

Coelenterazine Derivatives and Methods of Using Same
Cross-Reference to Related Applications

[001] This application claims the priority of U.S. Serial No. 61/409,413, filed November 2, 2010.

Field of the Invention

[002] The present invention provides compounds and methods for assaying the presence and activity of enzymes.

Background

[003] The presence and activity of enzymes can be used to determine the health or metabolic state of a cell. Enzymes can also be markers for a particular cell type since the occurrence and activity of certain enzymes is frequently characteristic of a particular cell. For instance, the activity of certain enzymes can often be used to distinguish cells of bacterial, plant or animal origin or to distinguish the identity of tissue from which the enzyme originates.

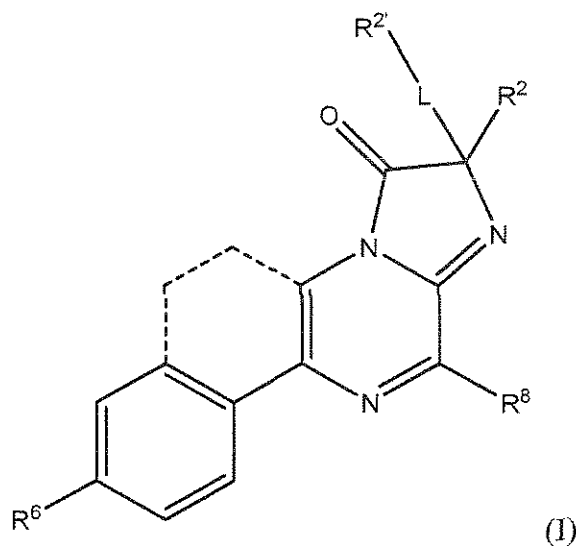
[004] Glycosidases, also known as glycoside hydrolases, catalyze the hydrolysis of the glycosidic linkage to generate two smaller sugars. They are extremely common enzymes with roles in nature including degradation of biomass such as cellulose and hemicellulose, in anti-bacterial defense strategies (e.g. lysozyme), in pathogenesis mechanisms (e.g., viral neuraminidases) and in normal cellular function (e.g. trimming mannosidases involved in N-linked glycoprotein biosynthesis). In bacteria and prokaryotes, glycosidases are found both as intracellular and extracellular enzymes that are largely involved in nutrient acquisition. One of the important occurrences of glycosidases in bacteria is the enzyme beta-galactosidase (LacZ), which is involved in the regulation of expression of the *lac* operon in *E. coli*. In higher organisms, glycosidases are found within the endoplasmic reticulum and Golgi apparatus where they are involved in processing of N-linked glycoproteins, and in the lysosome as enzymes involved in the degradation of carbohydrate structures. Deficiency in specific lysosome glycosidases can lead to a range of lysosomal storage disorders that result in development problems or death. Glycosidases are involved in the biosynthesis and degradation of glycogen in the body. Together with glycosyltransferases, glycosidases form the major catalytic machinery for the synthesis and breakage of glycosidic bonds.

[005] Dehydrogenases are a ubiquitous class of flavin-bound enzymes that catalyze the reduction of various compounds, which act as hydrogen acceptors, from the reduced form of di- and tri-phosphopyridine nucleotides, i.e., NADH, NADPH. Cellular energy metabolism is a complex process that allows cells to store energy through a series of enzymatic and chemical reactions. One essential aspect of cellular energy metabolism is the reduction-oxidation state of the cell.

The metabolic status of live cells as well as the assaying of enzyme activity and/or metabolite level can be determined by measuring the redox defining co-factor NAD(P)/NAD(P)H.

Summary

[006] In one aspect, the present invention provides a compound of formula (I):

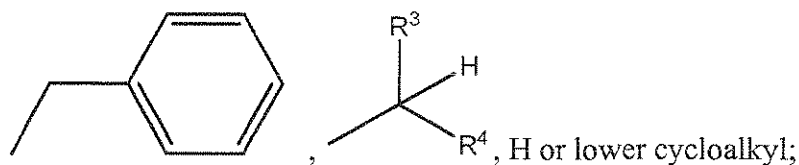


wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

$R^{2'}$ is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$;

R^6 is selected from the group consisting of $-H$, $-OH$, $-NH_2$, $-OC(O)R$ or $-OCH_2OC(O)R$;

R^8 is selected from the group consisting of



wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L is a linker;

n is 0 to 3;

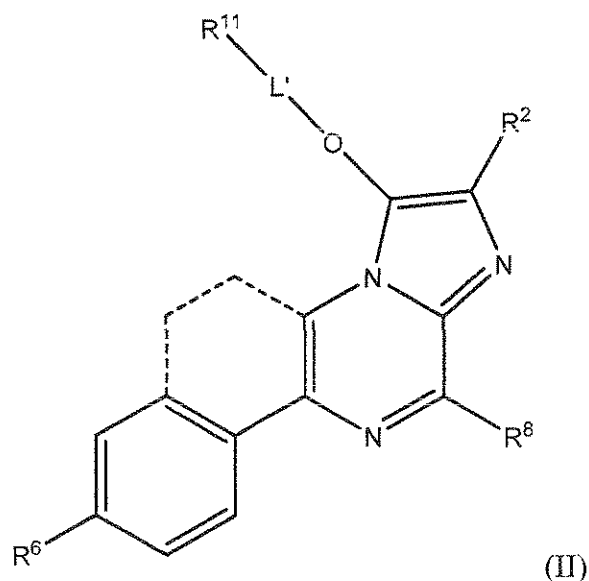
each R is independently a C_{1-7} alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is $-S-$ or $-O-$; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

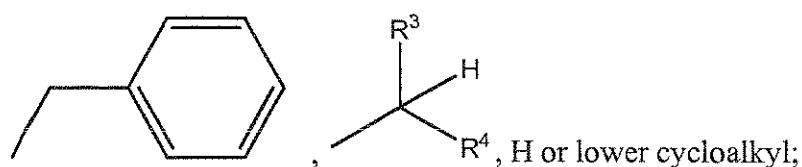
[007] In another aspect, the present invention provides a compound of formula (II):



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^6 is selected from the group consisting of $-H$, $-OH$, $-NH_2$, $-OC(O)R$ or $-OCH_2OC(O)R$;

R^8 is selected from the group consisting of



R^{11} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$;

wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

n is 0 to 3;

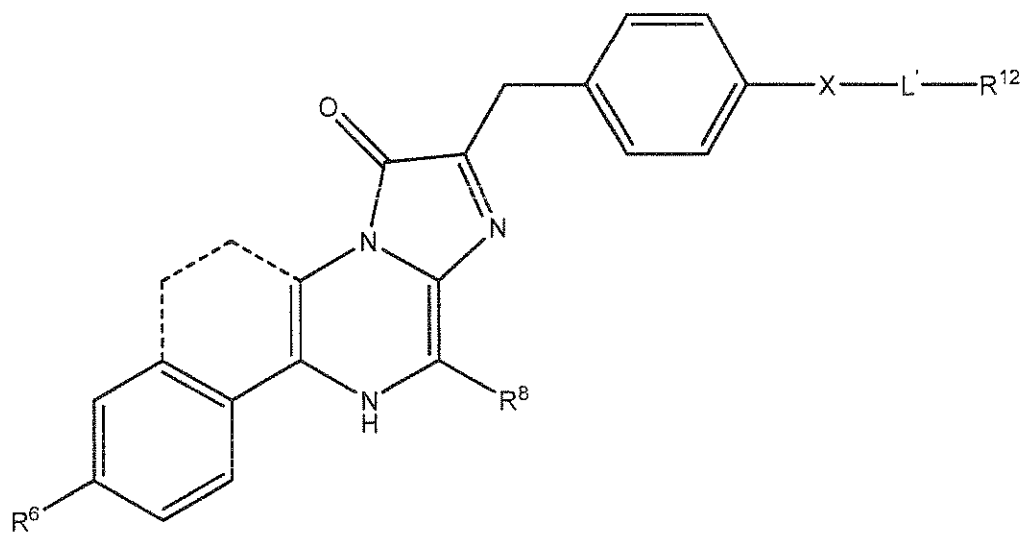
each R is independently a C_{1-7} alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is $-S-$ or $-O-$; and

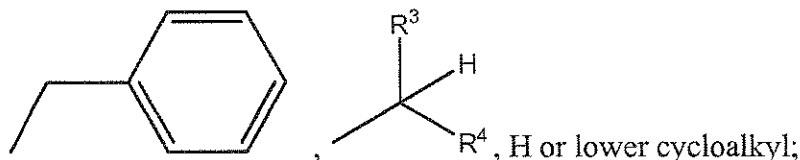
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

[008] In a further aspect, the present invention provides a compound of formula (III):



wherein R^6 is selected from the group consisting of -H, -OH, -NH₂, -OC(O)R or -OCH₂OC(O)R;

R^8 is selected from the group consisting of



R^{12} is selected from the group consisting of a peptide, an amino acid, a saccharide, -O- R^A , -OC(O)O- R^A , -N(R^B)₂, or -NHC(O)OR^A;

wherein R^3 and R^4 are both H or both C₁₋₂ alkyl;

R^A is C₁₋₄ alkyl, substituted C₁₋₄ alkyl, -CH₂- R^C or -CH₂-V- R^C ;

each R^B is independently -H or - R^A ;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

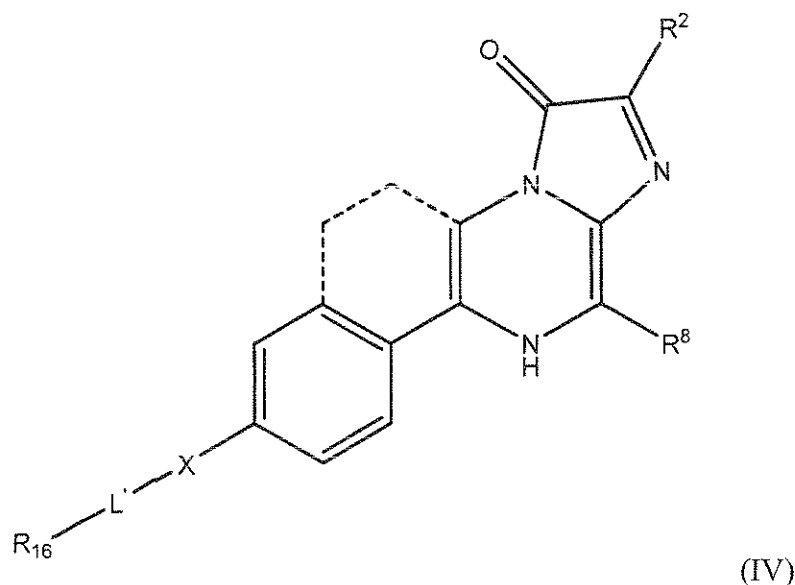
V is -S- or -O-;

each X is independently -S-, -O- or -NH-;

each R is independently C₁₋₇ alkyl; and

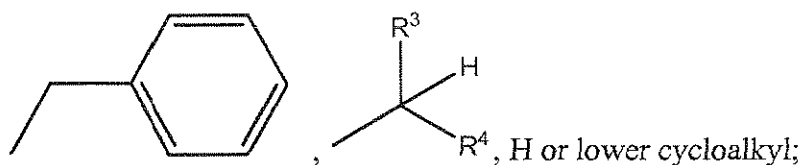
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

[009] In another aspect, the present invention provides a compound of formula (IV):



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^8 is selected from the group consisting of



R^{16} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$.

wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

n is 0 to 3;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is $-S-$ or $-O-$;

each X is independently $-S-$, $-O-$ or $-NH-$;

each R is independently C_{1-7} alkyl; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

[0010] The present invention also provides methods of using the above compounds.

Brief Description of the Drawings

[0011] FIG. 1 shows the results of biological testing of z-DEVD-coelenterazine-h.

[0012] FIG. 2 shows the results of a caspase 3 assay using an Oplophorus-derived luciferase and z-DEVD-coelenterazine-h.

[0013] FIG. 3 shows suitable linkers.

[0014] FIG. 4 shows coelenterazines which may be derivatized.

[0015] FIG. 5 shows examples of pro-coelenterazine saccharides useful in glycosidase assays.

[0016] FIG. 6 shows various peptidyl substrates for enzymes.

[0017] FIG. 7 shows suitable pro-coelenterazines for use in protease assays.

[0018] FIG. 8 shows a linear correlation between cell number and luminescence indicating a direct relationship between luminescence measured with compounds 40 and 50 and cell number.

[0019] FIG. 9 shows detection of NADH using pro-coelenterazines according to the present invention.

[0020] FIG. 10 shows other suitable pro-coelenterazine substrates according to the present invention.

Detailed Description

[0021] The present invention provides compounds and methods for assaying the presence and activity of various enzymes in a sample.

[0022] Unless expressly specified otherwise, the term "comprising" is used in the context of the present application to indicate that further members may optionally be present in addition to the members of the list introduced by "comprising". It is, however, contemplated as a specific embodiment of the present invention that the term "comprising" encompasses the possibility of no further members being present, i.e. for the purpose of this embodiment "comprising" is to be understood as having the meaning of "consisting of".

[0023] As used herein, the following terms and expressions have the indicated meanings. It will be appreciated that the compounds of the present invention contain asymmetrically substituted carbon atoms and may be isolated in optically active or racemic forms. It is well known in the art how to prepare optically active forms, such as by resolution of racemic forms or by synthesis from optically active starting materials. All chiral, diastereomeric, racemic forms and all geometric isomeric forms of a structure are part of this invention.

[0024] Specific values listed below for radicals, substituents, and ranges, are for illustration only. They do not exclude other defined values or other values within defined ranges for the radicals and substituents.

