibitory concentration of arsenic. To determine the minimal inhibitory concentration of arsenic, BLIM was supplemented with different concentrations of sodium arsenite (AsO_2^- , 1 to 100 mM) and sodium arsenate (AsO_3^- , 1 to 500 mM). Freshly grown cultures were sub-inoculated into the arsenite/arsenate media and incubated anaerobically at 37°C for 48 hours.

15 Adaptation of *B. longum* DJO10A to in vitro fermentation conditions. *B. longum* DJO10A was grown in BFM continuously up to ~ 1,000 generations. The culture was then serially diluted and plated on BFM agar. Ten colonies were randomly selected for analysis.

Mapping the deletions in strain DJO10A-JH1. To find the precise location of
20 the deletion of the lantibiotic operon in the *B. longum* DJO10A-JH1 genome, PCR was used to test for several genes within the lantibiotic operon. The two primers F3 (position 1,974,570-1,974,587 bp) and R3 (position 1,996,024-1,996,005 bp) were used to amplify a ~ 1.8 kb region spanning the deletion and sequencing located the precise borders (Figure 6). To map the position of the deletion in the 140.7 kb XbaI
25 fragment, primers MIC-F1 (position, 1,539,767-1,539,768) and MIC-R1 (position, 1,542,535-1,542,553) were used to amplify the upstream region of MIC III and primers MIC-F2 (position, 1,543,406-1,543,424) and MIC-R2 (position, 1,545,713-1,545,732) were used to amplify the downstream region.

Bioassay for lantibiotic activity. *B. longum* DJO10A was inoculated into the
30 center of an MRS agar plate and incubated anaerobically at 37°C for 2 days. After incubation, molten 0.5% top agar of the same medium containing 1% of an indicator strain was overlaid on the plates prior to incubation.

Simulated fecal competitive analysis of bifidobacteria. To access the competitive 'fitness' of the wild-type *B. longum* DJO10A compared to its in vitro

adapted derivative strain DJO10A-JH1, a simulated in vitro fecal system was developed. Triplicate experiments for each strain were used. Each experiment was conducted in 10 g sterilized feces in an anaerobic chamber, to which 0.38 g Reinforced Clostridial Medium (RCM) and 0.02 g mucin (Porcine gastric type III) was added. The two competitor bacteria were added to all tubes at calculated concentrations of 1.2×10^7 cfu/g for *E. coli* DJOec1 and 5.1×10^7 for *Clostridium difficile* DJOcd1. *B. longum* DJO10A was added to three tubes at a calculated concentration of 4.0×10^7 cfu/g and strain DJO10A-JH1 to the other three tubes at 4.4 cfu/g. Standard viable plate counts were used to calculate all bacterial concentrations. After thorough mixing in an anaerobic environment, the tubes were left at 37°C for 3 days, whereby the entire fecal samples were homogenized in 90 ml peptone water to conduct an accurate serial plate count analysis.

Example 2

Preparation of extracted *Bifidobacterium* lantibiotic

B. longum strain DJO10A was grown in MRS broth supplemented with 0.05% L-cysteine-HCl (Sigma) or Bifidobacteria Low-Iron Medium (BLIM). The broth was then used to cover the surface of an MRS agar plate supplemented with 100 mM PIPES or a BLIM agar plate supplemented with 100 mM PIPES. The plates were incubated under anaerobic conditions using either the BBL Anaerobic system (BBL) or the Bactron II Anaerobic/Environmental Chamber (Sheldon Manufacturing) at 37°C for 2 days. Twenty plates were used.

The cells and agar medium were crushed and the mixture was extracted with 95% methanol using routine methods. The extraction was allowed to proceed overnight. The final volume was placed in a SpeedVac to remove the methanol and concentrate the lantibiotic.

The remaining agar was removed by size fractionation using Millipore CentriPrep filtration for partial purification. The extract was fractionated with a Centriprep-30 (30 kDa cut-off) by centrifugation twice at 1,500 X g for 15 minutes and 10 minutes, respectively, and the filtrate (<30 kDa) transferred to a Centriprep-10 (10 kDa cut-off). This was subjected to centrifugation twice at 3,000 X g for 40 minutes and 10 minutes, respectively. The filtrate was transferred to a Centriprep-3 (3 kDa cut-off). This was subjected to centrifugation twice at 3,000 X g for 95

minutes and 35 minutes, respectively. The fractionated solution (3-10 kDa) was collected and concentrated by SpeedVac machine.

The concentrated lantibiotic was resuspended, and immediately tested using a diffusion method. Agar plates were made with MRS or BLIM and supplemented with PIPES, and a well of 5 millimeters cut into the middle of each plate. One hundred microliters of the suspended lantibiotic were placed in the well and allowed to diffuse until the liquid in the well was gone. The plates were then overlayed with the indicator strain.