Definitions

[0025] The term "alkyl" refers to a monovalent moiety obtained by removing a hydrogen atom from a hydrocarbon compound. An alkyl group may contain from 1-30 carbon atoms, or 1-12 carbon atoms, or 1-10 carbon atoms or 1-6 carbon atoms or 1-4 carbon atoms. The alkyl group may be a straight-chain or branched and may be saturated, partially unsaturated, or fully unsaturated. An alkyl group may be optionally substituted with, for example, halo. Examples of

straight-chain alkyl groups include, but are not limited to, ethyl, n-propyl, n-butyl, and n-propyl, n-hexyl and n-heptyl. Examples of straight-chain unsaturated alkyl groups which have one or more carbon-carbon double bonds include, but are not limited to, ethenyl (vinyl, $-\text{CH}=\text{CH}_2$), 2-propenyl (allyl, $-\text{CH}-\text{CH}=\text{CH}_2$), and butenyl. Examples of unsaturated alkyl which have one or more carbon-carbon triple bonds include, but are not limited to, ethynyl and 2-propynyl (propargyl). Examples of branched alkyl groups include isopropyl, iso-butyl, sec-butyl, t-butyl and iso-pentyl.

[0026] The term “amino acid” refers to both natural and unnatural amino acids. It also includes protected natural and unnatural amino acids.

[0027] The term “aryl” refers to a monovalent moiety obtained by removing a hydrogen atom from an aromatic ring. An aryl group may have from 6-10 carbon atoms (C_{6-10} aryl). For example, the aryl group may be phenyl or naphthyl.

[0028] The term “halo” refers to a halogen, such as Cl, F, Br or I.

[0029] The term “heteroaryl” refers to a monovalent moiety obtained by removing a hydrogen atom from a heteroaromatic ring. A heteroaromatic ring may have from 5-10 ring atoms (C_{5-10} heteroaryl (The use of “C” is understood to mean the total number of ring atoms regardless of whether the atom is C, N, O, or S).). The ring atoms may be carbon, nitrogen, sulfur or oxygen. More than one heteroatom may be present in the ring. For example, the heteroaryl group may be furyl, thienyl, thiazolyl, pyrazolyl, triazolyl or tetrazolyl.

[0030] The term “linker” refers to a chain of 2 to 50 atoms that link a substrate moiety to the coelenterazine core. Linkers may include one or more heteroatoms. Linkers may also be substituted by oxo groups, amino groups, alkyl groups, halogens and nitro groups. Linkers may also contain aryl groups. Suitable linkers include those shown in FIG. 3, such as a p-aminobenzyl linker. The linkers are suitably “traceless” or “self-immolative” linkers. The term “traceless linker” or “self-immolative linker” refers to a linker wherein cleavage of the substrate moiety from the linker results in spontaneous cleavage of the linker from the coelenterazine core to release coelenterazine. Exemplary “self-immolative linkers” include those shown in FIG. 3.

[0031] The term “lower cycloalkyl” refers to a monovalent moiety obtained by removing a hydrogen atom from a hydrocarbon compound having from 3 to 6 carbon atoms. Examples of saturated lower cycloalkyl groups include, but are not limited to, groups such as cyclopropyl, cyclobutyl, cyclopentyl and cyclohexyl. Examples of unsaturated lower cycloalkyl groups which have one or more carbon-carbon double bonds include, but are not limited to, groups such as cyclopropenyl, cyclobutenyl, cyclopentenyl and cyclohexenyl.

[0032] The term “luminescent enzyme” unless specified otherwise, refers to a naturally occurring, recombinant or mutant luminescent enzyme that uses a coelenterazine as a substrate.

The luminescent enzyme, if naturally occurring, may be obtained easily by the skilled person from an organism. If the luminescent enzyme is one that occurs naturally or is a recombinant or mutant luminescent enzyme, i.e. one which retains activity in a luciferase-coelenterazine reaction of a naturally occurring luminescent enzyme, it can be obtained readily from a culture of bacteria, yeast, mammalian cells, insect cells, plant cells, or the like, transformed to express a nucleic acid encoding the luminescent enzyme. Further, the recombinant or mutant luminescent enzyme can be derived from an *in vitro* cell-free system using a nucleic acid encoding the luciferase. Suitable luminescent enzymes include luciferases derived from bioluminescent decapods, such as from the Oplophoroidea, e.g. *Oplophorus*-derived luciferases, marine organisms such as cnidarians (e.g., *Renilla* luciferase), Aristeidae, Solenoceridae, Luciferidae, Sergestidae, Pasipheidae and Thalassocarididae decapoda families, and photoproteins, such as *Aequorin*.

[0033] A "luminescent reaction mixture" contains materials that will allow the luminescent enzyme to generate a light signal, i.e., luminescence. The mixture may also contain the enzyme. The materials needed, and the particular concentrations and/or amounts, of the materials needed to generate a luminescent signal will vary depending on the luminescent enzyme used as well as the type of assay being performed. Often other materials will be added to the solution including: a buffer to maintain the reaction at the proper pH, an additive such as PRIONEX or Bovine serum albumin (BSA) to help maintain enzyme activity, reducing agents, detergents, etc.

[0034] The term "peptide" refers to a sequence of at least two amino acids. In some embodiments, a peptide may contain no more than 80 amino acids, or no more than 35 amino acids, or no more than 10 amino acids.

[0035] The term "saccharide" refers to a sugar or other carbohydrate, especially a simple sugar. It includes both the alpha- and the beta-anomers. The saccharide can be a C₆-polyhydroxy compound, typically a C₆-pentahydroxy, and often a cyclic glycal. It includes the known simple sugars and their derivatives, as well as polysaccharides with two or more monosaccharide residues. The saccharide can include protecting groups on the hydroxyl groups. The hydroxyl groups of the saccharide can be replaced with one or more acetamido, halo or amino groups. Additionally, one or more of the carbon atoms can be oxidized, for example to keto or carbonyl groups. Suitable saccharides include galactose, glucose, glucuronic acid and neurominic acid.

[0036] The term "substituted" is intended to indicate that one or more (e.g., 1, 2, 3, 4, or 5; in some embodiments 1, 2, or 3; and in other embodiments 1 or 2) hydrogens on the group indicated in the expression using "substituted" is replaced with a selection from the indicated group(s), or with a suitable group known to those of skill in the art, provided that the indicated atom's normal valency is not exceeded, and that the substitution results in a stable compound. Suitable

substituents include halo, hydroxyl, phenyl, $-\text{NH}_2$, $-\text{NHMe}$, $-\text{NMe}_2$, $-\text{SH}$, $-\text{CH}(\text{OMe})_2$, $-\text{CF}_3$, $-\text{OCH}_3$, $-\text{SCH}_3$, C_{1-4} alkyl, piperazinyl, and piperazinyl substituted with aryl.

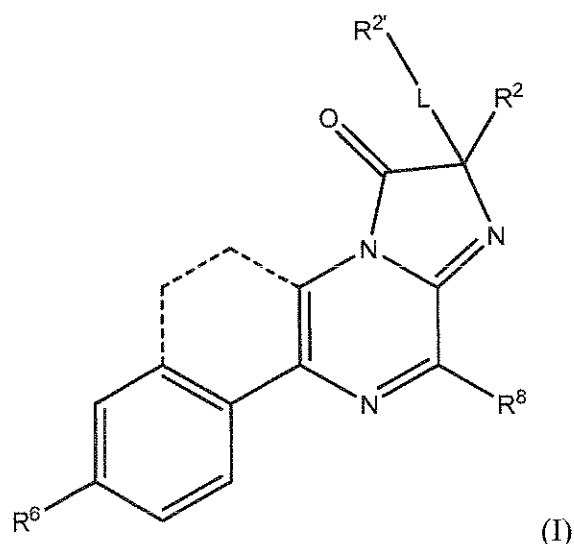
Compounds

[0037] Coelenterazines are known to luminesce when acted on by a wide variety of bioluminescent proteins, such as marine luciferases. Examples of marine luciferases include *Renilla* luciferase, Aequorin, *Gaussia* luciferase, *Oplophorus* luciferase, and *Cypridina* luciferase.

[0038] The invention provides coelenterazine derivatives which are both substrates for a non-luminescent enzyme and pro-substrates for a luminescent protein. Once acted on by the non-luminescent enzyme of interest, the derivative becomes a substrate for a luminescent protein, and thus is detectable by means known to one of ordinary skill in the art.

[0039] In some embodiments, the derivatives are compounds of Formulae I-IV shown below:

(1)

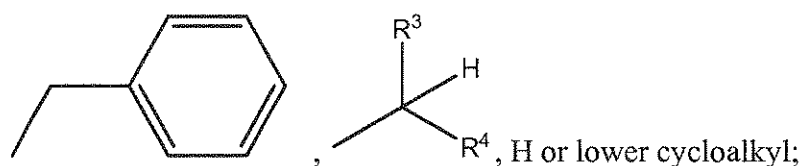


wherein R^2 is $-(\text{CH}_2)_n-\text{T}$ or C_{1-5} alkyl;

$\text{R}^{2'}$ is selected from the group consisting of a peptide, an amino acid, a saccharide, $-\text{O}-\text{R}^{\text{A}}$, $-\text{OC}(\text{O})\text{O}-\text{R}^{\text{A}}$, $-\text{N}(\text{R}^{\text{B}})_2$, or $-\text{NHC}(\text{O})\text{OR}^{\text{A}}$;

R^6 is selected from the group consisting of $-\text{H}$, $-\text{OH}$, $-\text{NH}_2$, $-\text{OC}(\text{O})\text{R}$ or $-\text{OCH}_2\text{OC}(\text{O})\text{R}$;

R^8 is selected from the group consisting of



wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^{A} is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-\text{CH}_2-\text{R}^{\text{C}}$ or $-\text{CH}_2-\text{V}-\text{R}^{\text{C}}$;

each R^{B} is independently $-\text{H}$ or $-\text{R}^{\text{A}}$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L is a linker;

n is 0 to 3;

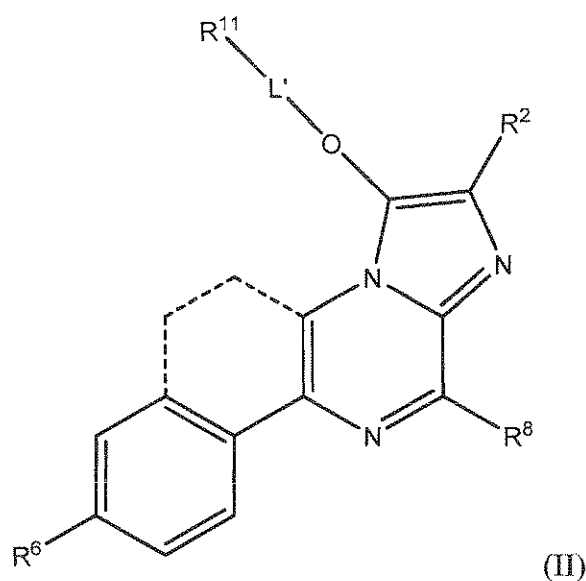
each R is independently a C_{1-7} alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is -S- or -O-; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated;

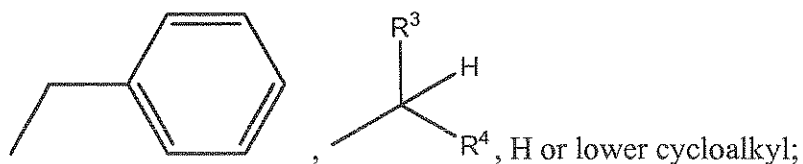
(2)



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^6 is selected from the group consisting of -H, -OH, -NH₂, -OC(O)R or -OCH₂OC(O)R;

R^8 is selected from the group consisting of



R^{11} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$;

wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently -H or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

n is 0 to 3;

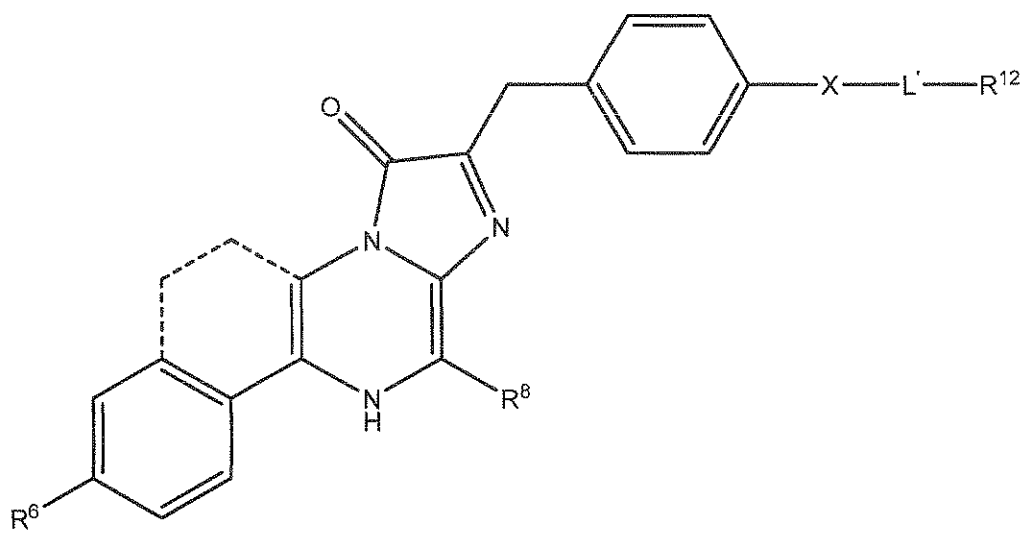
each R is independently a C₁₋₇ alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is -S- or -O-; and

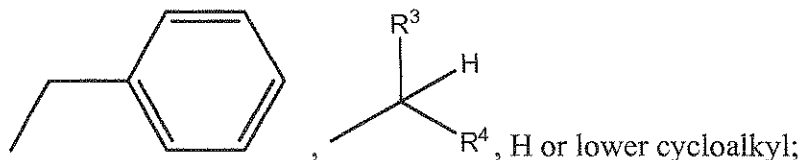
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated;

(3)



wherein R⁶ is selected from the group consisting of -H, -OH, -NH₂, -OC(O)R or -OCH₂OC(O)R;

R⁸ is selected from the group consisting of



R¹² is selected from the group consisting of a peptide, an amino acid, a saccharide, -O-R^A, -OC(O)O-R^A, -N(R^B)₂, or -NHC(O)OR^A;

wherein R³ and R⁴ are both H or both C₁₋₂ alkyl;

R^A is C₁₋₄ alkyl, substituted C₁₋₄ alkyl, -CH₂-R^C or -CH₂-V-R^C;

each R^B is independently -H or -R^A;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

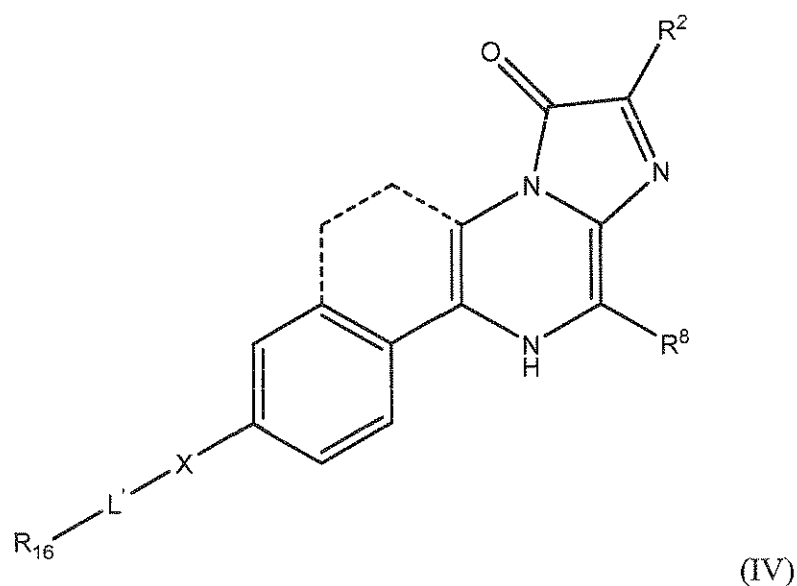
V is -S- or -O-;

each X is independently -S-, -O- or -NH-;

each R is independently C₁₋₇ alkyl; and

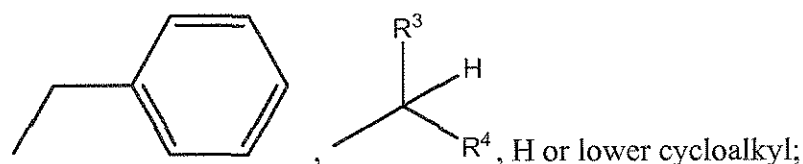
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated; or

(4)



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^8 is selected from the group consisting of



R^{16} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$.

wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a direct bond or a linker;

n is 0 to 3;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

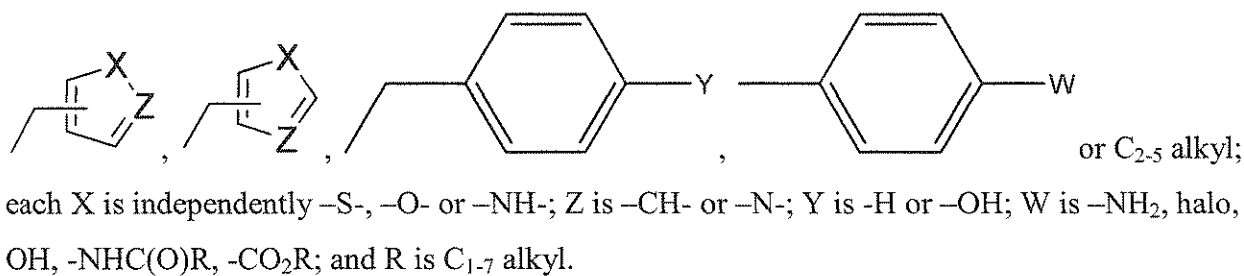
V is $-S-$ or $-O-$;

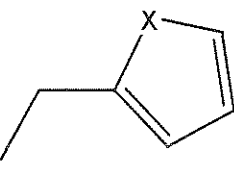
each X is independently $-S-$, $-O-$ or $-NH-$;

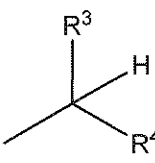
each R is independently C_{1-7} alkyl; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

[0040] In some embodiments, R^2 is



[0041] In some embodiments, R² is ; and X is O or S. In other embodiments,

R² is C₂₋₅ straight-chain alkyl. In certain embodiments, R⁸ is  lower cycloalkyl or H, wherein R³ and R⁴ are both H or C₁₋₂ alkyl. In other embodiments, R⁸ is benzyl.

[0042] In some embodiments, V is S.

[0043] Suitably the compounds of the present invention are derivatives of naturally-occurring (“native”) coelenterazines as well as analogs thereof, including coelenterazine-n, coelenterazine-f, coelenterazine-h, coelenterazine-hcp, coelenterazine-cp, coelenterazine-c, coelenterazine-e, coelenterazine-fcp, bis-deoxycoelenterazine (“coelenterazine-hh”), coelenterazine-i, coelenterazine-icp, and 2-methyl coelenterazine, in addition to those disclosed in WO 2003/040100 and U.S. Application Serial No. 12/056,073 (paragraph [0086]). Additional suitable coelenterazines that may be derivatized according to the present invention include those in FIG. 4.

[0044] In some embodiments, coelenterazine derivatives of the present invention are substrates for glycosidases. Suitable derivatives include those shown in FIG. 5.

[0045] In some embodiments, coelenterazine derivatives of the present invention are substrates for proteases such as caspase 2, caspases 3/7, caspase 6, caspase 8, caspase 9, dipeptidyl peptidase 4 (DPPIV), calpain, chymotrypsin-like proteasome, trypsin-like proteasome, caspase-like proteasome, granzyme B, cathepsins B/L/K, thrombin, trypsin, aminopeptidase, and SARS protease. Suitable peptides and amino acids, and the enzymes for which they are substrates, include those listed in FIG. 6. Additional suitable derivatives include those listed in FIG. 7.

[0046] In some embodiments, coelenterazine derivatives of the present invention are substrates for cytochrome P450 enzymes.

[0047] In some embodiments, coelenterazine derivatives of the present invention are substrates for diaphorase enzymes.

Methods of Use

[0048] The coelenterazine derivatives of the present invention may be used in assay reagents to detect the presence or activity of non-luminescent enzymes such as cytochrome P450 enzymes, proteases or glycosidases. Assays using luminescent enzymes and their substrates are well known in the art. For example, a luminescent enzyme, a luminescent reaction mixture and a coelenterazine derivative that is a substrate of the non-luminescent enzyme may be added to a sample suspected of containing the non-luminescent enzyme. If the non-luminescent enzyme is present in the sample, the non-luminescent enzyme will act on the coelenterazine derivative allowing it to be recognized by the luminescent enzyme to produce a luminescent signal. Alternatively, the non-luminescent enzyme may convert a luminogenic coelenterazine derivative to a non-luminescent form, i.e., in a loss of signal assay.

[0049] In some embodiments, the assay may utilize the chemiluminescence of coelenterazines. For example, a coelenterazine derivative that is a substrate of the non-luminescent enzyme may be added to a sample suspected of containing the non-luminescent enzyme. If the non-luminescent enzyme is present in the sample, the non-luminescent enzyme will act on the coelenterazine derivative allowing it to become chemiluminescent and detectable by well-known techniques.

[0050] The coelenterazine derivative may be added to the sample prior to or at the same time as the luminescent enzyme. In certain embodiments, the sample may be a cell. Cells may be eukaryotic cells, e.g., yeast, avian, plant, insect or mammalian cells, including but not limited to human, simian, murine, canine, bovine, equine, feline, ovine, caprine or swine cells, or prokaryotic cells, or cells from two or more different organisms, or cell lysates or supernatants thereof. The cells may have been genetically modified via recombinant techniques. In certain aspects, the cell may be in an animal, e.g., transgenic animals, or physiological fluid, e.g., blood, plasma, urine, mucous secretions or the like.

[0051] The sample may contain more than one non-luminescent enzyme to be detected. In this case, more than one luminescent enzyme may be used. In addition, more than one substrate may be used. Multiple substrates and/or luminescent enzymes may be used to detect multiple non-luminescent enzymes or other molecule(s) of interest, e.g. test compounds, at the same time, e.g. in a multiplex reaction.

[0052] The coelenterazine derivatives are also useful in *in situ* methods of analyzing cells. Methods of performing *in situ* analysis of cells using a luciferase are known in the art, see e.g. U.S. Patent No. 5,998,204. The coelenterazine derivatives are not substrates of the luminescent enzymes prior to exposure to a non-luminescent enzyme. However, upon exposure to the non-luminescent enzyme, the derivatives are converted into compounds that can be readily detected in

a light-emitting reaction in the presence of a luminescent enzyme. Thus, it may be determined where the non-luminescent enzyme is located in a cell by *in situ* imaging. This may be done by contacting a cell expressing a luminescent enzyme with a coelenterazine derivative.

[0053] Alternatively, a transgenic animal expressing a gene for a luminescent enzyme can be administered a coelenterazine derivative that is a substrate for a particular non-luminescent enzyme of interest. Imaging technology (e.g. *in vivo* biophotonic imaging) can then be used to measure luminescence at the site of luminescent enzyme expression in the living, intact animal. Thus, a transgenic animal expressing a luminescent enzyme may be administered a coelenterazine derivative that will be converted into a substrate for the luminescent enzyme in tissues where the appropriate non-luminescent enzyme of interest is expressed. If the luminescent enzyme is also expressed in that tissue, a luminescent signal will be produced and can be detected by any suitable means. Thus, test compounds, e.g. drugs, can be tested in an animal-based assay. The test compound should be administered to the animal prior to the coelenterazine derivative. Alternatively, tissue from transgenic animals can be used in tissue based assay.

[0054] In some embodiments, a non-transgenic animal may be administered a coelenterazine derivative that is a substrate for a particular non-luminescent enzyme of interest. The derivative will be converted into a substrate for a luminescent enzyme in tissues where the appropriate non-luminescent enzyme is expressed. A biological sample, e.g., blood, serum, bile, urine, feces, or tissue, can be obtained from the animal and contacted with a luminescent enzyme. The resulting signal can be detectable by any suitable means. Thus, test compounds, e.g. drugs, can be tested in an animal-based assay. The test compound should be administered to the animal prior to the coelenterazine derivative.

[0055] In some embodiments, test compounds such as candidate drugs can be screened and evaluated for their activities as, e.g., (1) substrates of a non-luciferase enzyme, (2) regulators, e.g. inhibitors, inducers or activators, of a non-luciferase enzyme, or (3) modifiers of a cellular condition (e.g., viability, increasing reactive oxygen species, or increasing reducing potential). The coelenterazine derivatives may also be used to distinguish between substrates and inhibitors of a non-luciferase enzyme. The screening may be performed either *in vitro* or *in vivo*.

[0056] In addition, for any of the bioluminogenic assays described herein, other reagents may be added to reaction mixtures, including but not limited to those that inhibit or prevent inactivation of luciferase, or otherwise extend or enhance luminescent signal.

Kits

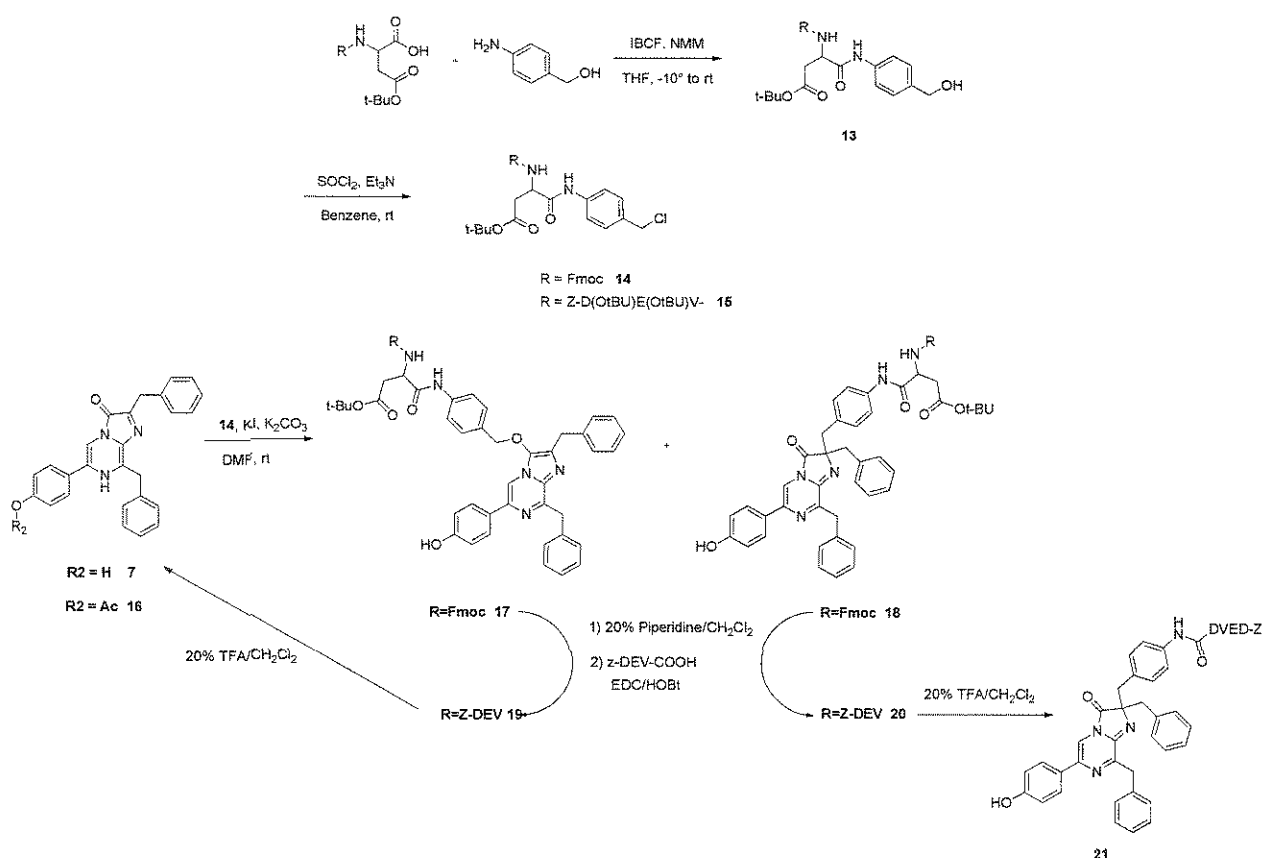
[0057] The invention also provides kits for determining the presence or activity of one or more non-luciferase enzymes. The kit may include one or more of the following: coelenterazine

derivative(s), non-luciferase enzyme(s), coelenterazine-dependent luminescent enzyme(s), and reaction buffer(s). The reaction buffers may be present in individual formulations for the non-luciferase enzyme reactions and the luminescent enzyme reactions or in a single formulation for a single step assay. The kits of the present invention may also contain inhibitors, activators and/or enhancers for the non-luciferase enzyme(s). The kits of the present invention may also contain a positive and/or negative control for the assay.