The lantibiotic inhibited the growth of the indicator strains *M. leuteus*, *L. lactis*, *S. aureus*, *S. epidermidis*, *E. coli*, *S. marcescens*, and *P. vulgaris*. The lantibiotic did not inhibit *P. aeruginosa* in this assay; however, it is not possible to conclude from these data that the lantibiotic will not inhibit *P. aeruginosa*.

Example 3

Heat resistance of extracted *Bifidobacterium* lantibiotic

The lantibiotic from example 2 was placed in a boiling water bath for 10 minutes and then tested for activity using the diffusion method and *M. leuteus* as the indicator strain. The lantibiotic was active after boiling for 10 minutes.

Example 4

Proteolytic analysis of the extracted *Bifidobacterium* lantibiotic

Stock solutions of the proteolytic enzymes were prepared as follows.

Pepsin (Sigma No. P6887) was dissolved in 2 mM Tris·HCl or water at pH 2, 37°C, at a concentration of 34600 U/ml (10 mg/ml).

Pronase E (Sigma No. P5147) was dissolved in 20 mM Tris·HCl or 50 mM phosphate buffer at pH 7.5, 37°C, at a concentration of 5500 U/ml (500 mg/ml).

α-Chymotrypsin (Sigma No. C4129) was dissolved in 80 mM Tris·HCl at pH 7.8, 25°C, at a concentration of 5100 U/ml (100 mg/ml).

Proteinase K (Sigma P2308) was dissolved in 10 mM Tris·HCl at pH 7.5, 37°C, at a concentration of 6000 U/ml (200 mg/ml).

Trypsin (MP biochemical (ICN) No. 15021310), pH 7.6, 25°C, was used at the concentration 4750 U/ml (50 mg/ml).

Thermolysin (Fluka No. 88303), pH 7.2, 37°C, was used at the concentration 6000 U/ml (150 mg/ml).

One hundred microliters of the lantibiotic from example 2 was used in each assay. The proteolytic enzymes were added to separate 100 mls of the lantibiotic as follows: pepsin, 5 μ l (173 U); pronase E, 20 μ l (110 U); α -Chymotrypsin, 20 μ l (102 U); proteinase K, 20 μ l (120 U); trypsin, 20 μ l (95 U); and thermolysin, 20 μ l (120 U). Samples containing pepsin, Pronase E, Proteinase K, or Thermolysin were incubated at 37°C, and samples containing α -Chymotrypsin or Trypsin were incubated at 25°C. The incubation was for 24 hours. After digestion, the sample was neutralized to pH7.5, and all samples were incubated in boiling water for 10 minutes to remove the proteolytic enzyme activity.

Each sample was tested for activity using the diffusion method, 50 μ l of the sample containing the inactivated proteolytic enzyme, and *M. leuteus* as the indicator strain. The extracted lantibiotic was sensitive to pepsin (at pH 2) and to pronase E (at pH7.5), and insensitive to the other 4 proteolytic enzymes.

The complete disclosure of all patents, patent applications, and publications, and electronically available material (including, for instance, nucleotide sequence submissions in, e.g., GenBank and RefSeq, and amino acid sequence submissions in, e.g., SwissProt, PIR, PRF, PDB, and translations from annotated coding regions in GenBank and RefSeq) cited herein are incorporated by reference. In the event that any inconsistency exists between the disclosure of the present application and the disclosure(s) of any document incorporated herein by reference, the disclosure of the present application shall govern. The foregoing detailed description and examples have been given for clarity of understanding only. No unnecessary limitations are to be understood therefrom. The invention is not limited to the exact details shown and described, for variations obvious to one skilled in the art will be included within the invention defined by the claims.

Unless otherwise indicated, all numbers expressing quantities of components, molecular weights, and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about."

Accordingly, unless otherwise indicated to the contrary, the numerical parameters set forth in the specification and claims are approximations that may vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not as an attempt to limit the doctrine of equivalents to the scope of

the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in
5 the specific examples are reported as precisely as possible. All numerical values, however, inherently contain a range necessarily resulting from the standard deviation found in their respective testing measurements.

All headings are for the convenience of the reader and should not be used to limit the meaning of the text that follows the heading, unless so specified.

What is claimed is:

1. An isolated biologically active compound comprising an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid sequence of SEQ ID NO:21 have at least 80% identity.
2. The isolated biologically active compound of claim 1 wherein the polypeptide comprises at least one conservative substitution of the amino acid sequence of SEQ ID NO:21.
3. The isolated biologically active compound of claim 1 wherein the compound comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
4. The isolated biologically active compound of claim 3 wherein the compound inhibits growth of an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp.
5. The isolated biologically active compound of claim 1 wherein the compound inhibits growth of a Gram positive microbe *Lactobacillus* spp., *Lactococcus* spp., a *Streptococcus* spp., a *Staphylococcus* spp., or a *Bacillus* spp.
6. The isolated biologically active compound of claim 1 wherein the compound is produced by a *Bifidobacterium*.
7. A composition comprising the isolated biologically active compound of claim 1 and a food product.
8. A composition comprising the isolated biologically active compound of claim 1 and a pharmaceutically acceptable carrier.
9. An isolated polynucleotide comprising: (a) a nucleotide sequence encoding a polypeptide, wherein the amino acid sequence of the polypeptide and the amino acid sequence of SEQ ID NO:21 have at least 80% identity, or (b) the full complement of the nucleotide sequence of (a).