[0058]

Examples

Example 1: Synthesis of z-DEVD-coelenterazine-h (compound 21)



[0059] *tert*-Butyl 3-(((9H-fluoren-9-yl)methoxy)carbonyl)amino)-4-((4-(hydroxymethyl)phenyl)amino)-4-oxobutanoate (13): A flask was charged with Fmoc-Asp(OtBu)-OH (6.7 g, 16.28 mmol) and 100 ml of dry THF. To this solution, at ambient temperature, neat N-methylmorpholine (1.9 mL, 17.28 mmol) was added, and the solution was cooled to -20 °C. The neat isobutylchloroformate (2.2 mL, 16.96 mmol) was added via syringe and the resulting suspension was stirred for 10 minutes. The amino alcohol (2.0 g, 16.24 mmol) was added in one portion, and the reaction mixture was stirred for 10 minutes before the cold bath was removed and stirring continued for 2 hours at ambient temperature. The reaction mixture was diluted with 300 mL of ethyl acetate, and the mixture was washed sequentially with two 50 mL portions of water, 50 mL of 0.5 M HCl and two 50 mL portions of brine solution.

The organic phase was dried (MgSO₄) and concentrated under vacuum. The residue was chromatographed over silica using a heptane/ethyl acetate gradient. This gave 5.2 g (10.7 mmol) of the product as a white solid. ¹H NMR (300 MHz, dmsO) δ 10.02 (s, 1H), 7.89 (d, J = 7.5, 2H), 7.81 – 7.67 (m, 3H), 7.55 (d, J = 8.4, 2H), 7.47 – 7.27 (m, 4H), 7.24 (d, J = 8.4, 2H), 5.09 (t, J = 5.7, 1H), 4.51 (m, 1H), 4.43 (d, J = 5.7, 2H), 4.37 – 4.16 (m, 3H), 2.76 – 2.51 (m, 2H), 1.37 (s, 9H).

[0060] *tert*-Butyl 3-(((9H-fluoren-9-yl)methoxy)carbonyl)amino)-4-((4-

(chloromethyl)phenyl)amino)-4-oxobutanoate (14): A flask was charged with alcohol (13) (0.5 g, 0.97 mmol) and 15 mL of dry benzene. To this suspension, at ambient temperature, neat triethylamine was added, and, after stirring for 2 minutes, the mixture was cooled in an ice/water bath for 10 minutes. To this, neat thionyl chloride (78 μL, 1.07 mmol) was added, and, after 2 minutes, the cold bath was removed and stirring continued at ambient temperature for 3 hours. The reaction mixture was filtered through a pad of celite, and the filter cake was rinsed with 30 mL of dry benzene. The filtrate was concentrated under vacuum, and the residue was purified by column chromatography over silica using methylene chloride. This gave 457 mg (0.85 mmol) of the product as a sticky white solid. ¹H NMR (300 MHz, dmsO) δ 10.16 (s, 1H), 7.89 (d, J = 7.5, 2H), 7.79 (d, J = 8.1, 1H), 7.76 – 7.68 (m, 2H), 7.61 (d, J = 8.5, 2H), 7.44 – 7.27 (m, 6H), 4.72 (s, 2H), 4.58 – 4.44 (m, 1H), 4.33 – 4.18 (m, 3H), 2.63 (ddd, J = 6.0, 14.6, 21.8, 2H), 1.37 (s, 9H).

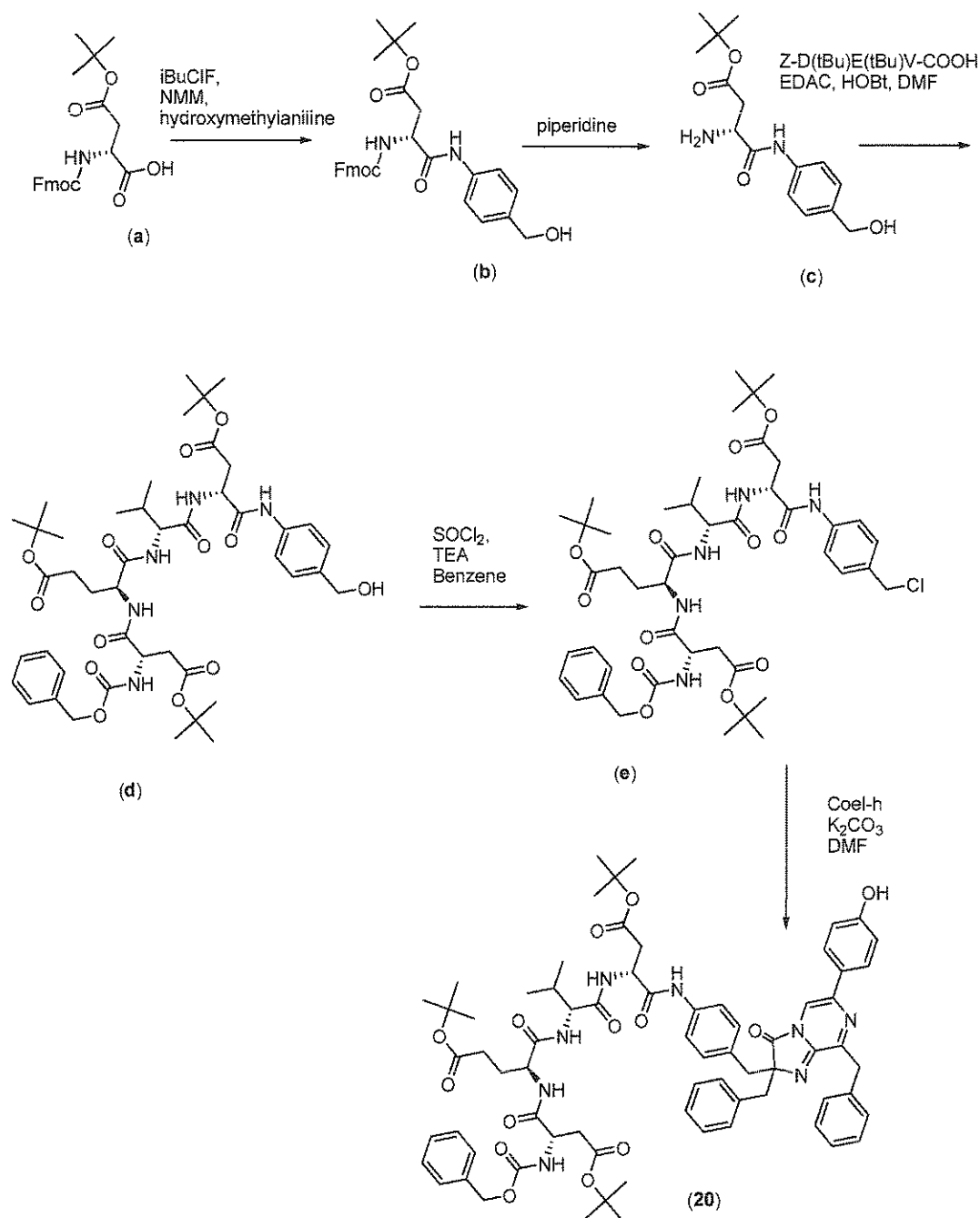
[0061] *Compounds 17 and 18*: A dry flask was charged with coelenterazine-h (7) (200 mg, .37 mmol) and 15 mL of anhydrous, deoxygenated DMF under an argon atmosphere. To this solution, at ambient temperature, potassium iodide (31 mg, 0.19 mmol) and potassium carbonate (51 mg, 0.37 mmol) were added, and the mixture was stirred for about 2 minutes. To this, compound 14 was added, and the mixture was stirred for 18 hours. The products were purified by both reverse and normal phase chromatography.

[0062] *Compounds 19 and 20*: To a solution of either compound 17 or 18 (365 mg, 0.4 mmol) in 3 mL of dichloromethane at ambient temperature, a solution of piperidine (2 mL) in 7 mL of dichloromethane was added. The reaction mixture was stirred for 30 minutes, diluted with 50 mL of toluene and concentrated under vacuum. The residue was purified by reverse phase chromatography using a gradient of 0.1% TFA/water to acetonitrile. The mixture of regioisomers (133 mg, 0.19 mmol) was dissolved in 2 mL of dry DMF, and HOBt (30 mg, 0.22 mmol) and z-DEVD-CO₂H (140 mg, 0.23 mmol) was added. To this solution, at ambient temperature, EDC (42 mg, 0.22 mmol) was added, and the reaction mixture was stirred overnight. The crude reaction mixture was diluted with 1 mL of acetonitrile and purified by reversed phase column chromatography using a gradient of 20 mM ammonium acetate to acetonitrile. This gave 54 mg of compound 19 and 69 mg of compound 20.

[0063] **Compound 21:** A crude mixture of compounds 19 and 20 were dissolved in 2 mL of dichloromethane, and, to this solution at ambient temperature, a deprotection cocktail comprised of 4 mL trifluoroacetic acid, 2 mL of dichloromethane, 0.4 mL of triisopropylsilane and 0.4 mL of thioanisole was added. The reaction mixture was stirred for 3 hours and diluted with 30 mL of diethyl ether. The suspension was centrifuged, and the solid was triturated twice with 10 mL portions of diethyl ether. The residue was dissolved in 2 mL of methanol and purified by reverse phase chromatography using a gradient of 20 mM ammonium acetate to acetonitrile. This gave 9 mg of compound 21 as an orange solid.

Example 2: Biological Testing of z-DEVD-coelenterazine-h (compound 21)

[0064] Compound 21 (50 μ M) was combined with *Renilla* luciferase (6.5 μ g/ml, Renilla-GST fusion) in 50 mM HEPES buffer pH 7.2, 2 mM DTT, and 0.5% CHAPS and incubated for 20 minutes to remove any free coelenterazine derivatives that may be substrates for *Renilla* luciferase. Purified caspase-3 enzyme (50 U/ml) or buffer control was added in a 1:1 volume ratio for final concentrations of 25 μ M Z-DEVD-coelenterazine h derivative substrate, 25U/ml caspase-3 and 3.25 μ g/ml luciferase. Luminescence was measured over 110 minutes. Over time, a one hundred-fold increase in luminescence was seen relative to control samples that did not contain caspase, indicating enzymatic release of coelenterazine and validating that the coelenterazine compounds of the present invention can be used to detect caspase enzymes (FIG. 1).

Example 3: Alternative Synthesis of z-DEVD-coelenterazine-h (compound 21)

[0065] *(R)*-*tert*-butyl 3-amino-4-(4-(hydroxymethyl)phenylamino)-4-oxobutanoate (*c*). In a 250 mL round bottom flask, *b* (6 g, 0.011 mole) was dissolved in dimethyl formamide (60 mL). Piperidine (10 mL) was added. After 4 hours, TLC showed reaction completion. Solvent was evaporated. Residue was purified by loading on Celite (15 g in 250 mL EtOAc) and eluting over silica (80 g) with DCM ramping to MeOH (10% in DCM). Combined fractions were evaporated. Yield (76%); $R_f = 0.2$ (50/50 Hept/EtOAc), ^1H NMR (300 MHz, dmsO) δ 7.56 (d, $J = 8.3$, 2H), 7.22 (d, $J = 8.3$, 2H), 5.06 (t, $J = 5.4$, 1H), 4.41 (d, $J = 4.6$, 2H), 3.61 (t, $J = 6.5$, 1H), 2.59 (dd, $J = 5.8$, 15.5, 1H), 2.41 (dd, $J = 7.2$, 15.6, 1H), 1.35 (s, 9H); m/z .

[0066] *(5S,8S,11R,14R)-tert-butyl 5-(2-tert-butoxy-2-oxoethyl)-8-(3-tert-butoxy-3-oxopropyl)-14-(4-(hydroxymethyl)phenylcarbamoyl)-11-isopropyl-3,6,9,12-tetraoxo-1-phenyl-2-oxa-4,7,10,13-tetraazahexadecan-16-oate (d)*. To a 100 mL round bottom flask, Z-D(tBu)E(tBu)V-OH (3.96 g, 6.5 mmol), c (1.6 g, 5.4 mmol), HOBt (0.915 g, 5.9 mmol), and DMF (25 mL) were added. To the stirring solution, EDAC (1.15 g, 5.9 mmol) was added. After 18 hours, the solvent was evaporated, and the residue redissolved in EtOAc (200 mL). The solution was washed with citric acid (30% - 50 mL), bicarbonate_{sat} (50 mL), water (2 x 50 mL) and brine (50 mL). The material was adsorbed on Celite (15 g) and purified over silica ramping from heptane to EtOAc. Yield (74%). ¹H NMR (300 MHz, dmso) δ 9.85 (s, 1H), 8.33 (d, J = 7.7, 1H), 7.95 (d, J = 8.1, 1H), 7.83 (d, J = 8.3, 1H), 7.59 (d, J = 8.3, 1H), 7.53 (d, J = 8.5, 2H), 7.43 – 7.26 (m, 5H), 7.21 (d, J = 8.6, 2H), 5.06 (t, J = 5.7, 1H(disappears on D2O shake)), 5.02 (d, J = 4.7, 2H), 4.70 (q, J = 7.7, 1H), 4.41 (d, J = 5.6, 2H(collapses to s on D2O shake)), 4.38 – 4.25 (m, 2H), 4.17 – 4.09 (m, 1H), 2.79 – 2.63 (m, 1H), 2.62 – 2.35 (m, 4H), 2.26 – 2.11 (m, 2H), 2.00 – 1.79 (m, 2H), 1.73 (d, J = 6.0, 1H), 1.34 (dd, J = 4.7, 7.4, 31H), 0.81 (t, J = 6.3, 6H). MS: Calcd for C₄₅H₆₅N₅O₁₃ 883.5; found 883.7.

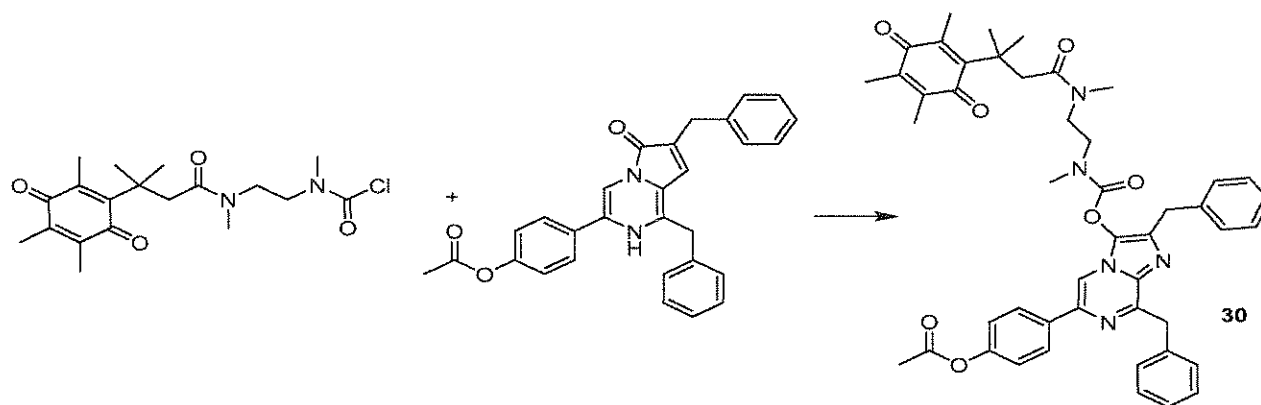
[0067] *(5S,8S,11R,14R)-tert-butyl 5-(2-tert-butoxy-2-oxoethyl)-8-(3-tert-butoxy-3-oxopropyl)-14-(4-(chloromethyl)phenylcarbamoyl)-11-isopropyl-3,6,9,12-tetraoxo-1-phenyl-2-oxa-4,7,10,13-tetraazahexadecan-16-oate (e)*. To a 100 mL RB flask, d (3.56 g, 4 mmol) with benzene (50 mL) was added. The solution was evaporated and stored overnight under high vacuum. Dry benzene (70 mL) was added to the solid along with TEA (610 μL, 4.4 mmol). The solution was chilled in an ice bath, and SOCl₂ (320 μL, 4.4 mmol) was added slowly. The solution was allowed to warm to room temperature. After 4 hours, additional TEA (241 μL) and SOCl₂ (100 μL) was added. After additional 2 hours, the reaction mixture was adsorbed onto Celite (10 g) and eluted over silica ramping from DCM to 5% MeOH in DCM. Yield (33%). ¹H NMR (300 MHz, dmso) δ 10.00 (s, 1H), 8.35 (d, J = 7.8, 1H), 7.95 (d, J = 7.8, 1H), 7.84 (d, J = 8.3, 1H), 7.67 (d, J = 8.6, 3H), 7.41 – 7.22 (m, 7H), 5.11 – 4.91 (m, 2H), 4.77 – 4.59 (m, 3H), 4.43 – 4.21 (m, 2H), 4.19 – 4.04 (m, 1H), 3.30 (s, (water)), 2.79 – 2.32 (m, 4H+DMSO), 2.26 – 2.07 (m, 2H), 2.00 – 1.79 (m, 2H), 1.77 – 1.60 (m, 1H), 1.40 – 1.24 (m, 27H), 0.81 (t, J = 6.4, 6H).

[0068] *(5S,8S,11R,14R)-tert-butyl 5-(2-tert-butoxy-2-oxoethyl)-8-(3-tert-butoxy-3-oxopropyl)-14-(4-((2,8-dibenzyl-6-(4-hydroxyphenyl)imidazo[1,2-a]pyrazin-3-ylloxy)methyl)phenylcarbamoyl)-11-isopropyl-3,6,9,12-tetraoxo-1-phenyl-2-oxa-4,7,10,13-tetraazahexadecan-16-oate (20)*. To an argon degassed vial containing coelenterazine-h (50 mg, 122 μmol) and K₂CO₃ (34 mg, 245 μmol), a degassed solution of e (133 mg, 147 μmol) in DMF (500 μL) was added. After 2 hours, the reaction was injected directly on RP-HPLC and eluted

with a ramp of 0.1% TFA (aq) to acetonitrile. The major peak was isolated and evaporated.

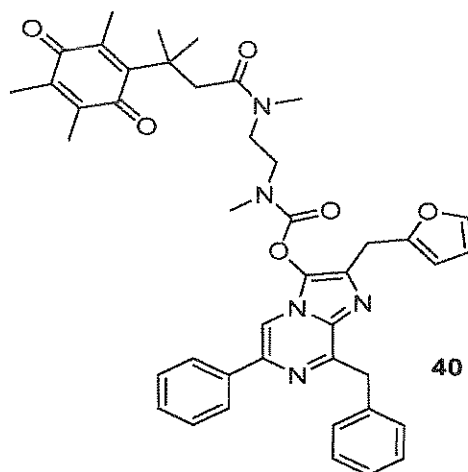
Yield (13%). UV: peaks 250, 300, and 420 nm. ^1H NMR (300 MHz, dmso) δ 9.79 (s, 1H), 8.27 (d, $J = 7.5$, 1H), 7.92 (d, $J = 8.0$, 1H), 7.85 (d, $J = 10.1$, 1H), 7.58 (d, $J = 8.3$, 1H), 7.53 (d, $J = 8.7$, 2H), 7.45 – 7.14 (m, 15H), 7.09 – 6.80 (m, 6H), 6.72 (d, $J = 8.8$, 2H), 5.13 – 4.90 (m, 2H), 4.73 – 4.53 (m, 1H), 4.22 (dd, $J = 5.0, 17.7$, 3H), 4.16 – 4.01 (m, 3H(2H after D_2O shake)), 3.25 – 3.01 (m, $J = 10.0, 16.5$, 4H), 2.76 – 2.53 (m, $J = 15.6$, 2H), 2.51 – 2.33 (m, 2H+DMSO), 2.24 – 2.04 (m, 2H), 1.99 – 1.77 (m, 2H), 1.76 – 1.61 (m, 1H), 1.40 – 1.07 (m, 27H), 0.89 – 0.62 (m, 6H). MS: Calcd for $\text{C}_{71}\text{H}_{84}\text{N}_8\text{O}_{14}$ 1272.6; found 1272.8.

Example 4. Synthesis of 30



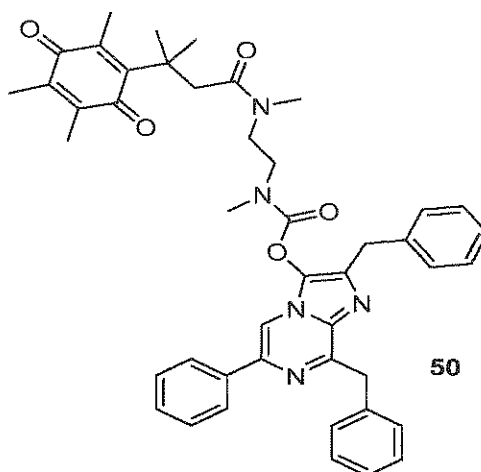
[0069] A mixture of coelenterazine acetyl ester (0.50 g, 1.14 mmol), quinone trimethyllock C2-diamine carbonyl chloride (0.436 g, 1.14 mmol), DMAP (0.139 g, 1.14 mmol) and TEA (0.115 g, 1.14 mmol) in 20 ml of methylene dichloride was stirred overnight at room temperature. The compound was purified by silica chromatography using heptane/ethyl acetate as an eluent to give a yield of 20% (0.184 g). ^1H NMR (300 MHz, CD_2Cl_2) δ 8.47 (s, 1H), 8.04 (d, 2H), 7.55 (d, 2H), 7.0-7.5 (m, 9H), 4.57 (s, 2H, CH_2), 4.16 (s, 2H, CH_2), 3.2-3.7 (m, 4H, NCH_2), 2.7-3.2 (m, 8H, $2\text{NCH}_3 + \text{CH}_2$), 2.30 (s, 3H, CH_3), 1.0-2.2 (m, 15 H, CH_3). MS (m/e): 796.5 (M^+).

Example 5. Synthesis of 40



[0070] **40** was made by employing the similar method for preparing **30** (Example 4). The compound was purified by silica chromatography using heptane/ethyl acetate as an eluent to give a yield of 60% (0.32 g). ¹H NMR (300 MHz, CD₂Cl₂) δ 8.47 (s, 1H), 8.03 (m, 2H), 7.57 (d, 2H), 7.1-7.5 (m, 7H), 6.33 (s, 1H), 6.17 (s, 1H), 4.58 (s, 2H, CH₂), 4.19 (s, 2H, CH₂), 3.3-3.7 (m, 4H, NCH₂), 2.7-3.2 (m, 8H, 2NCH₃ + CH₂), 1.0-2.2 (m, 15 H, CH₃). MS (m/e): 728.5 (M⁺). HPLC purity: 90% at 262 nm.

Example 6. Synthesis of 50



[0071] **50** was made by employing the similar method for preparing PBI 4442 (Example 20). The compound was purified by silica chromatography using heptane/ethyl acetate as an eluent to give a yield of 17% (0.15 g). ¹H NMR (300 MHz, CD₂Cl₂) δ 8.42 (s, 1H), 7.99 (m, 2H), 7.57 (d, 2H), 7.1-7.5 (m, 10H), 4.58 (s, 2H, CH₂), 4.19 (s, 2H, CH₂), 3.3-3.7 (m, 4H, NCH₂), 2.7-3.2 (m, 8H, 2NCH₃ + CH₂), 1.0-2.2 (m, 15 H, CH₃). MS (m/e): 738.5 (M⁺). HPLC purity: 95% at 262 nm.

Example 7. Measuring Metabolically Active Cells using Quinone Derivatives.

[0072] This example demonstrates the use of quinone-containing coelenterazine derivatives to measure the amount of metabolically active cells. Viable cells maintain a metabolically active state that is inevitably lost when cells are damaged. Upon entering the living cells, the quinone coelenterazine is reduced to a coelenterazine derivative that is a substrate for a coelenterazine-utilizing luciferase, e.g., *Oplophorus* or *Renilla* luciferase. Conversion of the quinone coelenterazine is proportional to the number of metabolically active cells, and therefore can be measured quantitatively by monitoring light produced by luciferase reaction.

[0073] Two-fold serial dilutions of Jurkat cells were prepared in PBS, and 50 μl per well transferred to wells in 96-well plates. Compounds **40** and **50** were diluted in PBS to make 50 μM and 100 μM stocks, respectively. 10 μl of prepared compound stocks were added to the cells, and the cells were placed into 37°C, 5% CO₂ incubator. Following 30 minutes incubation, the cells were removed from incubator, cooled at room temperature for 10 minutes, and 50 μl of *Oplophorus* luciferase detection reagent added directly to the wells. The samples were mixed,

incubated at room temperature for 20 minutes, and luminescence measured. FIG. 8 shows the linear correlation between cell number and luminescence indicating a direct relationship between luminescence and cell number.

Example 8: Caspase 3 Assay using an *Oplophorus* luciferase and Compound 21

[0074] An *Oplophorus* luciferase (OgLuc) variant, 9B8 opt, was used in a bioluminescent assay using a pro-coelenterazine substrate comprising the DEVD caspase-3 cleavage sequence. Purified caspase-3 enzyme was mixed with an *E. coli* lysate sample expressing the variant 9B8 opt, which was purified using the HALOLINK™ Resin (Promega Corp.) according to manufacturer's instructions, and diluted 10-fold in a buffer containing 100 mM MES pH 6.0, 1 mM CDTA, 150 mM KCl, 35 mM thiourea, 2 mM DTT, 0.25% TERGITOL® NP-9 (v/v), 0.025% MAZU®, with or without 23.5 μ M z-DEVD-coelenterazine-h in 100 mM HEPES pH 7.5. The caspase-3 enzyme was incubated with the lysate sample for 3 hrs at room temperature, and luminescence detected on a Turner MODULUS™ luminometer at various time points. A sample containing only bacterial lysate and a sample containing only caspase-3 were used as controls. Three replicates were used. FIG. 2 and Table 1 demonstrate that the pro-coelenterazine substrates of the present invention can be used to detect an enzyme of interest.