10. The isolated polynucleotide of claim 9 wherein the nucleotide sequence encodes a polypeptide comprising the amino acid sequence SEQ ID NO:21.
11. A polynucleotide comprising the isolated polynucleotide of claim 9 operably linked to a heterologous regulatory sequence.
12. A vector comprising the isolated polynucleotide of claim 9.
13. A cell comprising the isolated polynucleotide of claim 9.
14. An isolated lantibiotic, wherein the lantibiotic inhibits growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
15. The lantibiotic of claim 14 wherein the lantibiotic comprises an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid sequence of SEQ ID NO:21 have at least 80% identity.
16. The isolated lantibiotic of claim 15 wherein the Gram negative microbe is an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp.
17. A composition comprising a lantibiotic and a food product, wherein the lantibiotic comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
18. The composition of claim 17 wherein the lantibiotic is present on the surface of the food product.
19. The composition of claim 17 wherein the lantibiotic is present in the food product.

20. The composition of claim 17 wherein the lantibiotic comprises an amino acid sequence, wherein the amino acid sequence of the lantibiotic and the amino acid sequence of SEQ ID NO:21 have at least 80% identity.
21. The composition of claim 17 wherein the Gram negative microbe is an *E. coli*, a *Serratia proteus*, or a *Salmonella* spp.
22. A composition comprising a lantibiotic and a pharmaceutically acceptable carrier, wherein the lantibiotic comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
23. A method for producing a lantibiotic, comprising:
growing an isolated *Bifidobacterium* under conditions suitable for producing the lantibiotic, wherein the *Bifidobacterium* produces a lantibiotic.
24. The method of claim 23 wherein the growing comprises growing the *Bifidobacterium* on a surface.
25. The method of claim 23 wherein the *Bifidobacterium* is *B. longum*.
26. A lantibiotic produced by the process of claim 23.
27. A method for producing a lantibiotic, comprising:
growing a microbe comprising a polynucleotide encoding a polypeptide comprising an amino acid sequence, wherein the amino acid sequence of the polypeptide and the amino acid sequence of SEQ ID NO:21 have at least 80% identity, wherein the microbe is grown under conditions suitable for producing the polypeptide, and wherein the microbe produces the polypeptide.
28. The method of claim 27 wherein the microbe further comprises a polynucleotide encoding a polypeptide selected from SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:10, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16, or a combination thereof.

29. The method of claim 27 wherein the growing comprises growing the microbe on a surface.
30. The method of claim 27 wherein the microbe is a *Bifidobacterium* spp.
31. The method of claim 27 wherein the isolating comprises extraction with a composition comprising an alcohol.
32. The method of claim 31 wherein the alcohol is methanol.
33. A method of using a lantibiotic comprising adding the lantibiotic to a food product, wherein the lantibiotic comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
34. The method of claim 32 wherein the adding comprises applying the lantibiotic to the surface of the food product.
35. The method of claim 34 wherein the lantibiotic is applied by bringing a surface of a casing, film, or packaging material comprising the lantibiotic into contact with the food product.
36. The method of claim 33 wherein the adding comprises adding the lantibiotic to the food product.
37. The method of claim 33 wherein the lantibiotic is a food preservative.
38. A dentifrice comprising a biologically active compound comprising an amino acid sequence, wherein the amino acid sequence of the compound and the amino acid sequence of SEQ ID NO:21 have at least 80% identity, wherein the compound comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.

39. The dentifrice of claim 38 wherein the dentifrice is a mouthwash or a toothpaste.
40. A method of using a lantibiotic comprising administering a composition comprising a lantibiotic to an animal, wherein the subject has or is at risk of an infection by a microbe that is inhibited by the lantibiotic, and wherein the lantibiotic comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
41. The method of claim 38 wherein the composition is administered topically.
42. The method of claim 38 wherein the composition comprises a pharmaceutically acceptable carrier.
43. The method of claim 40 wherein the animal is a human.
44. An isolated biologically active polypeptide, wherein the amino acid sequence of the polypeptide and the amino acid sequence of SEQ ID NO:2 have at least 80% identity.
45. An isolated polynucleotide encoding the polypeptide of claim 44.
46. A composition comprising a *Bifibobacterium* that produces a lantibiotic, wherein the lantibiotic comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.
47. The composition of claim 46 wherein the *Bifidobacterium* is encapsulated.
48. The composition of claim 46 wherein the composition further comprises a food product.

49. A method comprising administering a *Bifidobacterium* to an animal in need thereof, wherein the *Bifidobacterium* will produce a lantibiotic that comprises the characteristic of inhibiting growth of a Gram negative microbe in conditions that do not damage the outer membrane of the Gram negative microbe.