Table 1

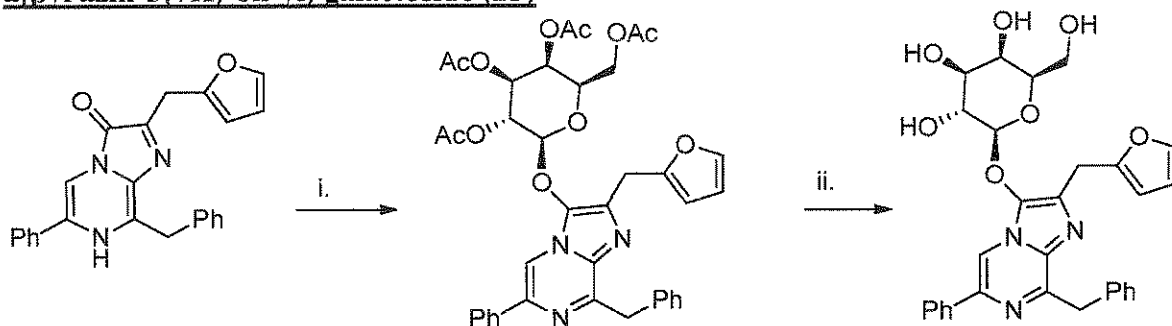
+/- caspase time (min)	- RLU	+ RLU
5.0	26,023	25,411
15.3	7,707	36,906
29.9	4,013	41,854
60.9	2,305	43,370
190.3	1,155	42,448

[0075] Another *Oplophorus* luciferase variant, L27V02 ("L27V"), was used in a bioluminescent assay using a pro-coelenterazine substrate comprising the DEVD caspase-3 cleavage sequence. Purified caspase-3 enzyme (1 mg/mL) in 100 mM MES pH 6 (50 μ L) was mixed with 227 nM of the L27V02 variant and 47 μ M PBI-3741 (z-DEVD-coelenterazine-h) in 50 μ L assay buffer (100 mM MES pH 6, 35 mM Thiourea, 0.5% TERGITOL® NP-9 (v/v), 1 mM CDTA, 2 mM DTT and 150 mM KCl). Reactions were incubated for 3 hrs at room temperature, and luminescence detected as previously described. The assay with the L27V02 variant was compared to a firefly luciferase version of the assay, Caspase 3/7 Glo (Caspase-Glo; Promega Corp.). Table 2 demonstrates that the compounds of the present invention can be used in a bioluminescent assay to detect an enzyme of interest.

Table 2

	(+) caspase	+/-	(-) caspase	+/-
L27V	11,532	93	803	25
Caspase-Glo	15,156,567	793,981	302	5

Prophetic Example 9: Synthesis of O-(8-benzyl-2-(furan-2-ylmethyl)-6-phenylimidazo[1,2-a]pyrazin-3(7H)-on-yl) galactoside (25)

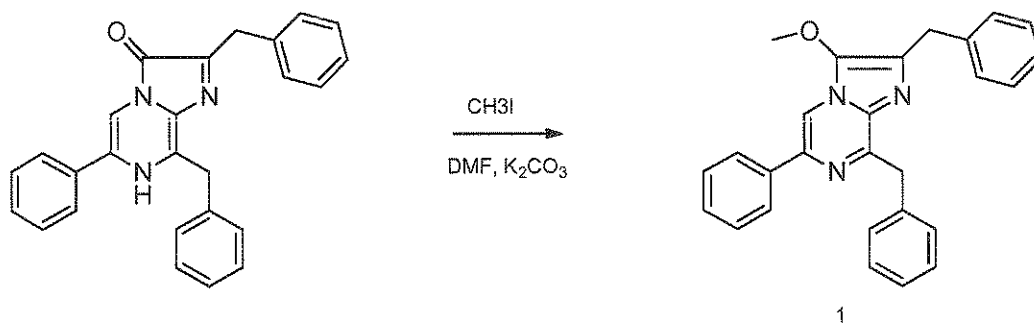


i. acetobromo alpha-D-galactose, AgOTf, TMU, DCM. ii. KOMe, THF

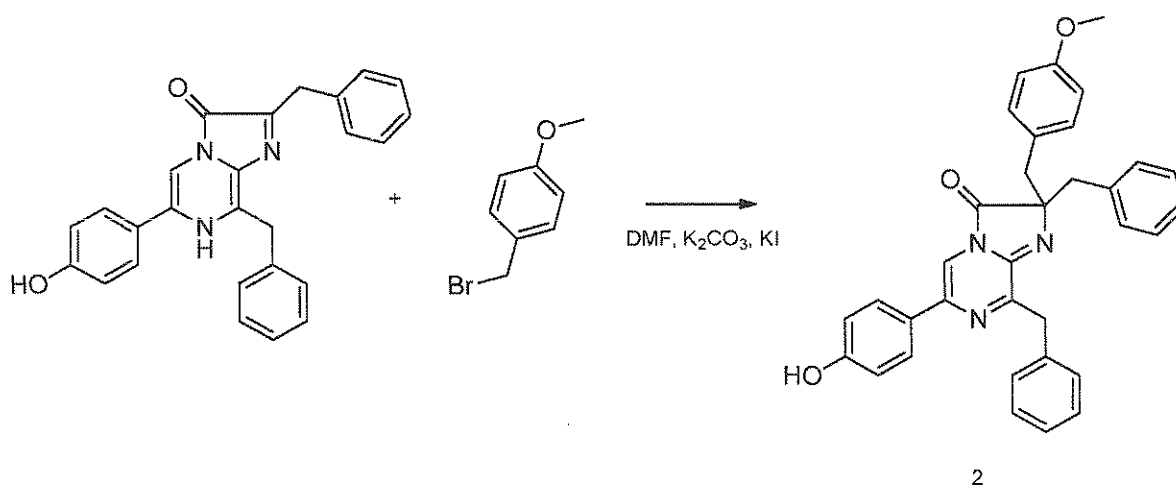
[0076] *Typical synthesis of typical beta sugar pro-coelenterazine.* (O-(8-benzyl-2-(furan-2-ylmethyl)-6-phenylimidazo[1,2-a]pyrazin-3(7H)-on-yl) 3,4,5,6-tetraacetoxy-beta-galactoside)

[0077] To a 100 mL round bottom flask, the appropriate acetobromo-alpha sugar (e.g. acetobromo alpha-D-galactose) (1.1EQ), appropriate coelenterazine (e.g. (8-benzyl-2-(furan-2-ylmethyl)-6-phenylimidazo[1,2-a]pyrazin-3(7H)-one) (1.0 EQ, 100 mg), and silvertriflate (67mg, 1EQ) is added and is degassed with argon for 30 minutes. 2 mL dichloromethane and 70μL of tetramethylurea is injected and is stirred at room temperature for 3 hours. 4mL Acetonitrile is added, and the solids are filtered. The sample is purified by injecting the supernatant on preparative 250x41mm C18 RP-HPLC column and the appropriate fractions are collected by eluting with a gradient of water to acetonitrile or other appropriate solvent. The fractions can be evaporated to yield compound.

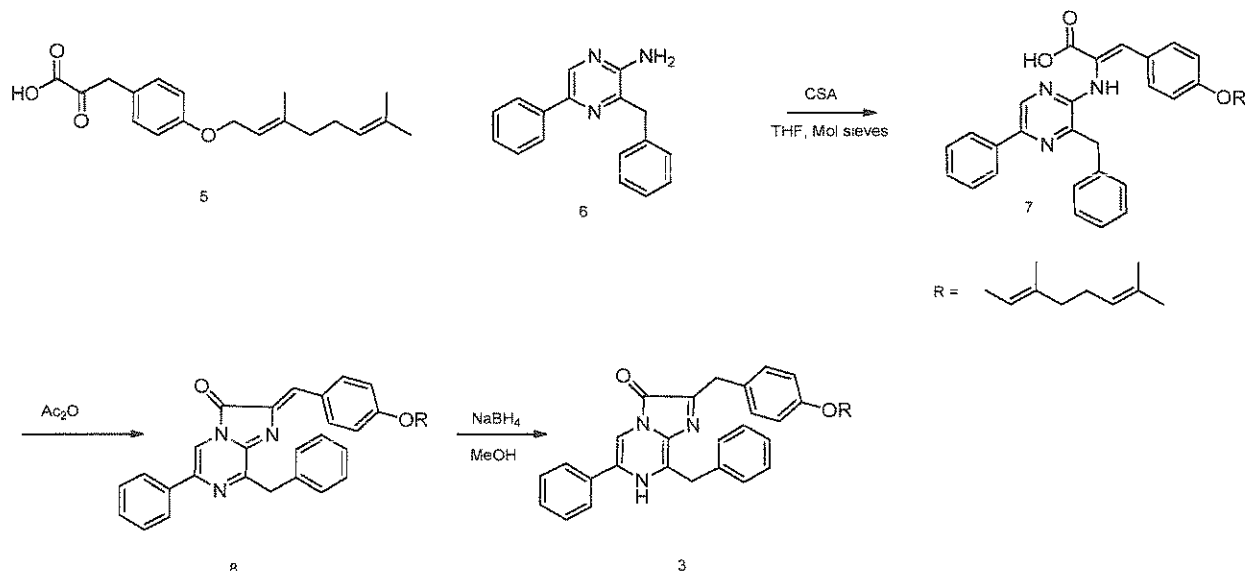
[0078] To the sample above, 1mL methanol is added and cooled to 0°C in ice bath. A solution of potassium methoxide (5.2 EQ) in methanol or THF can then be added. After 30 min, exactly 5.2 equivalents of acetic acid is added. 3mL acetonitrile can then be added, and the sample can be filtered. The sample can be purified by injecting the supernatant on preparative 250x41mm C18 RP-HPLC column, and the appropriate fractions can be collected by eluting with a gradient of water to acetonitrile or other appropriate solvent. The fractions can be evaporated to yield compound (25).

Prophetic Example 10: Synthesis of various P450 substrates

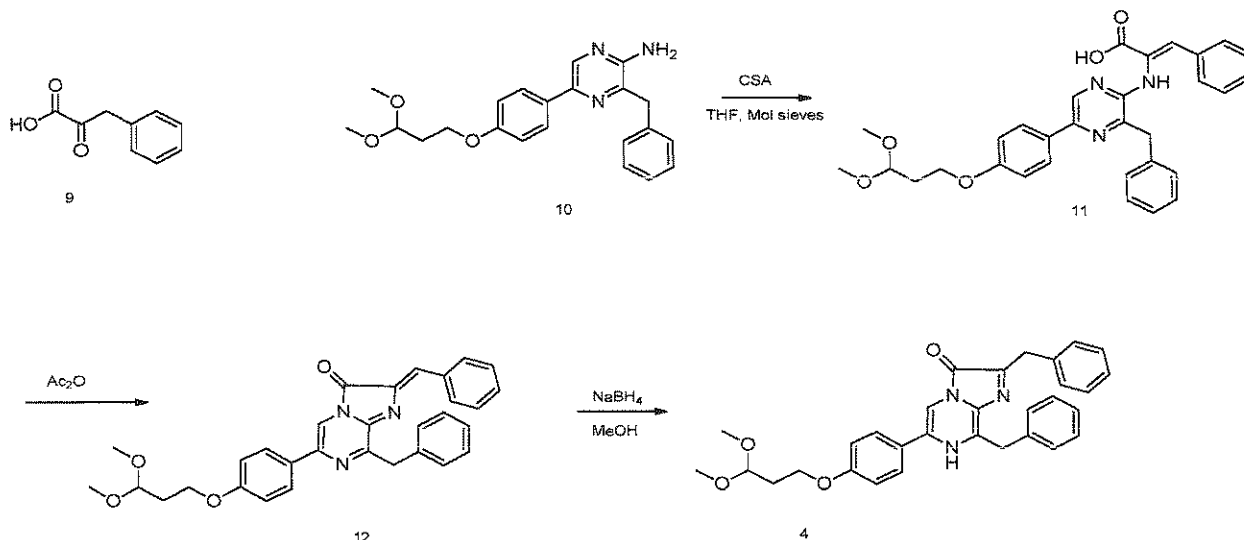
[0079] To a mixture of the coelenterazine and 1.1 equivalents of potassium carbonate in DMF, under an argon atmosphere, could be added one equivalent of methyl iodide at room temperature. Reaction progress can be monitored by thin layer chromatography. Upon completion of the reaction, the mixture can be cooled in an ice bath for several minutes and a volume of water equal to the reaction volume can be added. The resulting mixture can be extracted with a suitable organic solvent (e.g. ethyl acetate), and the extracts can be concentrated to give the crude compound 1. The material may be further purified by chromatography over silica gel.



[0080] To a mixture of the coelenterazine and 1.1 equivalents of both potassium carbonate and potassium iodide, in DMF under an argon atmosphere, one equivalent of p-methoxybenzyl bromide at room temperature could be added. Reaction progress can be monitored by thin layer chromatography, and upon completion, the reaction mixture can be cooled in an ice bath for several minutes before addition of a volume of water equal to the reaction volume. The resulting mixture can be extracted with a suitable organic solvent (e.g. ethyl acetate), and the extracts can be concentrated to give the crude compound 2. The material may be further purified by chromatography over silica gel.



[0081] A mixture of 3-benzyl-5-phenylpyrazin-2-amine (6) (1 equiv), (E)-3-(4-((3,7-dimethylocta-2,6-dien-1-yl)oxy)phenyl)-2-oxopropanoic acid (5) (1.5 equiv) and camphor sulfonic acid (1.5 equiv) in THF is heated at reflux in the presence of molecular sieves until condensation of the starting materials is complete. The reaction mixture is diluted with ethyl acetate to 3 times its volume and washed with water and brine solution. After drying over sodium sulfate, the solvent is removed under vacuum and the residue containing compound 7 is dissolved in dry DMF. The resulting solution is treated with acetic anhydride (1.5 equiv) and pyridine (1.5 equiv) at room temperature. The progress of the reaction can be monitored by TLC, and once complete, the reaction mixture is cooled in an ice bath for several minutes before addition of a volume of water equal to the reaction volume. The resulting mixture is extracted with a suitable organic solvent (e.g. ethyl acetate), and the extracts are concentrated to provide compound 8. The material is dissolved in methanol and, after cooling to approximately 0 °C, treated with sodium borohydride (5-10 equiv) in small portions until the product formation is complete. While still cold, the reaction mixture can be treated with acetic acid in an amount equivalent to the moles of hydride previously added, and the reaction mixture can be concentrated under vacuum. The residue can be triturated with water several times to give crude compound 3. This material can be purified using chromatography over silica gel.



[0082] A mixture of 3-benzyl-5-(4-(3,3-dimethoxypropoxy)phenyl)pyrazin-2-amine (**10**) (1 equiv), 2-oxo-3-phenylpropanoic acid (**9**) (1.5 equiv) and camphor sulfonic acid (CSA) (1.5 equiv) in THF is heated at reflux in the presence of molecular sieves until condensation of the starting materials is complete. The reaction mixture is diluted with ethyl acetate to 3 times its volume and washed with water and brine solution. After drying over sodium sulfate, the solvent is removed under vacuum and the residue containing **11** is dissolved in dry DMF. The resulting solution is treated with acetic anhydride (1.5 equiv) and pyridine (1.5 equiv) at room temperature. The progress of the reaction can be monitored by TLC, and once complete, the reaction mixture is cooled in an ice bath for several minutes before addition of a volume of water equal to the reaction volume. The resulting mixture is extracted with a suitable organic solvent (e.g. ethyl acetate), and the extracts are concentrated to give compound **12**. The material is dissolved in methanol and, after cooling to approximately 0° C, treated with sodium borohydride (5-10 equiv) in small portions until the formation of product is complete. While still cold, the reaction mixture is treated with acetic acid in an amount equivalent to the moles of hydride previously added, and the reaction mixture is concentrated under vacuum. The residue is triturated with water several times to give crude compound **4**. This material can be purified using chromatography over silica gel.

Example 11: Measurement of NADH

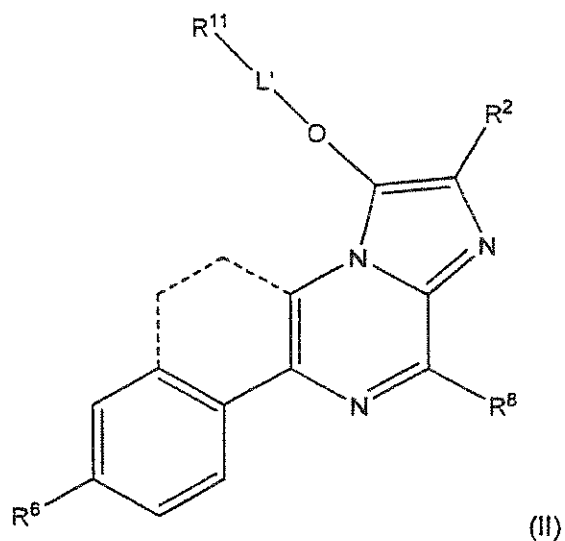
[0083] A pro-coelenterazine substrate of the present invention for detecting diaphorase was used to measure the amount of NADH present in a sample. By combining NADH, diaphorase, the pro-coelenterazine substrate, and esterases, the NADH present in the sample was detected. The pro-coelenterazine substrate utilized by the diaphorase was converted to coelenterazine. The amount of coelenterazine generated was detected by an Oplophorus luciferase variant, and the luminescence generated is proportional to the amount of NADH present in the sample.

[0084] For the assay, 10 μ L NADH (titrated from 60 μ M to 0 μ M), 10 μ L 12 U/mL diaphorase enzyme in PBS, 10 μ L 165 U esterase in PBS and 10 μ L 60 μ M PBI-4600 in PBS were

[0084] For the assay, 10 μ L NADH (titrated from 60 μ M to 0 μ M), 10 μ L 12 U/mL diaphorase enzyme in PBS, 10 μ L 165 U esterase in PBS and 10 μ L 60 μ M PBI-4600 in PBS were incubated at room temperature for 1 hour. After incubation, an Oplophorus luciferase detection reagent (100mM MES pH 6, 1mM CDTA, 150mM KCl, 35mM Thiourea, 1mM DTT, 0.5% Tergitol and 0.05% Mazu) containing an Oplophorus luciferase variant (L27V) at a 10^9 dilution was added. Luminescence was measured at 5 minutes and 1 hour (FIG. 9). The data demonstrates that the compounds of the present invention can be used to measure NADH in a sample by detecting an enzyme which utilizes NADH.

CLAIMS

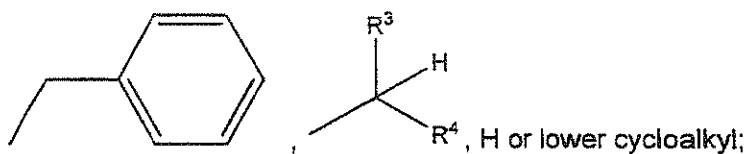
1. A compound of formula (II):



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^6 is selected from the group consisting of $-H$, $-OH$, $-NH_2$, $-OC(O)R$ or $-OCH_2OC(O)R$;

R^B is selected from the group consisting of



R^{11} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$;

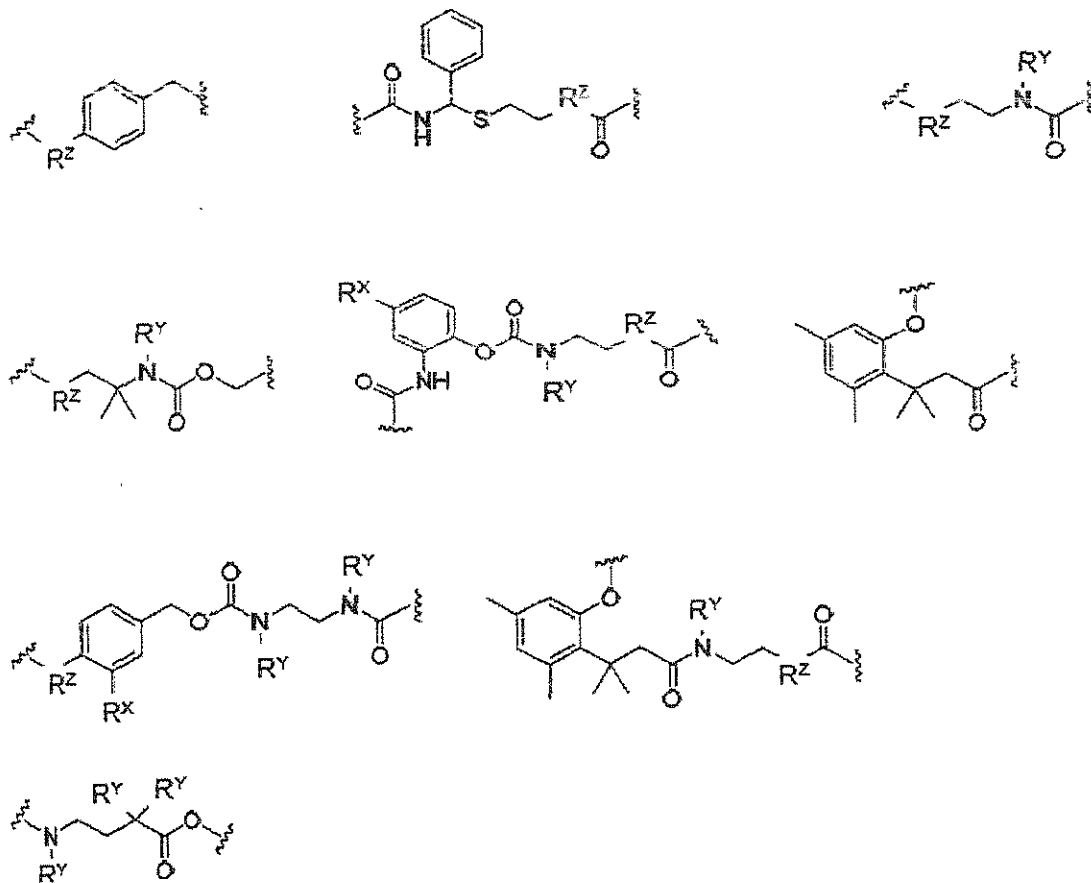
wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a linker selected from



each R^X is independently H, halogen or NO_2

each R^Y is independently H, or Me

each R^Z is independently NH, NMe, O or S

n is 0 to 3;

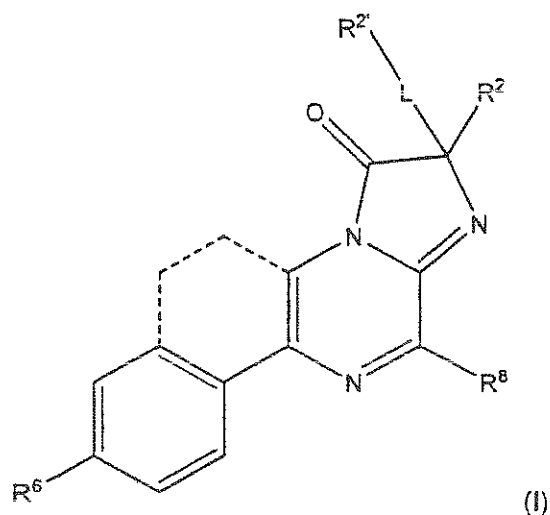
each R is independently a C_{1-7} alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is $-\text{S}-$ or $-\text{O}-$; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

2. A compound of formula (I):

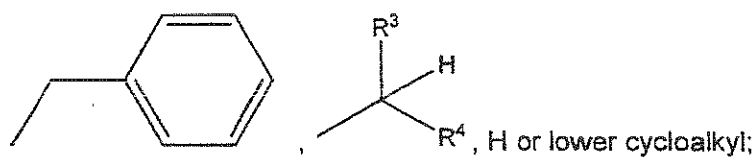


wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^2 is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$;

R^6 is selected from the group consisting of $-H$, $-OH$, $-NH_2$, $-OC(O)R$ or $-OCH_2OC(O)R$;

R^8 is selected from the group consisting of



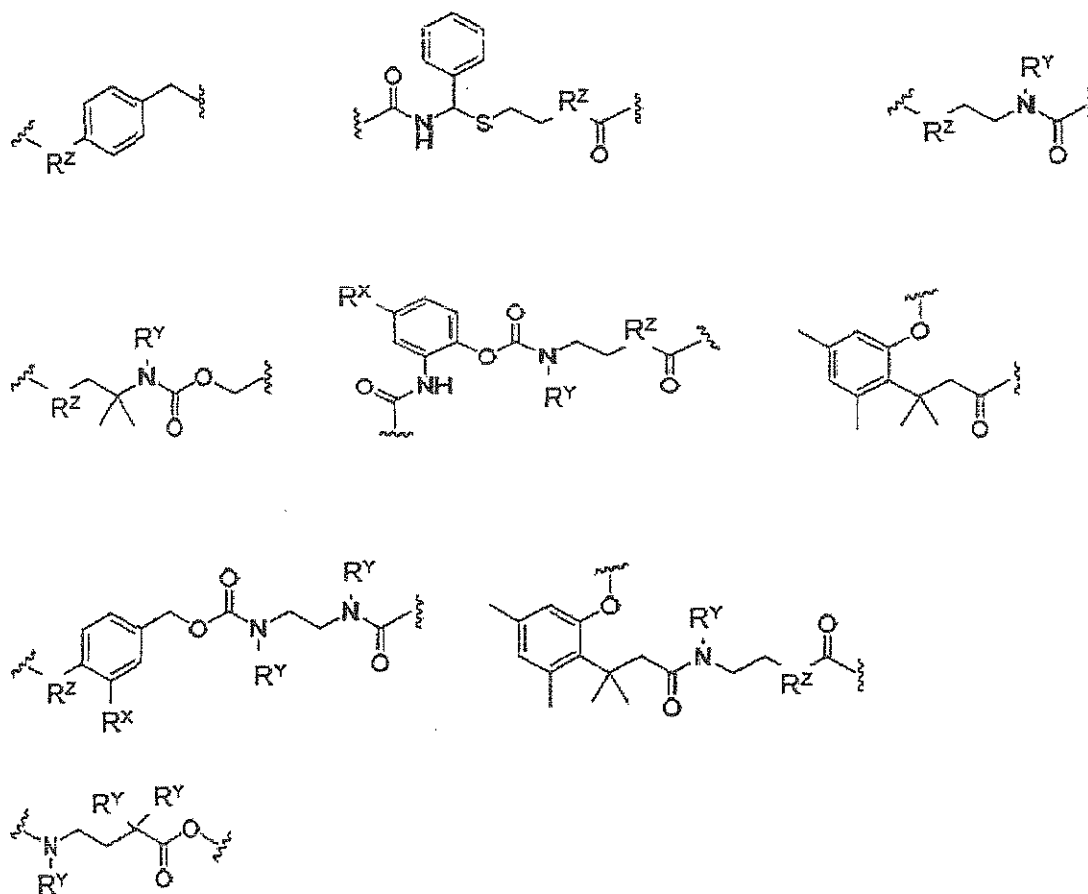
wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently $-H$ or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L is a linker selected from



each R^X is independently H, halogen or NO_2

each R^Y is independently H, or Me

each R^Z is independently NH, NMe, O or S

n is 0 to 3;

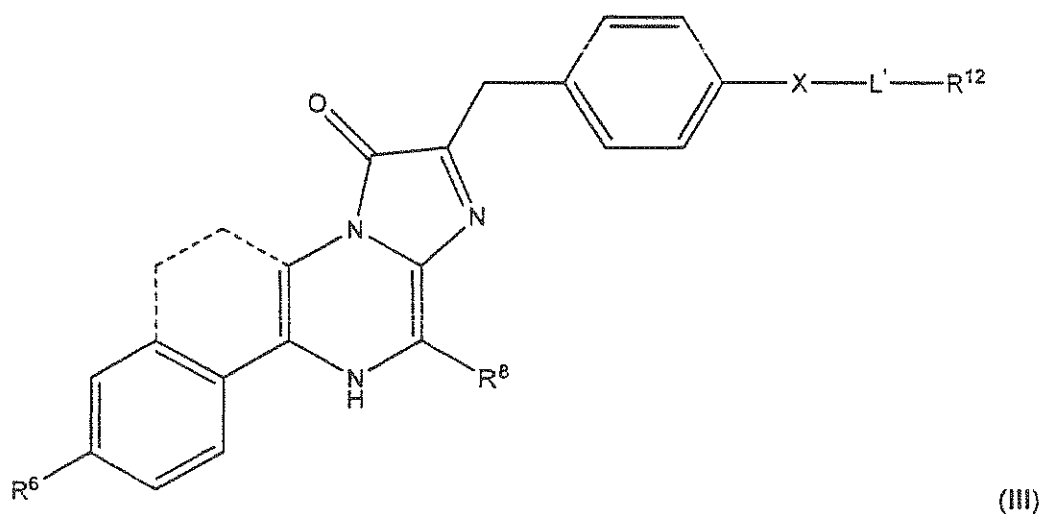
each R is independently a C_{1-7} alkyl;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

V is $-\text{S}-$ or $-\text{O}-$; and

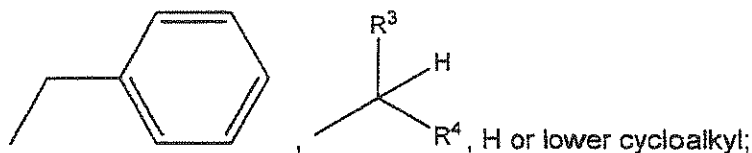
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

3. A compound of formula (III):



wherein R^6 is selected from the group consisting of -H, -OH, -NH₂, -OC(O)R or -OCH₂OC(O)R;

R^8 is selected from the group consisting of



R^{12} is selected from the group consisting of a peptide, an amino acid, a saccharide, -O- R^A , -OC(O)O- R^A , -N(R^B)₂, or -NHC(O)OR^A;

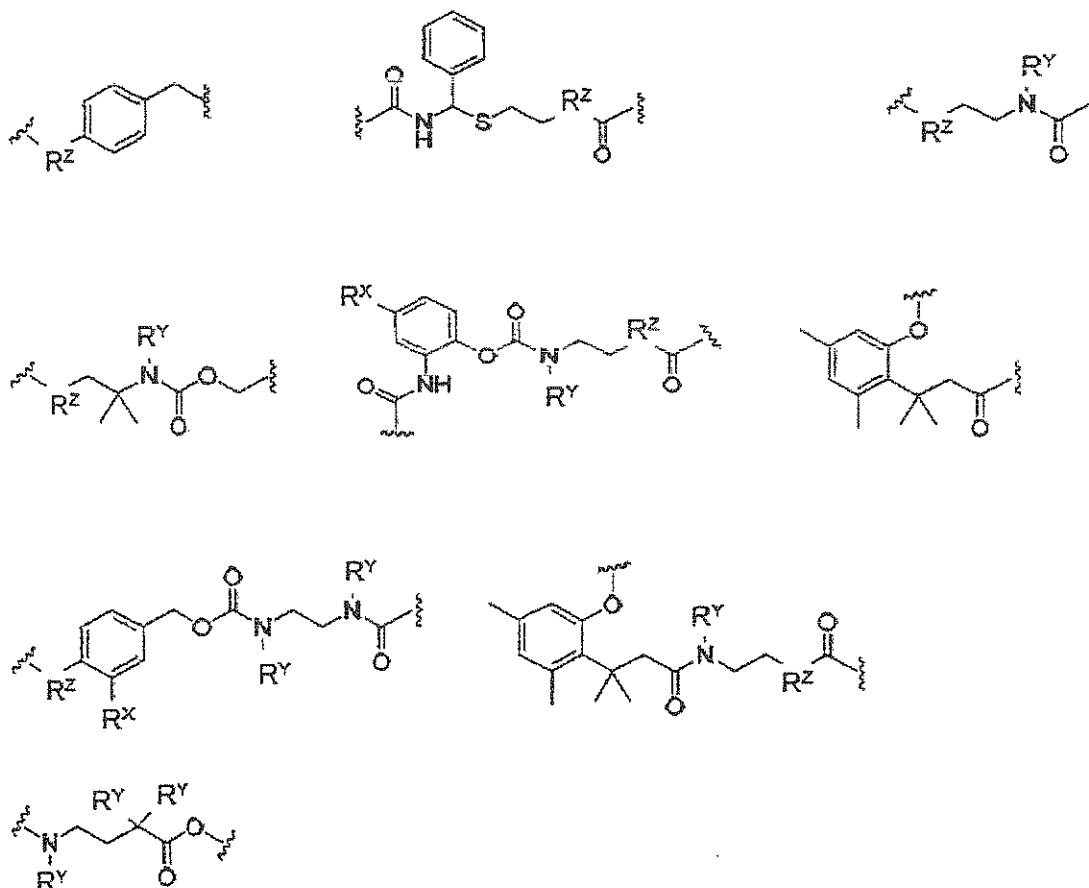
wherein R^3 and R^4 are both H or both C₁₋₂ alkyl;

R^A is C₁₋₄ alkyl, substituted C₁₋₄ alkyl, -CH₂-R^C or -CH₂-V-R^C;

each R^B is independently -H or - R^A ;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a linker selected from



each R^X is independently H, halogen or NO_2

each R^Y is independently H, or Me

each R^Z is independently NH, NMe, O or S

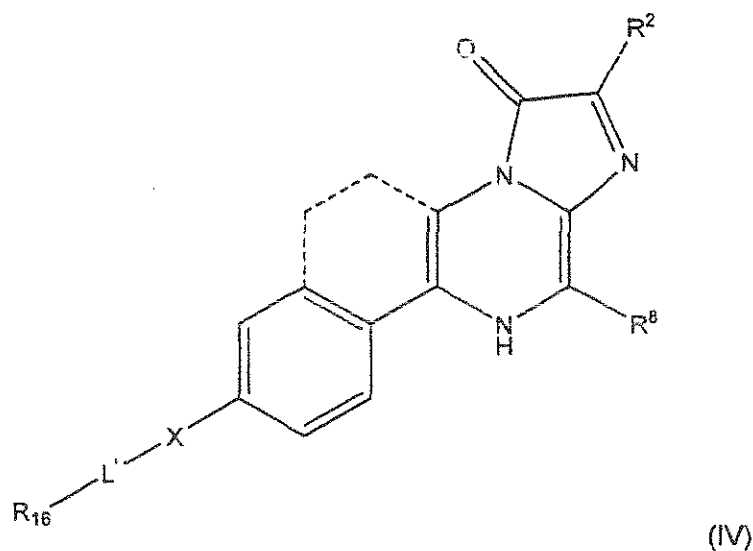
V is $-\text{S}-$ or $-\text{O}-$;

each X is independently $-\text{S}-$, $-\text{O}-$ or $-\text{NH}-$;

each R is independently C_{1-7} alkyl; and

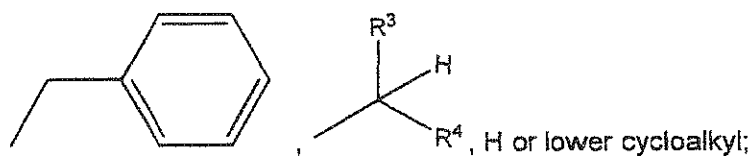
the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

4. A compound of formula (IV):



wherein R^2 is $-(CH_2)_n-T$ or C_{1-5} alkyl;

R^8 is selected from the group consisting of



R^{16} is selected from the group consisting of a peptide, an amino acid, a saccharide, $-O-R^A$, $-OC(O)O-R^A$, $-N(R^B)_2$, or $-NHC(O)OR^A$.

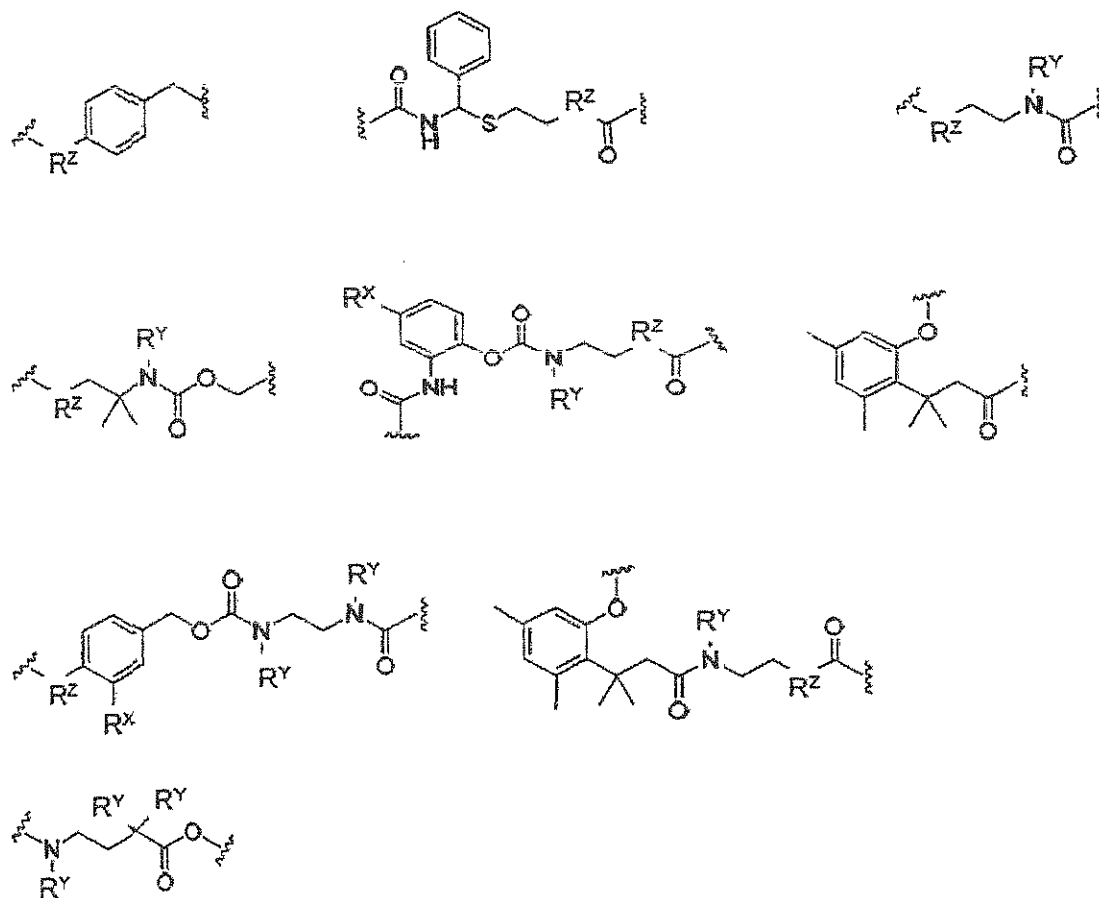
wherein R^3 and R^4 are both H or both C_{1-2} alkyl;

R^A is C_{1-4} alkyl, substituted C_{1-4} alkyl, $-CH_2-R^C$ or $-CH_2-V-R^C$;

each R^B is independently -H or $-R^A$;

R^C is aryl, heteroaryl, substituted aryl or substituted heteroaryl;

L' is a linker selected from



each R^X is independently H, halogen or NO_2

each R^Y is independently H, or Me

each R^Z is independently NH, NMe, O or S

n is 0 to 3;

T is aryl, heteroaryl, substituted aryl, substituted heteroaryl or cycloalkyl;

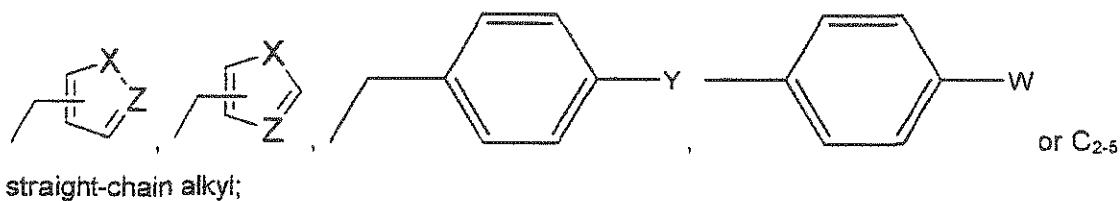
V is $-\text{S}-$ or $-\text{O}-$;

each X is independently $-\text{S}-$, $-\text{O}-$ or $-\text{NH}-$;

each R is independently C_{1-7} alkyl; and

the dashed bonds indicate the presence of an optional ring, which may be saturated or unsaturated.

5. A compound according to any one of claims 1, 2 and 4,
wherein R^2 is



each X is independently -S-, -O- or -NH-;

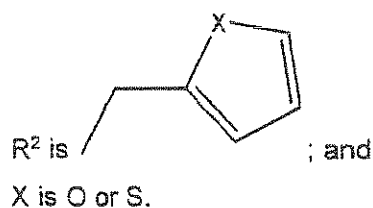
Z is -CH- or -N-;

Y is -H or -OH;

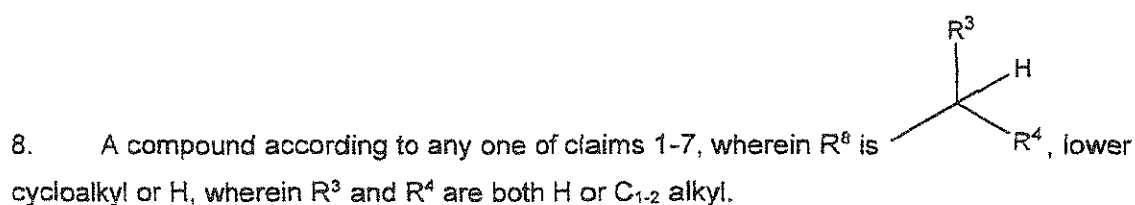
W is -NH₂, halo, -OH, -NHC(O)R, -CO₂R; and

R is C₁₋₇ alkyl.

6. A compound according to claim 5, wherein



7. A compound according to claim 5, wherein R² is C₂₋₅ straight-chain alkyl.



9. A compound according to any one of claims 1-7, wherein R⁸ is benzyl.

10. A compound according to any one of claims 1-9, wherein V is S.

11. A method of detecting the presence or amount of an enzyme comprising:
contacting a sample suspected of containing the enzyme with a compound according to
any one of claims 1 to 10; and
detecting luminescence of the sample.

12. The method of claim 11, wherein the luminescence is quantified.

13. The method of claim 11, wherein the sample is suspected of containing a second
enzyme, comprising
contacting the sample with a second compound according to any one of claims 1 to 10,
wherein the second compound contains a substrate for the second enzyme; and
detecting the luminescence of the sample.

14. A method of detecting the presence of an enzyme *in vivo* comprising:

administering a compound according to any one of claims 1 to 10 to a transgenic animal;
and
detecting luminescence.

15. A method of detecting the presence of an enzyme comprising:
administering a compound according to any one of claims 1 to 10 to an animal;
obtaining a sample from the animal; and
detecting luminescence of the sample.
16. A compound selected from the group consisting of:

