



US012385026B2

(12) **United States Patent**  
Shulman et al.(10) **Patent No.:** US 12,385,026 B2  
(45) **Date of Patent:** \*Aug. 12, 2025(54) **STABILIZED ALPHA-GALACTOSIDASE AND USES THEREOF**

- (71) Applicant: **Protalix Ltd.**, Carmiel (IL)
- (72) Inventors: **Avidor Shulman**, Rakefet (IL); **Ilya Ruderfer**, Carmiel (IL); **Tehila Ben-Moshe**, Koranit (IL); **Talia Shekhter**, Petach-Tikva (IL); **Yaniv Azulay**, Akko (IL); **Tali Kizhner**, Atzmon-Segev (IL); **Yoseph Shaaltiel**, Timrat (IL)
- (73) Assignee: **Protalix Ltd.**, Carmiel (IL)
- (\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.  
This patent is subject to a terminal disclaimer.
- (21) Appl. No.: **17/716,348**
- (22) Filed: **Apr. 8, 2022**

(65) **Prior Publication Data**

US 2023/0074255 A1 Mar. 9, 2023

**Related U.S. Application Data**

- (63) Continuation of application No. 17/391,208, filed on Aug. 2, 2021, now abandoned, which is a continuation of application No. 17/111,464, filed on Dec. 3, 2020, now abandoned, which is a continuation of application No. 16/356,238, filed on Mar. 18, 2019, now Pat. No. 10,870,842, which is a continuation of application No. 15/636,753, filed on Jun. 29, 2017, now Pat. No. 10,280,414, which is a continuation of application No. 14/936,720, filed on Nov. 10, 2015, now Pat. No. 9,708,595, which is a continuation of application No. 13/582,482, filed as application No. PCT/IL2011/000209 on Mar. 2, 2011, now Pat. No. 9,194,011, which is a continuation-in-part of application No. PCT/IL2010/000956, filed on Nov. 17, 2010.
- (60) Provisional application No. 61/434,499, filed on Jan. 20, 2011, provisional application No. 61/434,503, filed on Jan. 20, 2011, provisional application No. 61/309,487, filed on Mar. 2, 2010, provisional application No. 61/261,787, filed on Nov. 17, 2009.
- (51) **Int. Cl.**  
**C12N 9/40** (2006.01)  
**A61K 38/00** (2006.01)
- (52) **U.S. Cl.**  
CPC .... **C12N 9/2465** (2013.01); **C12Y 302/01022** (2013.01); **A61K 38/00** (2013.01)
- (58) **Field of Classification Search**  
CPC ..... C12N 9/2465; C12Y 302/01022; A61K 38/00; A61P 3/00
- See application file for complete search history.

## (56)

**References Cited**

## U.S. PATENT DOCUMENTS

5,580,757 A	12/1996	Desnick et al.
5,595,756 A	1/1997	Bally et al.
5,614,587 A	3/1997	Rhee et al.
5,705,153 A	1/1998	Shorr et al.
5,766,897 A	6/1998	Braxton
5,994,086 A	11/1999	Benoff
6,083,725 A	7/2000	Selden et al.
6,309,646 B1	10/2001	Lees
6,395,884 B1	5/2002	Selden et al.
6,458,574 B1	10/2002	Selden et al.
6,583,158 B1	6/2003	Fan et al.
6,846,968 B1	1/2005	Erwin et al.
7,011,831 B2	3/2006	Calhoun et al.
7,087,728 B2	8/2006	Margolin et al.
7,341,720 B2	3/2008	Stefano
7,935,336 B2	5/2011	Sakuraba et al.
8,426,357 B2	4/2013	Kraehmer et al.
9,194,011 B2 *	11/2015	Shulman ..... C12N 9/2465
9,708,595 B2 *	7/2017	Shulman ..... A61P 3/00
10,280,414 B2 *	5/2019	Shulman ..... C12Y 302/01022
10,870,842 B2 *	12/2020	Shulman ..... C12Y 302/01022
2002/0088024 A1	7/2002	Garger et al.
2002/0137125 A1	9/2002	Zhu
2003/0190304 A1	10/2003	Thompson et al.
2003/0228612 A1	12/2003	Kenward et al.

(Continued)

## FOREIGN PATENT DOCUMENTS

AU	2008290217 A1	2/2009
CN	1354796 A	6/2002

(Continued)

## OTHER PUBLICATIONS

Auclair et al., Strategies for stabilizing superoxide dismutase (SOD1), the protein destabilized in the most common form of familial amyotrophic lateral sclerosis. Proc Natl Acad Sci U S A. Dec. 14, 2010;107(50):21394-9.

(Continued)

*Primary Examiner* — Ganapathirama Raghu*(74) Attorney, Agent, or Firm* — McCarter & English, LLP; Jill Mello; Yelena Margolin

## (57)

**ABSTRACT**

Multimeric protein structures comprising at least two alpha-galactosidase monomers being covalently linked to one another via a linking moiety are disclosed herein, as well as a process for preparing same, and methods of treating Fabry disease via administration of a multimeric protein structure. The disclosed multimeric protein structures exhibit an improved performance, in terms of enhanced activity and/or a longer lasting activity under both lysosomal conditions and in a serum environment.

16 Claims, 45 Drawing Sheets

Specification includes a Sequence Listing.

# US 12,385,026 B2

Page 2

---

(56)

## References Cited

### U.S. PATENT DOCUMENTS

2005/0048047 A1	3/2005	Kakkis
2005/0058634 A1	3/2005	Zhu
2005/0059097 A1	3/2005	Daunert et al.
2005/0180948 A1	8/2005	Desjarlais et al.
2005/0282225 A1	12/2005	Daunert et al.
2006/0084163 A1	4/2006	Schaffer et al.
2006/0204487 A1	9/2006	Shaaltiel et al.
2006/0228348 A1	10/2006	Stefano
2007/0172449 A1	7/2007	Carmichael et al.
2007/0207961 A1	9/2007	Dahiyat et al.
2008/0038232 A1	2/2008	Shaaltiel et al.
2011/0105379 A1	5/2011	Shulman et al.
2012/0230974 A1	9/2012	Shaaltiel et al.
2012/0328589 A1	12/2012	Ruderfer et al.
2012/0328592 A1	12/2012	Shulman et al.
2013/0017169 A1	1/2013	Ruderfer et al.
2013/0295065 A1	11/2013	Shulman et al.
2014/0256017 A1	9/2014	Shulman et al.
2016/0053247 A1	2/2016	Shulman et al.

### FOREIGN PATENT DOCUMENTS

CN	1875111 A	12/2006
CN	101855232 A	10/2010
EP	0747066 A2	12/1996
EP	1172372 A1	1/2002
EP	1955712 A1	8/2008
GB	2402677 A	12/2004
JP	2005-043317 A	2/2005
JP	2006-524506 A	11/2006
JP	2010-515677 A	5/2010
JP	2010-519182 A	6/2010
JP	2010-525806 A	7/2010
JP	2013-520986 A	6/2013
KR	20070065157 A	6/2007
WO	WO-1991/14697 A1	10/1991
WO	WO-1993/18148 A2	9/1993
WO	WO-1995/01994 A1	1/1995
WO	WO-1995/06478 A1	3/1995
WO	WO-1996/23869 A1	8/1996
WO	WO-1997/10353 A1	3/1997
WO	WO-1998/13469 A1	4/1998
WO	WO-1999/67401 A2	12/1999
WO	WO-2000/59926 A1	10/2000
WO	WO-2001/25277 A1	4/2001
WO	WO-2002/057435 A2	7/2002
WO	WO-2003/035686 A2	5/2003
WO	WO-2003/042244 A2	5/2003
WO	WO-2003/090695 A2	11/2003
WO	WO-2003/097791 A2	11/2003
WO	WO-2004/081053 A1	9/2004
WO	WO-2004/091475 A2	10/2004
WO	WO-2004/096978 A2	11/2004
WO	WO-2004/111198 A2	12/2004
WO	WO-2005/056760 A2	6/2005
WO	WO-2005/077093 A2	8/2005
WO	WO-2005/093422 A2	10/2005
WO	WO-2006/093524 A2	9/2006
WO	WO-2006/108052 A2	10/2006
WO	WO-2007/010533 A2	1/2007
WO	WO-2008/012540 A1	1/2008
WO	WO-2008/075957 A1	6/2008
WO	WO-2008/082274 A1	7/2008
WO	WO-2008/089403 A2	7/2008
WO	WO-2008/096012 A2	8/2008
WO	WO-2008/132743 A2	11/2008
WO	WO-2008/143679 A2	11/2008
WO	WO-2009/024977 A2	2/2009
WO	WO-2010/004568 A1	1/2010
WO	WO-2011/107990 A1	9/2011

WO	WO-2011/107992 A2	9/2011
WO	WO-2012/098537 A1	7/2012

### OTHER PUBLICATIONS

- Bendele et al., Short communication: renal tubular vacuolation in animals treated with polyethylene-glycol-conjugated proteins. *Toxicol Sci*. Apr. 1998;42(2):152-7.
- Benesch et al., Hemoglobin tetramers stabilized by a single intra-molecular cross-link. *J Protein Chem*. Oct. 1991;10(5):503-10.
- Benoff et al., Use of mannose ligands in IVF screens to mimic zona pellucida-induced acrosome reactions and predict fertilization success. *Mol Hum Reprod*. Oct. 1997;3(10):839-46.
- Bishop et al., Human alpha-galactosidase A: nucleotide sequence of a cDNA clone encoding the mature enzyme. *Proc Natl Acad Sci U S A*. Jul. 1986;83(13):4859-63.
- Broun et al., Catalytic plasticity of fatty acid modification enzymes underlying chemical diversity of plant lipids. *Science*. Nov. 13, 1998;282(5392):1315-7.
- Brown et al., Biochemistry of protein-isocyanate interactions: a comparison of the effects of aryl vs. alkyl isocyanates. *Environ Health Perspect*. Jun. 1987;72:5-11.
- Buckmann et al., Functionalization of Poly(Ethylene Glycol) and Monomethoxy-Poly(Ethylene Glycol). *Die Makromolekulare Chemie*. May 1981;182(5):1379-1384.
- Buckmann et al., Synthesis of Water Soluble Polymers With Covalently Bound General Ligands. *Enzyme Engineering*. Springer, Boston, Broun G.B. (Ed.). 1978;4:395-397.
- Chen et al., Directed evolution of a lysosomal enzyme with enhanced activity at neutral pH by mammalian cell-surface display. *Chem Biol*. Dec. 22, 2008;15(12):1277-86.
- Chica et al., Semi-rational approaches to engineering enzyme activity: combining the benefits of directed evolution and rational design. *Curr Opin Biotechnol*. Aug. 2005;16(4):378-84.
- Cramer et al., Transgenic plants for therapeutic proteins: linking upstream and downstream strategies. *Curr Top Microbiol Immunol*. 1999;240:95-118.
- Den Dulk-Ras et al., Electroporation of *Agrobacterium tumefaciens*. *Methods Mol Biol*. 1995;55:63-72.
- Devos et al., Practical limits of function prediction. *Proteins*. Oct. 1, 2000;41(1):98-107.
- Fernandez-Megia et al., Conjugation of bioactive ligands to PEG-grafted chitosan at the distal end of PEG. *Biomacromolecules*. Mar. 2007;8(3):833-42.
- Gao et al., A novel alkaline alpha-galactosidase from melon fruit with a substrate preference for raffinose. *Plant Physiol*. Mar. 1999;119(3):979-88.
- Garman et al., The molecular defect leading to Fabry disease: structure of human alpha-galactosidase. *J Mol Biol*. Mar. 19, 2004;337(2):319-35.
- Garman, Structure-function relationships in alpha-galactosidase A. *Acta Paediatr*. Apr. 2007;96(455):6-16.
- GenBank Accession No. AY093754.1. *Arabidopsis thaliana* AT4g02980/T419 14 mRNA, complete CDs. Apr. 13, 2002.
- GenBank Accession No. S31584. Auxin-Binding Protein T419.14 Precursor—*Arabidopsis thaliana*. Sep. 30, 1993.
- Gleba et al., Magnification—a new platform for expressing recombinant vaccines in plants. *Vaccine*. Mar. 18, 2005;23(17-18):2042-8.
- Gotte et al., Cross-linked trimers of bovine ribonuclease A: activity on double-stranded RNA and antitumor action. *FEBS Lett*. Oct. 6, 1997;415(3):308-12.
- Grosje et al., Intracellular rate-limiting steps of gene transfer using glycosylated polylysines in cystic fibrosis airway epithelial cells. *Gene Ther*. Aug. 2002;9(15):1000-7.
- Hoffmann, Fabry disease: recent advances in pathology, diagnosis, treatment and monitoring. *Orphanet J Rare Dis*. Oct. 11, 2009;4:21.
- Huang et al., Research Advances in Auxin-Binding Proteins. *Journal of Anhui Agricultural Sciences*. 2007;35(29):9119-9120.
- Invitrogen, Fluorophores and Their Amine-Reactive Derivatives. Molecular Probes™ Handbook, A Guide to Fluorescent Probes and Labeling Technologies, 11th Edition. ThermoFisher Scientific, Chapter 1, pp. 11-96, 2010.

(56)

**References Cited****OTHER PUBLICATIONS**

- Kapoor, How to cross-link proteins. Cellular, Molecular and Microbial Biology Division, University of Calgary, Calgary, Canada, T2N 1N4. 6 pages, (1996).
- Kizhner et al., Characterization of a chemically modified plant cell culture expressed human a-Galactosidase-A enzyme for treatment of Fabry disease. *Mol Genet Metab.* Feb. 2015;114(2):259-67.
- Laville et al., Photodynamic efficiency of diethylene glycol-linked glycoconjugated porphyrins in human retinoblastoma cells. *J Med Chem.* Apr. 20, 2006;49(8):2558-67.
- Li et al., Bacteria targeted by human natural antibodies using alpha-Gal conjugated receptor-specific glycopolymers. *Bioorg Med Chem.* Aug. 1999;7(8):1549-58.
- Lindhorst et al., Trivalent alpha-D-Mannoside Clusters as Inhibitors of Type-1 Fimbriae-Mediated Adhesion of *Escherichia coli*: Structural Variation and Biotinylation. *Journal of the Chemical Society, Perkin Transactions 1.* 2001;8:823-831.
- Lopez-Alonso et al., Carbodiimide EDC induces cross-links that stabilize RNase A C-dimer against dissociation: EDC adducts can affect protein net charge, conformation, and activity. *Bioconjug Chem.* Aug. 19, 2009;20(8):1459-73.
- Mayer et al., Sequence and analysis of chromosome 4 of the plant *Arabidopsis thaliana*. *Nature.* Dec. 16, 1999;402(6763):769-77.
- Mayes et al., alpha-galactosidase A from human placenta. Stability and subunit size. *Biochim Biophys Acta.* Oct. 13, 1977;484(2):408-16.
- Mayes et al., Endocytosis of lysosomal alpha-galactosidase A by cultured fibroblasts from patients with Fabry disease. *Am J Hum Genet.* Jul. 1982;34(4):602-10.
- Murali et al., Crystallization and preliminary X-ray analysis of human alpha-galactosidase A complex. *J Mol Biol.* Jun. 17, 1994;239(4):578-80.
- Napier, Towards an understanding of ABP1. *Journal of Experimental Botany.* Dec. 1995;46(12):1787-1795.
- Neumann et al., Protein transport in plant cells: in and out of the Golgi. *Ann Bot.* Aug. 2003;92(2):167-80.
- Pagny et al., Signals and Mechanisms for Protein Retention in the Endoplasmic Reticulum. *Journal of Experimental Botany.* Feb. 1999;50(331):157-164.
- Pierce, Crosslinking Reagents. The Pierce Technical Handbook. 48 pages, (2006).
- Potrykus, Gene Transfer to Plants: Assessment of Public Approaches and Results. *Ann Rev Plant Physiol Plant Mol Biol.* 1991;42:205-225.
- Rade et al., Retroviral vector-mediated expression of hirudin by human vascular endothelial cells: implications for the design of retroviral vectors expressing biologically active proteins. *Gene Ther.* Mar. 1999;6(3):385-92.
- Rathnam et al., Conjugation of a fetuin glycopeptide to human follie-stimulating hormone and its subunits by photoactivation. *Biochim Biophys Acta.* Aug. 21, 1980;624(2):436-42.
- Rayon et al., he Protein N-Glycosylation in Plants. *Journal of Experimental Botany.* Sep. 1998;49(326):1463-1472.
- Sakuraba et al., Comparison of the effects of agalsidase alfa and agalsidase beta on cultured human Fabry fibroblasts and Fabry mice. *J Hum Genet.* 2006;51(3):180-8.
- Schottelius et al., Detection and quantitation of cell-surface sugar receptor(s) of *Leishmania donovani* by application of neoglycoenzymes. *Parasitol Res.* 1992;78(6):529-33.
- Seffernick et al., Melamine deaminase and atrazine chlorohydrolase: 98 percent identical but functionally different. *J Bacteriol.* Apr. 2001;183(8):2405-10.
- Sen et al., Developments in directed evolution for improving enzyme functions. *Appl Biochem Biotechnol.* Dec. 2007;143(3):212-23.
- Shaaltiel et al., Alpha-Gal-KDEL Construct DNA Encoding Protein SEQ ID:20. Score Database [Online], Database Accession No. AT59772, Jan. 8, 2009.
- Shaaltiel et al., Human Recombinant Alpha Galactosidase A 47.6 kDa Protein. Score Database [Online], Database Accession No. AT59778, Jan. 8, 2009.
- Shimamoto et al., Fertile Transgenic Rice Plants Regenerated From Transformed Protoplasts. *Nature.* Mar. 16, 1989;338:274-276.
- Sigma-Aldrich, Innovations in Peptide Synthesis and Conjugation: Tools for Drug Discovery. *ChemFiles.* 2005;5(12):1-24.
- Snyder et al., Enzyme therapy. II. Purified human alpha-galactosidase A. Stabilization to heat and protease degradation by complexing with antibody and by chemical modification. *Biochim Biophys Acta.* Jun. 18, 1974;350(2):432-6.
- Sorrentino et al., Dimerization of deoxyribonuclease I, lysozyme and papain. Effects of ionic strength on enzymic activity. *Eur J Biochem.* May 1982;124(1):183-9.
- Takahashi et al., A New Method for the Formation of the ?-Glycose Bond of Sialyl Conjugates Based on Long-Range Participation. *Tetrahedron Letters.* Nov. 1997;38(47):8223-8226.
- Takahashi et al., Design and synthesis of a water-soluble taxol analogue: taxol-sialyl conjugate. *Bioorg Med Chem Lett.* Jan. 6, 1998;8(1):113-6.
- Tardi et al., Liposomal encapsulation of topotecan enhances anti-cancer efficacy in murine and human xenograft models. *Cancer Res.* Jul. 1, 2000;60(13):3389-93.
- Terrier et al., Two new disposable bioreactors for plant cell culture: The wave and undertow bioreactor and the slug bubble bioreactor. *Biotechnol Bioeng.* Apr. 1, 2007;96(5):914-23.
- Thermo Fisher Scientific, Instructions BM(PEG)2 and BM(PEG)3. Thermo Fisher Scientific Inc., Pierce Biotechnology, Rockford, IL, USA, 3 P, 2007.
- Thermo Fisher Scientific, Instructions BS(PEG)n. Homofunctional, Amine-Reactive Crosslinkers With Polyethylene Glycol (PEG) Spacer Arms. Thermo Fisher Scientific Inc., Pierce Biotechnology, Rockford, IL, USA, 3 P, 2008.
- UniProt, Accession No. P33487, ERABPI; OrderedLocusNames= At4g02980;ORFNames=T4I9.14; *Arabidopsis thaliana* (Mouse-Ear Cress). Feb. 1, 1994.
- Vamvakaki et al., Fluorescence detection of enzymatic activity within a liposome based nano-biosensor. *Biosens Bioelectron.* Aug. 15, 2005;21(2):384-8.
- Vargas et al., Endocytosis of liposomes containing lysosomal proteins increases intracellular protein degradation in growing L-132 cells. *Eur J Biochem.* Feb. 22, 1990;188(1):99-109.
- Wang et al., Human alpha-N-acetylglucosaminidase-molecular cloning, nucleotide sequence, and expression of a full-length cDNA. Homology with human alpha-galactosidase A suggests evolution from a common ancestral gene. *J Biol Chem.* Dec. 15, 1990;265(35):21859-66.
- Wen et al., ABP1: Supperstar of Auxin-Binding Proteins. *Biotechnology Bulletin.* Dec. 2007;3:16-21.
- Whisstock et al., Prediction of protein function from protein sequence and structure. *Q Rev Biophys.* Aug. 2003;36(3):307-40.
- Witkowski et al., Conversion of a beta-ketoacyl synthase to a malonyl decarboxylase by replacement of the active-site cysteine with glutamine. *Biochemistry.* Sep. 7, 1999;38(36):11643-50.
- Wolf et al., A mechanism of the irreversible inactivation of bovine pancreatic ribonuclease by diethylpyrocarbonate. A general reaction of diethylpyrocarbonate . A general reaction of diethylpyrocarbonate with proteins. *Eur J Biochem.* Apr. 1970; 13(3):519-25.
- Xu et al., Dumbbell-like Au—Fe<sub>3</sub>O<sub>4</sub> nanoparticles for target-specific platin delivery. *J Am Chem Soc.* Apr. 1, 2009;131(12):4216-7.
- Yamaguchi et al., Polysaccharide-poly(ethylene glycol) star copolymer as a scaffold for the production of bioactive hydrogels. *Biomacromolecules.* Jul.-Aug. 2005;6(4):1921-30.
- Yan et al., Research Progress in the Linker of Fusion Protein. *Biotechnology.* 2008;18(3):92-94.
- Zambrano et al., Receptor binding activity and in vitro biological activity of the human FSH charge isoforms as disclosed by heterologous and homologous assay systems: implications for the structure-function relationship of the FSH variants. *Endocrine.* Apr. 1999; 10(2):113-21.

(56)

**References Cited****OTHER PUBLICATIONS**

- Advisory Action Before the Filing of an Appeal Brief Dated Jul. 22, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,464.
- Advisory Action Before the Filing of an Appeal Brief Dated Mar. 5, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Applicant-Initiated Interview Summary Dated May 22, 2015 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,482.
- Communication Pursuant to Article 94(3) EPC Dated Jun. 14, 2017 From the European Patent Office Re. Application No. 16173953.7, 4 pages.
- Communication Pursuant to Article 94(3) EPC Dated Apr. 8, 2014 From the European Patent Office Re. Application No. 08789815.1.
- Communication Pursuant to Article 94(3) EPC Dated Jan. 16, 2014 From the European Patent Office Re. Application No. 11711151.8.
- Communication Pursuant to Article 94(3) EPC Dated Jul. 15, 2013 From the European Patent Office Re. Application No. 11711151.8.
- Communication Pursuant to Article 94(3) EPC Dated Jun. 18, 2015 From the European Patent Office Re. Application No. 11767776.5.
- Communication Pursuant to Article 94(3) EPC Dated Oct. 10, 2014 From the European Patent Office Re. Application No. 11767776.5.
- Communication Pursuant to Article 94(3) EPC Dated Oct. 7, 2010 From the European Patent Office Re. Application No. 08789815.1.
- Communication Relating to the Results of the Partial International Search Dated Sep. 18, 2009 From the International Searching Authority Re.: Application No. PCT/IL2008/001143.
- Communication Relating to the Results of the Partial International Search Dated Jul. 4, 2011 From the International Searching Authority Re. Application No. PCT/IL2011/000211.
- Decision on Rejection Dated Sep. 13, 2016 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7.
- European Search Report and the European Search Opinion Dated Sep. 13, 2016 From the European Patent Office Re. Application No. 16173953.7.
- European Search Report Dated Mar. 31, 2015 From the European Patent Office Re. Application No. 14195875.1.
- Examination Report Dated Apr. 10, 2013 From the Intellectual Property Office of New Zealand Re. Application No. 602317.
- Examination Report Dated Apr. 16, 2014 From the Intellectual Property Office of New Zealand Re. Application No. 623294.
- Examination Report Dated Feb. 28, 2013 From the Australian Government, IP Australia Re. Application No. 2008290217.
- Examination Report Under Sections 12 & 13 of the Patents Act, 1970 and the Patents Rules, 2003 dated Feb. 16, 2018 from the Government of India, Intellectual Property India, Patents, Designs, Trade Marks, Geographical Indications Re. Application No. 226/MUMNP/2012, 6 pages.
- Further Examination Report Postponed Acceptance Dated Jul. 28, 2015 From the Intellectual Property Office of New Zealand Re. Application No. 623294.
- International Preliminary Report on Patentability Dated Aug. 1, 2013 From the International Bureau of WIPO Re. Application No. PCT/IL2011/000719.
- International Preliminary Report on Patentability Dated Mar. 4, 2010 From the International Bureau of WIPO Re.: Application No. PCT/IL2008/001143.
- International Preliminary Report on Patentability Dated May 31, 2012 From the International Bureau of WIPO Re. Application No. PCT/IL2010/000956.
- International Preliminary Report on Patentability Dated Sep. 13, 2012 From the International Bureau of WIPO Re. Application No. PCT/IL2011/000209.
- International Preliminary Report on Patentability Dated Sep. 13, 2012 From the International Bureau of WIPO Re. Application No. PCT/IL2011/000210.
- International Preliminary Report on Patentability Dated Sep. 13, 2012 From the International Bureau of WIPO Re. Application No. PCT/IL2011/000211.
- International Search Report and the Written Opinion Dated Feb. 2, 2012 From the International Searching Authority Re. Application No. PCT/IL2011/000719.
- International Search Report and the Written Opinion Dated Jun. 22, 2011 From the International Searching Authority Re. Application No. PCT/IL2011/000210.
- International Search Report and the Written Opinion Dated Jun. 24, 2011 From the International Searching Authority Re. Application No. PCT/IL2011/000209.
- International Search Report and the Written Opinion Dated Mar. 14, 2011 From the International Searching Authority Re. Application No. PCT/IL2010/000956.
- International Search Report and the Written Opinion Dated Nov. 23, 2009 From the International Searching Authority Re.: Application No. PCT/IL2008/001143.
- International Search Report and the Written Opinion Dated Sep. 28, 2011 From the International Searching Authority Re. Application No. PCT/IL2011/000211.
- Invitation Pursuant to Article 94(3) and Rule 71(1) EPC Dated Feb. 2, 2016 From the European Patent Office Re. Application No. 08789815.1.
- Notice of Allowance Dated Mar. 14, 2017 from the US Patent and Trademark Office Re. U.S. Appl. No. 14/936,720, 9 pages.
- Notice of Preliminary Rejection Dated Apr. 18, 2017 From the Korean Patent Office Re. Application No. 2012-7025725 and Its Translation Into English. (9 Pages).
- Notice of Preliminary Rejection Dated Feb. 27, 2017 from the Korean Intellectual Property Office Re. Application No. 2013-7021693 and its Translation into English, 8 pages.
- Notice of Preliminary Rejection Dated Jul. 29, 2016 from the Korean Intellectual Property Office Re. Application No. 2013-7021693 and its Translation into English.
- Notice of Reason for Rejection Dated Apr. 8, 2014 From the Japanese Patent Office Re. Application No. 2012-555542 and Its Translation Into English.
- Notice of Reason for Rejection Dated Jun. 19, 2015 From the Japanese Patent Office Re. Application No. 2014-160449 and Its Translation Into English.
- Notice of Reasons for Rejection Dated Jul. 28, 2015 From the Japanese Patent Office Re. Application No. 2013-549932 and Its Translation Into English.
- Notification of Office Action and Search Report Dated Jul. 31, 2015 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7 and Its Translation Into English.
- Notification of Office Action Dated Apr. 23, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7 and Its Translation Into English.
- Notification of Office Action Dated Feb. 25, 2016 from the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7 and its Translation into English.
- Notification of Office Action Dated Mar. 18, 2015 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7 and Its Translation Into English.
- Notification of Office Action Dated May 14, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180022145.6 and Its Translation Into English.
- Notification of Office Action Dated Nov. 26, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180022145.6.
- Notification of Office Action Dated Nov. 4, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7.
- Office Action dated Apr. 3, 2017 from the Israel Patent Office Re. Application No. 227552 and its translation into English, 4 pages.
- Office Action Dated Dec. 10, 2014 From the Israel Patent Office Re. Application No. 221740.
- Office Action Dated Jul. 29, 2015 From the Israel Patent Office Re. Application No. 204037.
- Office Action Dated Jun. 24, 2014 From the Israel Patent Office Re. Application No. 204037 and Its Translation Into English.
- Office Action Dated Mar. 11, 2013 From the Israel Patent Office Re. Application No. 204037 and Its Translation Into English.

(56)

**References Cited****OTHER PUBLICATIONS**

- Official Action datt Aug. 31, 2016 from the US Patent and Trademark Office Re. U.S. Appl. No. 14/936,720.
- Official Action Dated Apr. 8, 2015 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,482.
- Official Action dated Apr. 22, 2016 from the US Patent and Trademark Office Re. U.S. Appl. No. 13/980,910.
- Official Action Dated Feb. 19, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,464.
- Official Action Dated Feb. 4, 2015 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,441.
- Official Action Dated Jul. 1, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Official Action Dated Jul. 16, 2012 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Official Action Dated Jul. 18, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,464.
- Official Action Dated May 8, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,482.
- Official Action Dated Nov. 12, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Official Action Dated Nov. 28, 2012 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Official Action dated Nov. 4, 2016 from the US Patent and Trademark Office Re. U.S. Appl. No. 13/980,910.
- Official Action Dated Oct. 17, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,482.
- Official Decision of Rejection Dated Nov. 7, 2014 From the Japanese Patent Office Re. Application No. 2012-555542 and Its Translation Into English.
- Patent Examination Report Dated Sep. 11, 2014 From the Australian Government, IP Australia Re. Application No. 2011222452.
- Replacing Examination Report dated Mar. 20, 2017 from the Intellectual Property Office of Singapore Re. Application No. 10201502609Q, 12 pages.
- Replacing Search Report and Replacing Written Opinion dated Feb. 16, 2016 from the Intellectual Property Office of Singapore Re. Application No. 10201502609Q.
- Request for Examination Dated Feb. 24, 2015 From the Rospatent, Federal Government Institution, Federal Institute of Industrial Property of the Federal Service for Intellectual Property, Patents and Trademarks of the Russian Federation Re. Application No. 2012141651 and Its Translation Into English.
- Request for Examination Dated Mar. 17, 2016 From the Rospatent, Federal Government Institution, Federal Institute of Industrial Property of the Federal Service for Intellectual Property, Patents and Trademarks of the Russian Federation Re. Application No. 2012141651 and its Translation Into English.
- Requisition by the Examiner Dated Jan. 30, 2017 From the Canadian Intellectual Property Office Re. Application No. 2,791,461.
- Requisition by the Examiner Dated Oct. 15, 2014 From the Canadian Intellectual Property Office Re. Application No. 2,696,699.
- Response dated Feb. 3, 2011 to Communication Pursuant to Article 94(3) EPC of Oct. 7, 2010 from the European Patent Office Re: Application No. 08789815.1.
- Restriction Official Action Dated Apr. 12, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,464.
- Restriction Official Action Dated Apr. 17, 2012 From the US Patent and Trademark Office Re. U.S. Appl. No. 12/673,987.
- Restriction Official Action Dated Feb. 28, 2013 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/510,340.
- Restriction Official Action Dated Jan. 28, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,482.
- Restriction Official Action Dated Jul. 22, 2015 From the US Patent and Trademark Office Re. U.S. Appl. No. 14/281,981.
- Restriction Official Action Dated Sep. 3, 2014 From the US Patent and Trademark Office Re. U.S. Appl. No. 13/582,441.
- Search and Examination Report Dated Sep. 19, 2014 From the Intellectual Property Office of Singapore Re. Application No. 201206458-0.
- Search Report and Written Opinion Dated Mar. 3, 2014 From the Intellectual Property Office of Singapore Issued by Hungarian Intellectual Property Office Re. Application No. 201206458-0.
- Search Report Dated Apr. 23, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7 and Its Translation Into English.
- Summons to Attend Oral Proceedings Pursuant to Rule 115(1) EPC dated Mar. 31, 2016 from the European Patent Office Re. Application No. 11767776.5.
- Translation Dated Aug. 25, 2015 of Office Action Dated Jul. 29, 2015 From the Israel Patent Office Re. Application No. 204037.
- Translation Dated Dec. 10, 2014 of Notification of Office Action Dated Nov. 26, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180022145.6.
- Translation Dated Dec. 24, 2014 of Notification of Office Action Dated Nov. 4, 2014 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7.
- Translation Dated Jan. 15, 2015 of Office Action Dated Dec. 10, 2014 From the Israel Patent Office Re. Application No. 221740.
- Translation of Decision on Rejection Dated Sep. 13, 2016 from the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180069560.7.
- Translation of Notification of Office Action Dated Aug. 28, 2013 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180022145.6.
- Translation of Search Report Dated Aug. 28, 2013 From the State Intellectual Property Office of the People's Republic of China Re. Application No. 201180022145.6.

\* cited by examiner

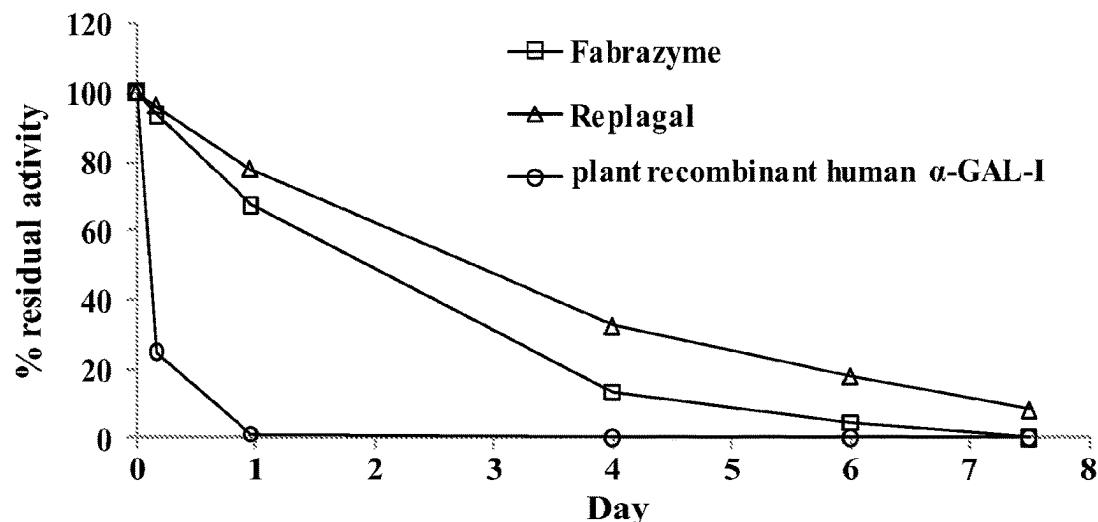


FIG. 1

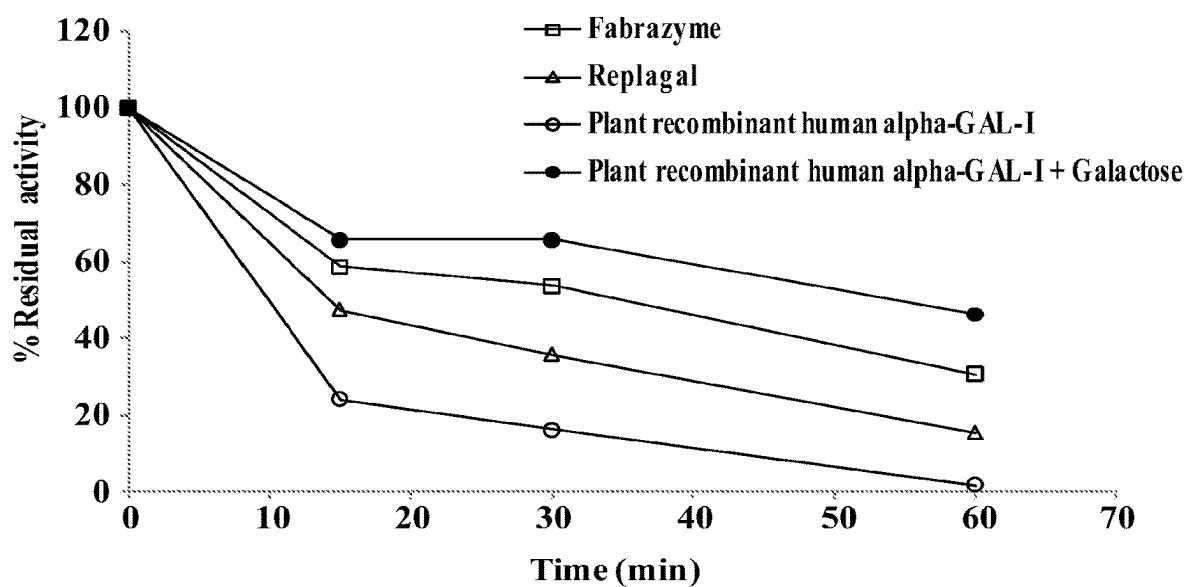


FIG. 2

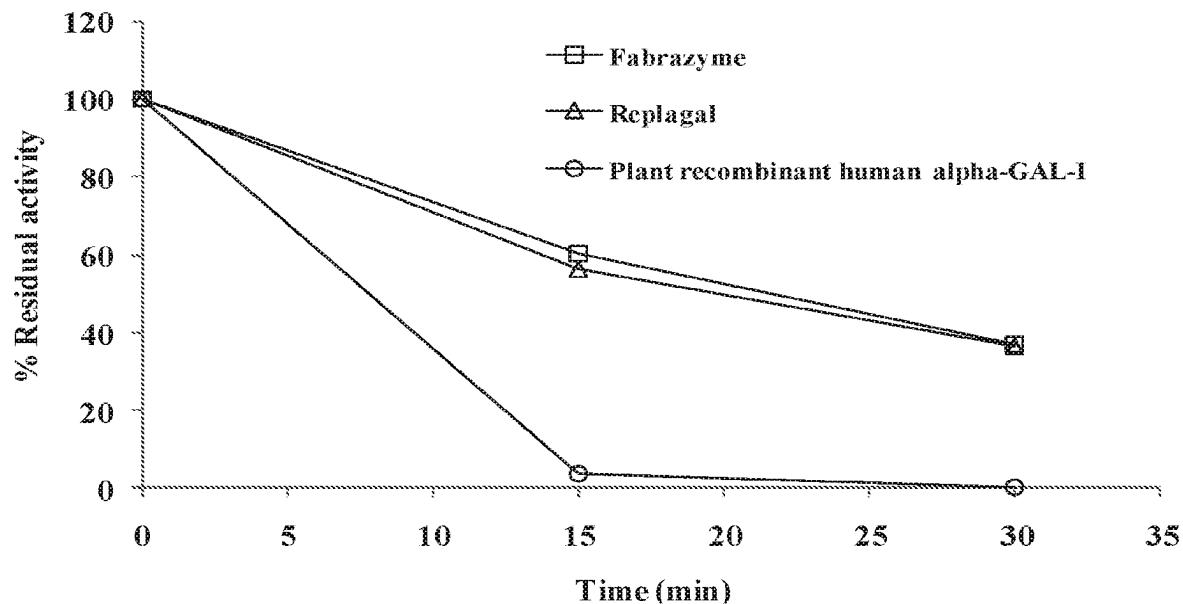


FIG. 3

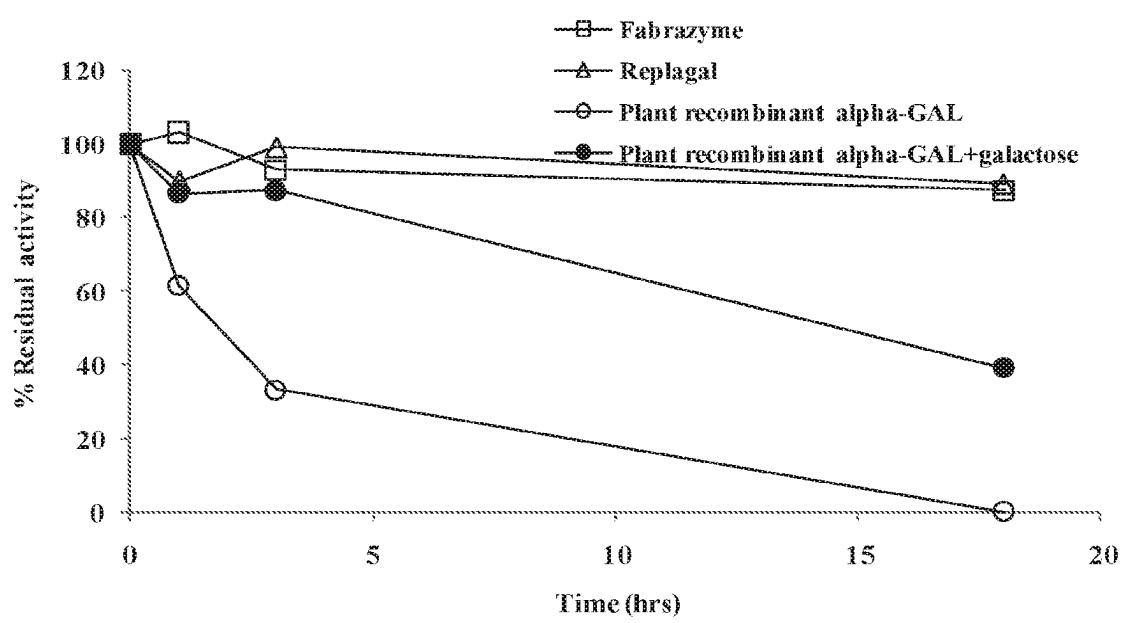


FIG. 4

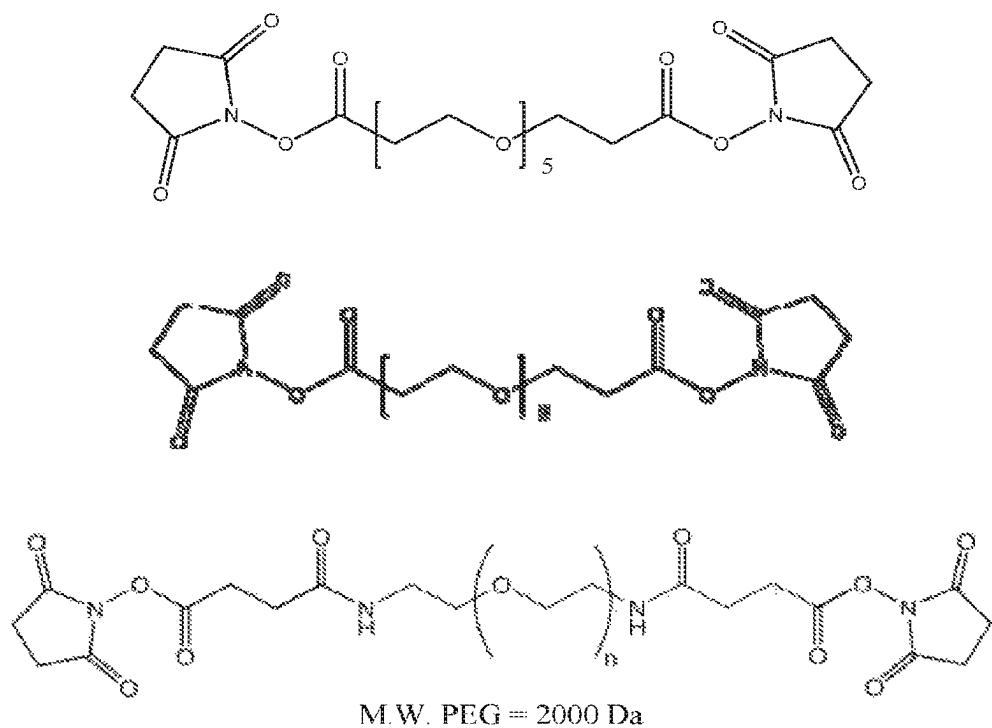


FIG. 5

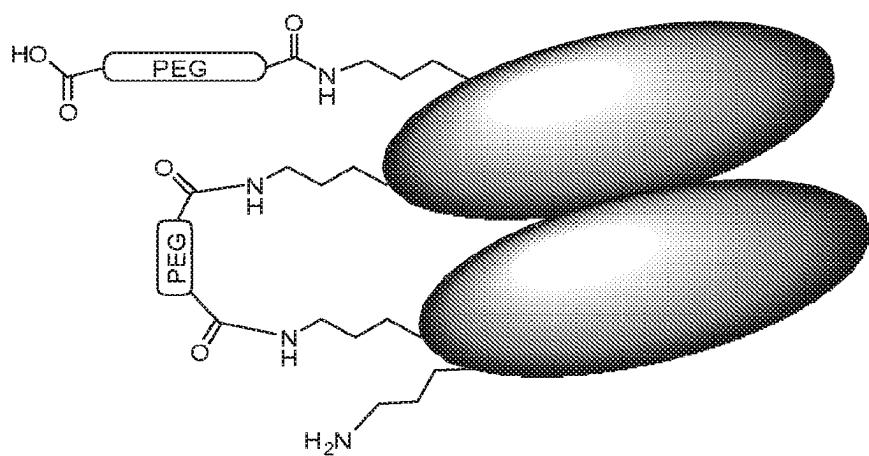


FIG. 6

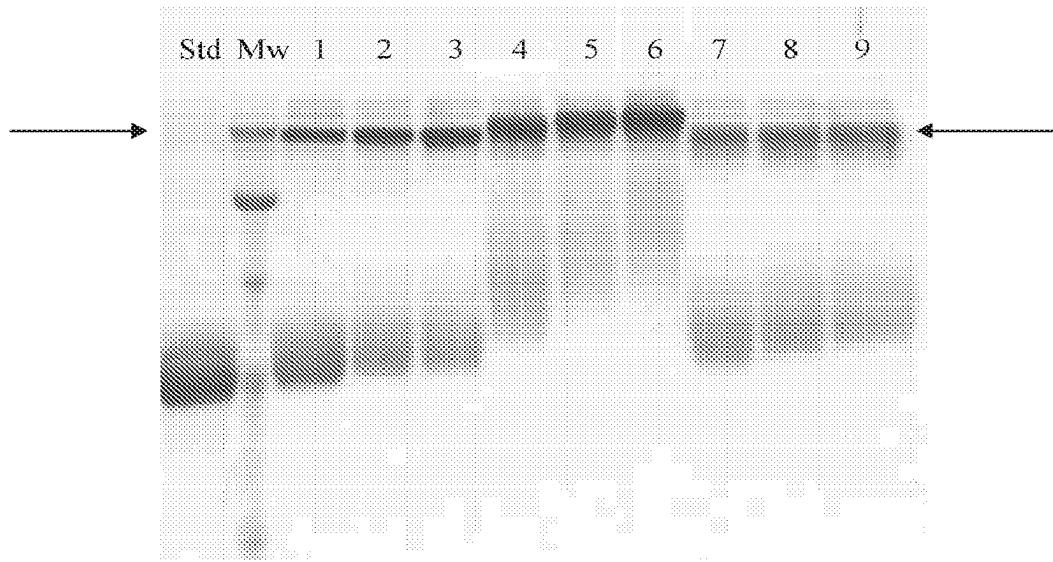


FIG. 7

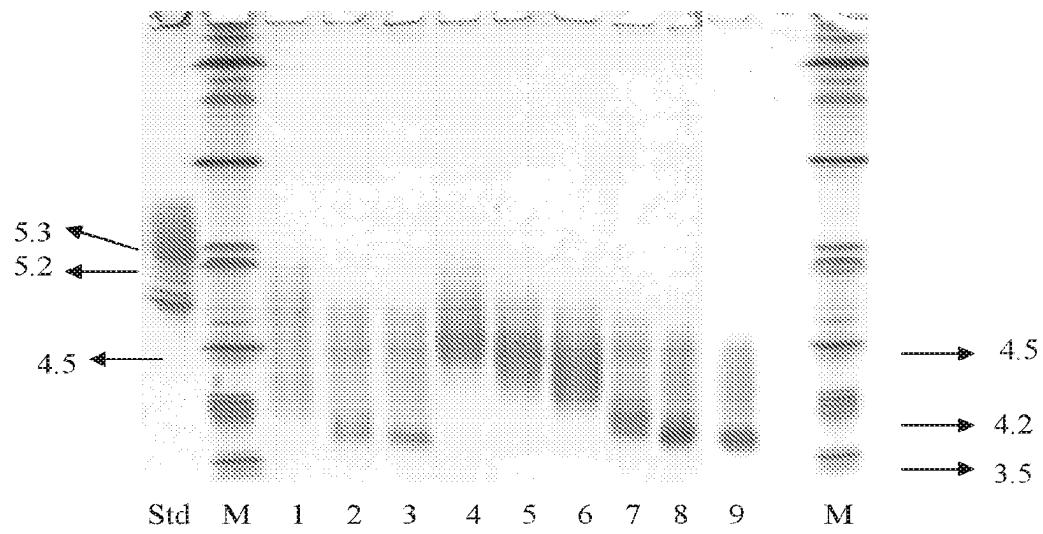


FIG. 8

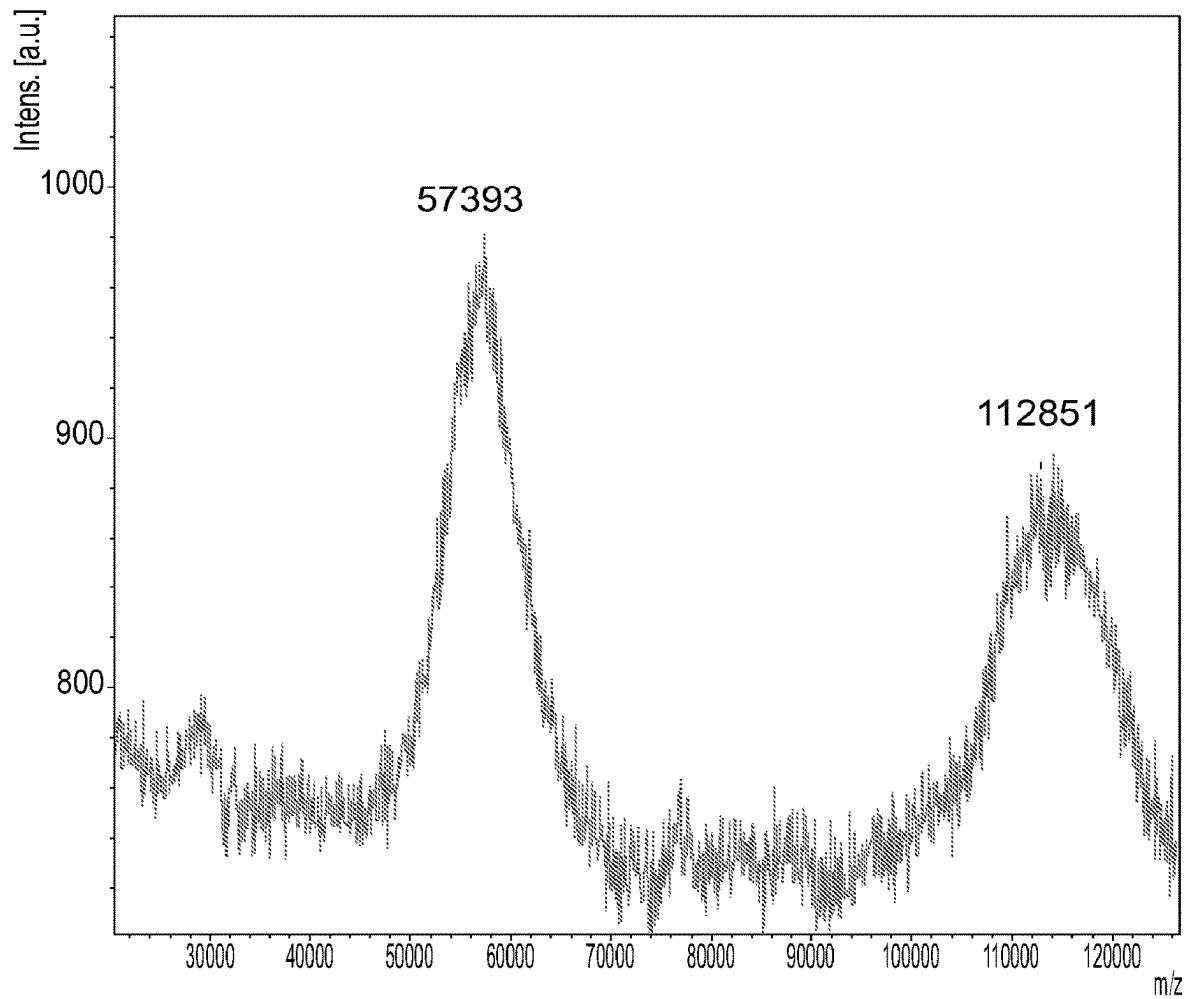


FIG. 9

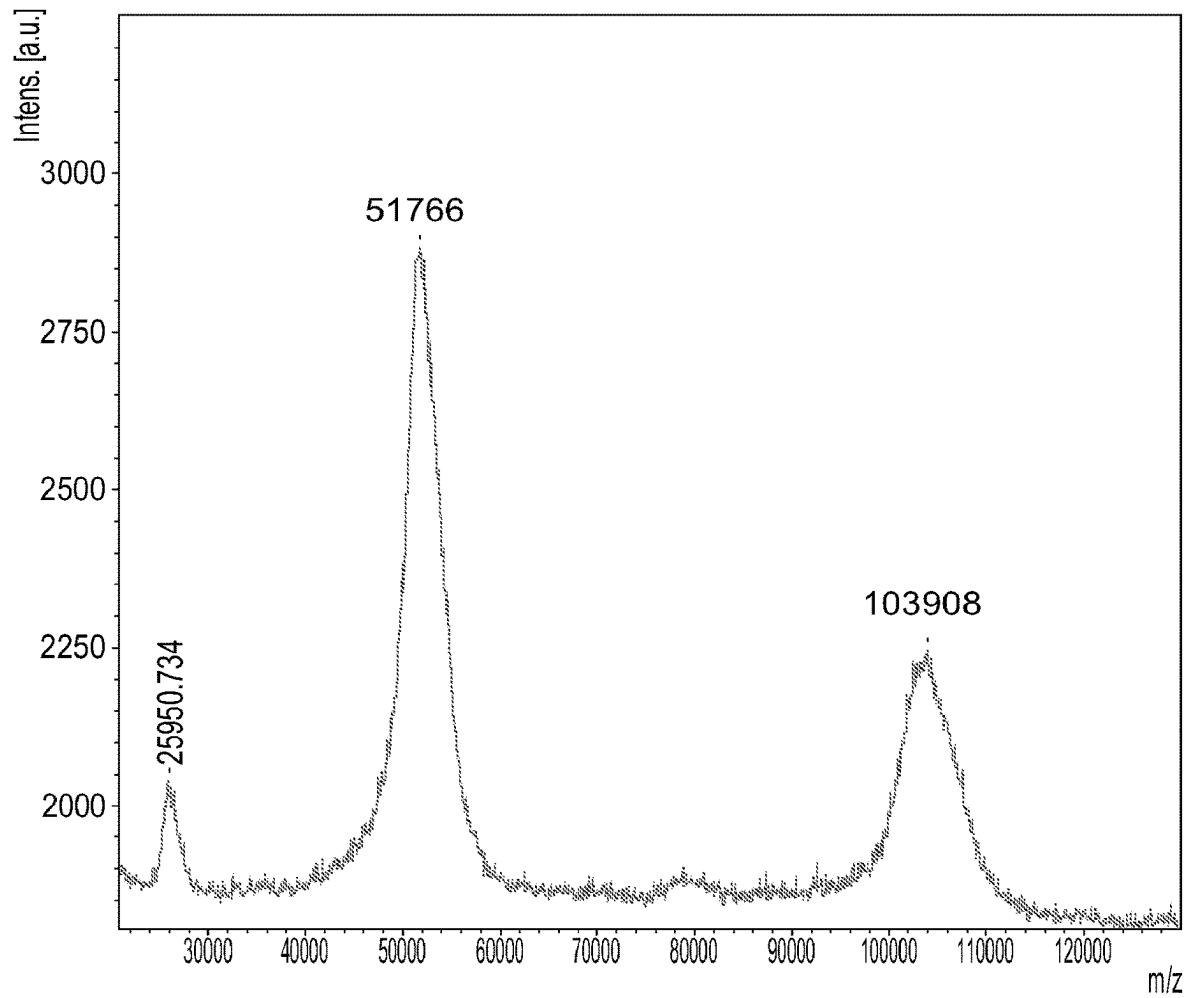


FIG. 10

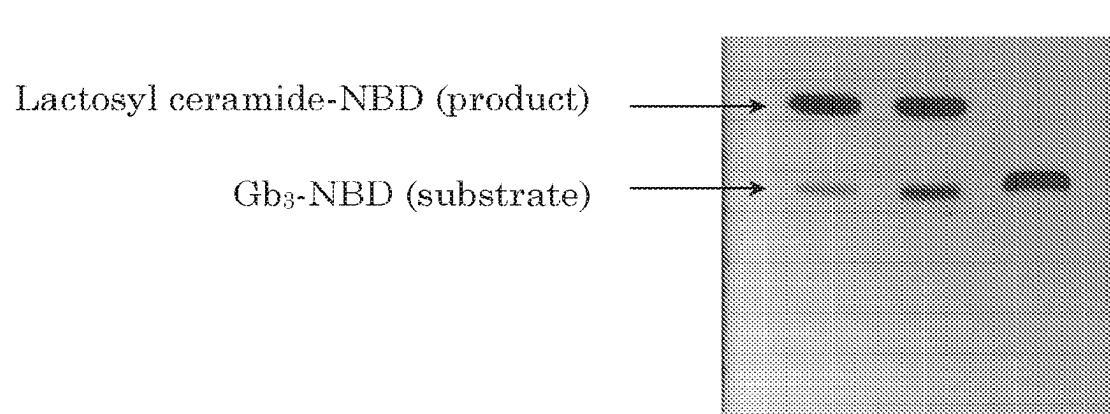


FIG. 11

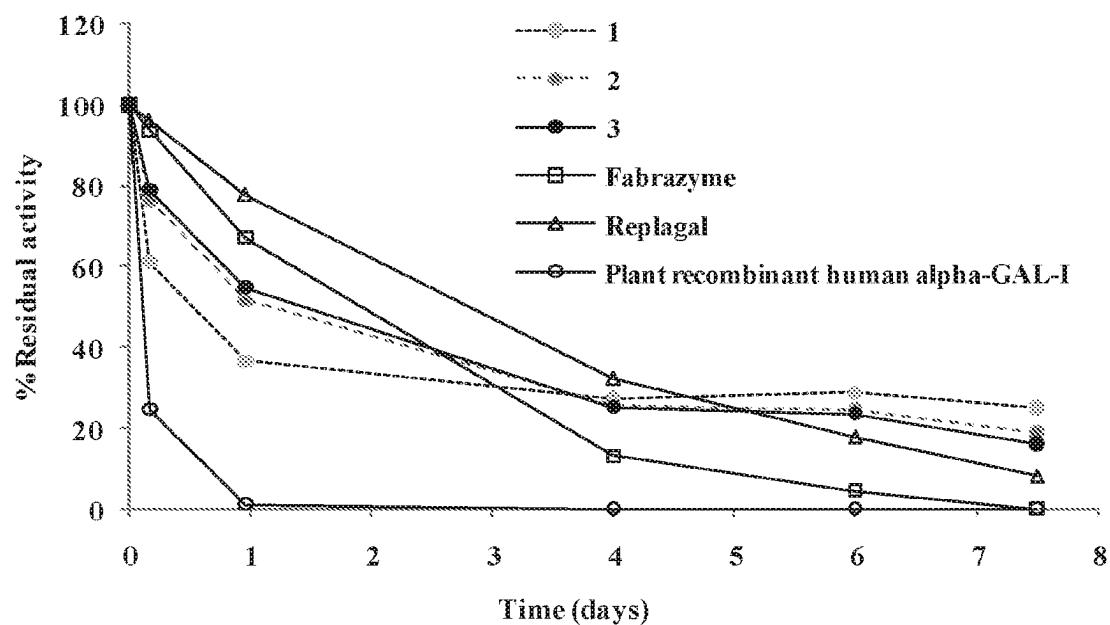


FIG. 12A

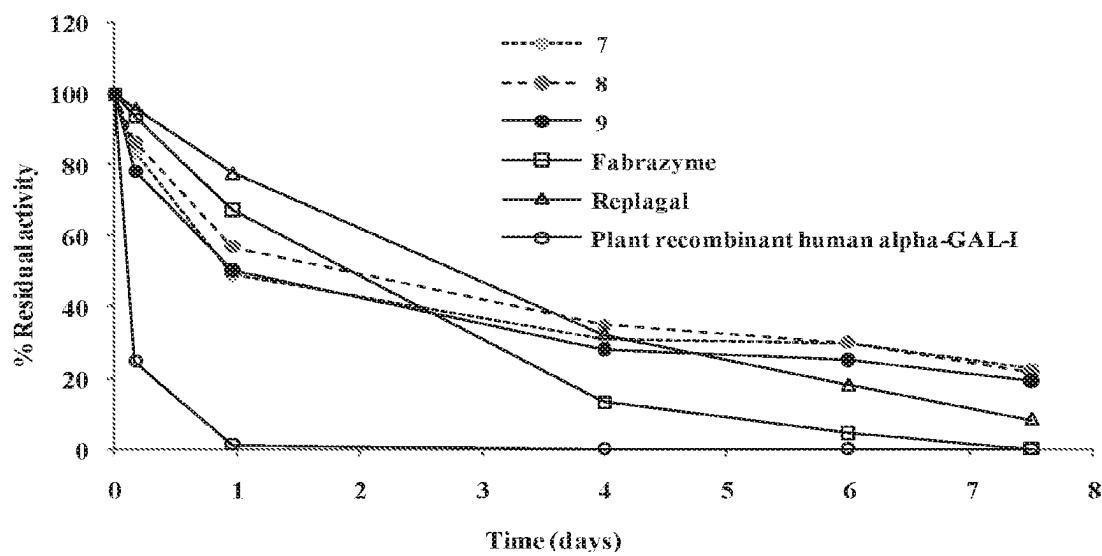


FIG. 12B

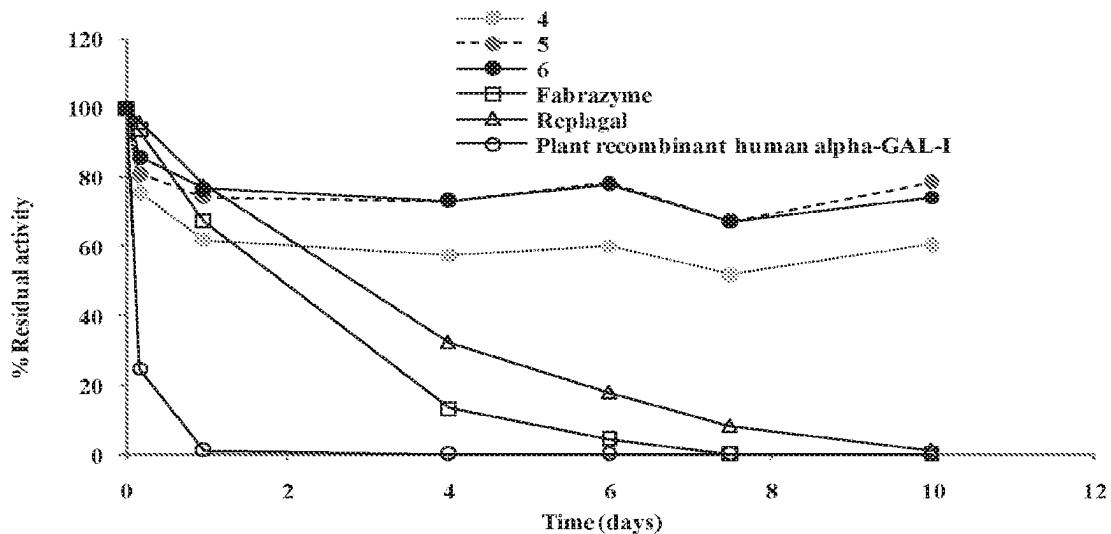


FIG. 12C

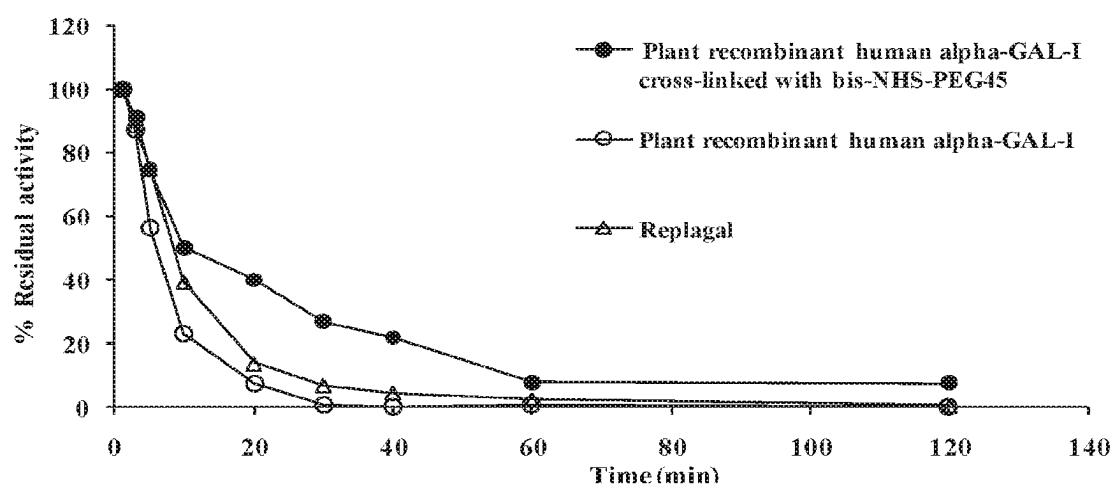


FIG. 13

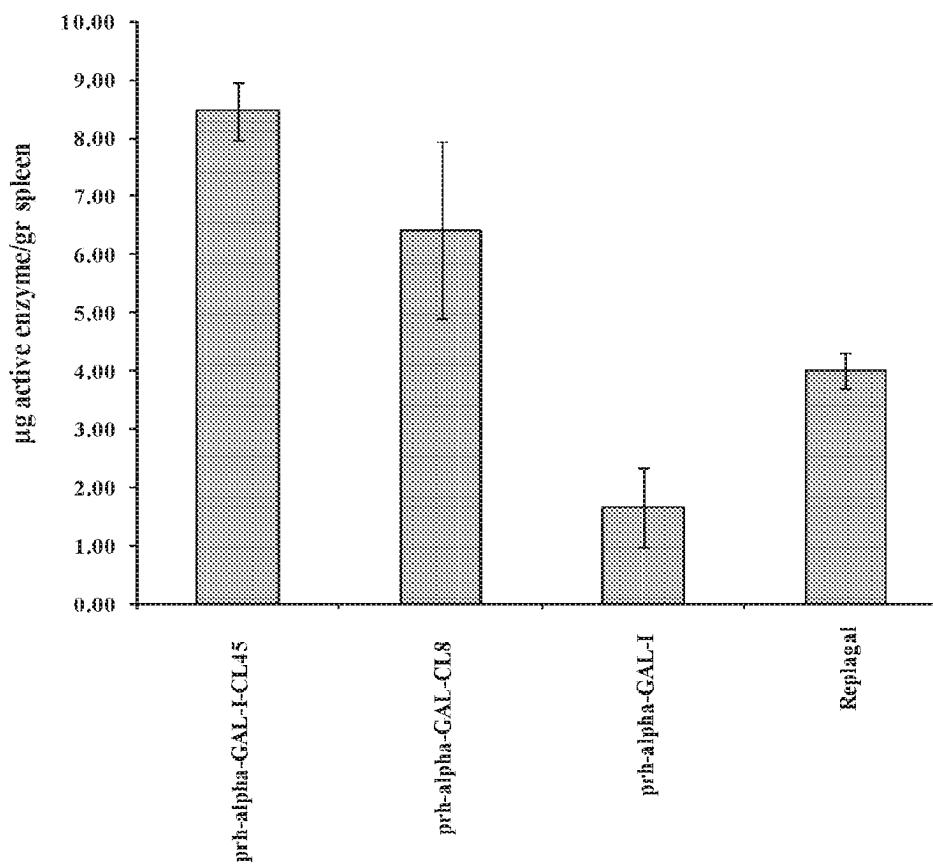


FIG. 14A

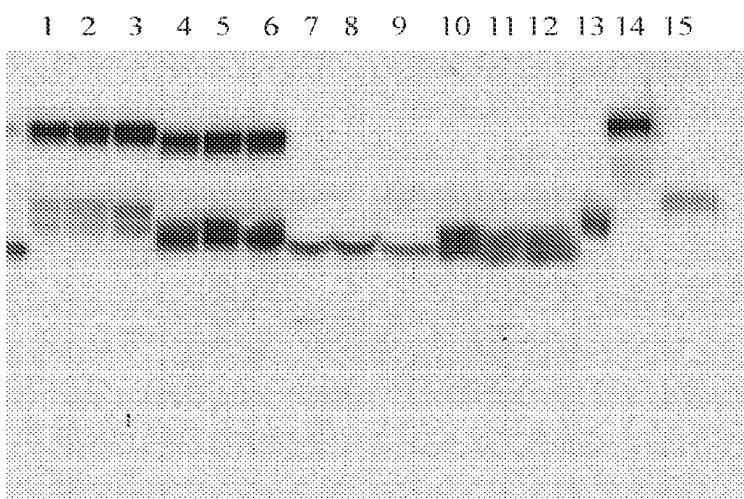


FIG. 14B

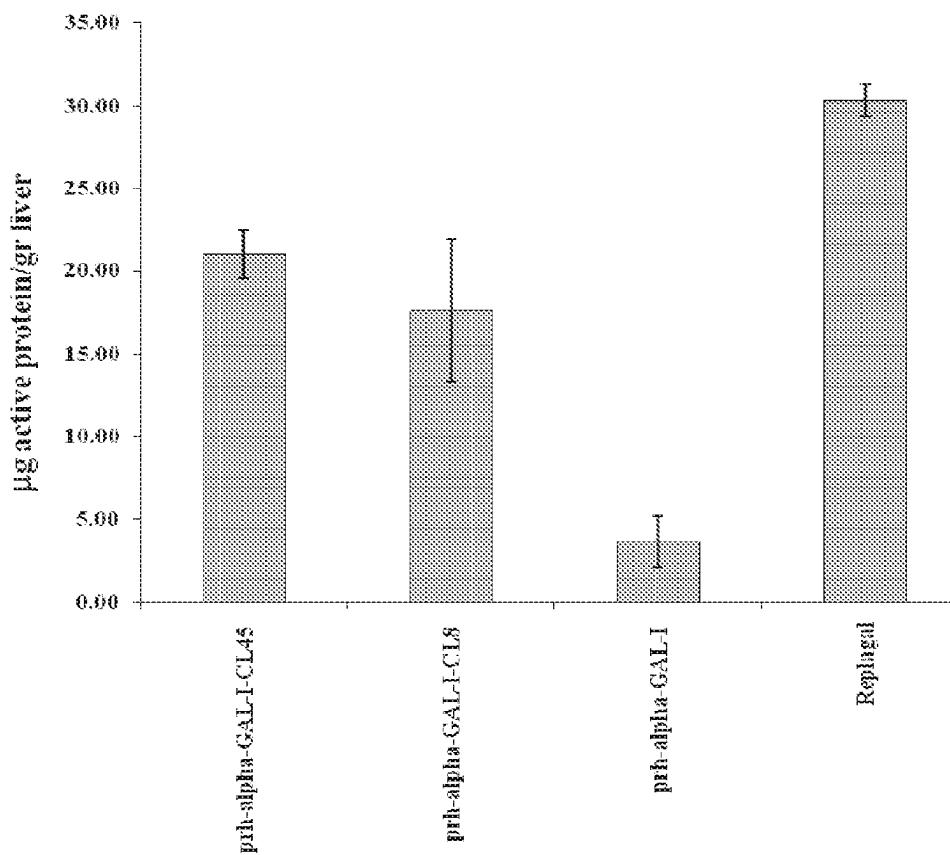


FIG. 15A

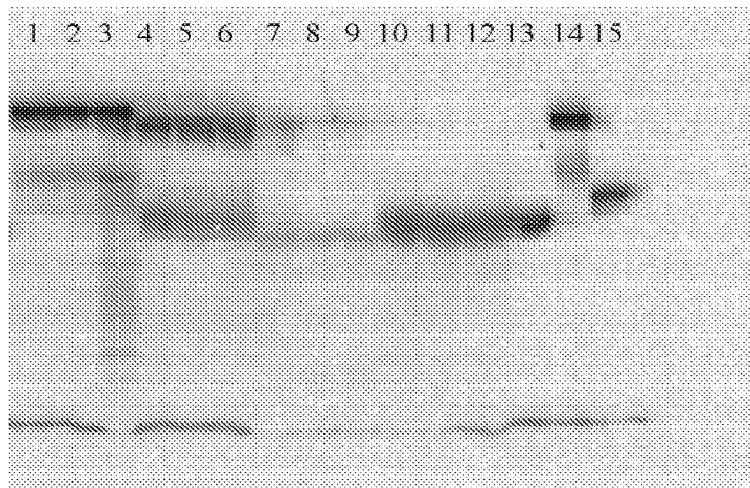


FIG. 15B

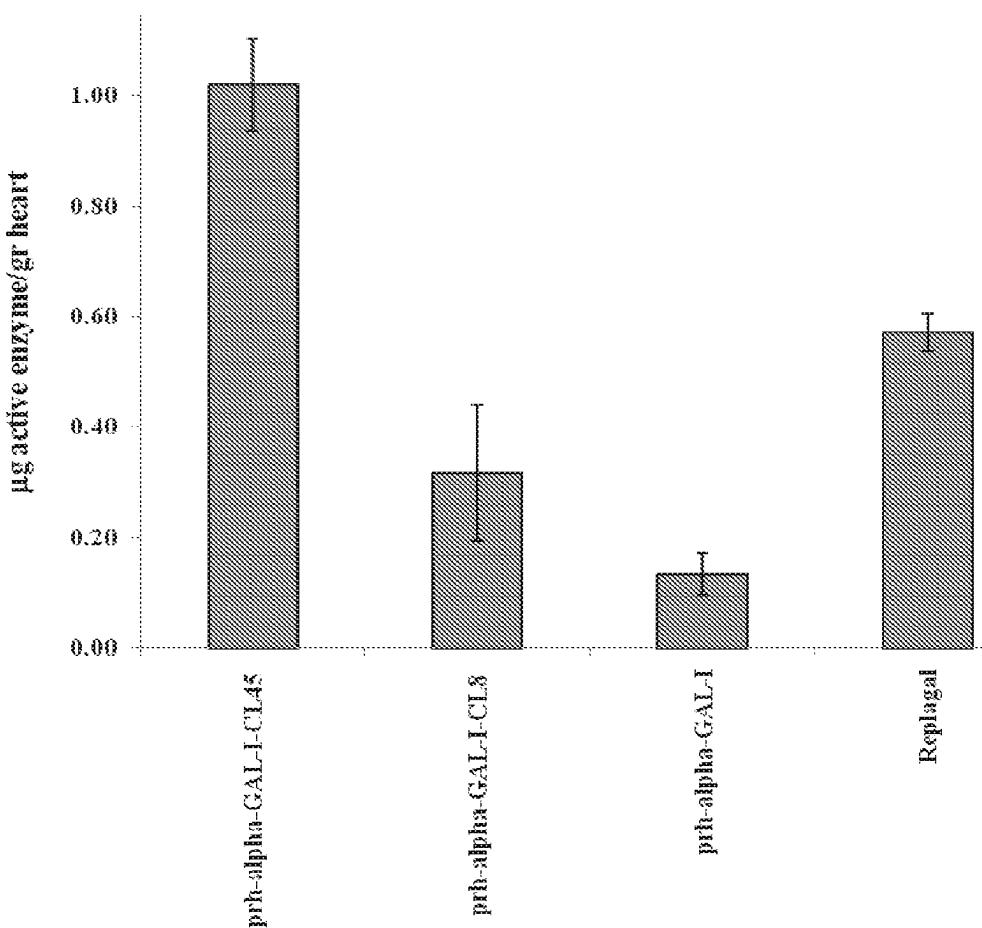


FIG. 16

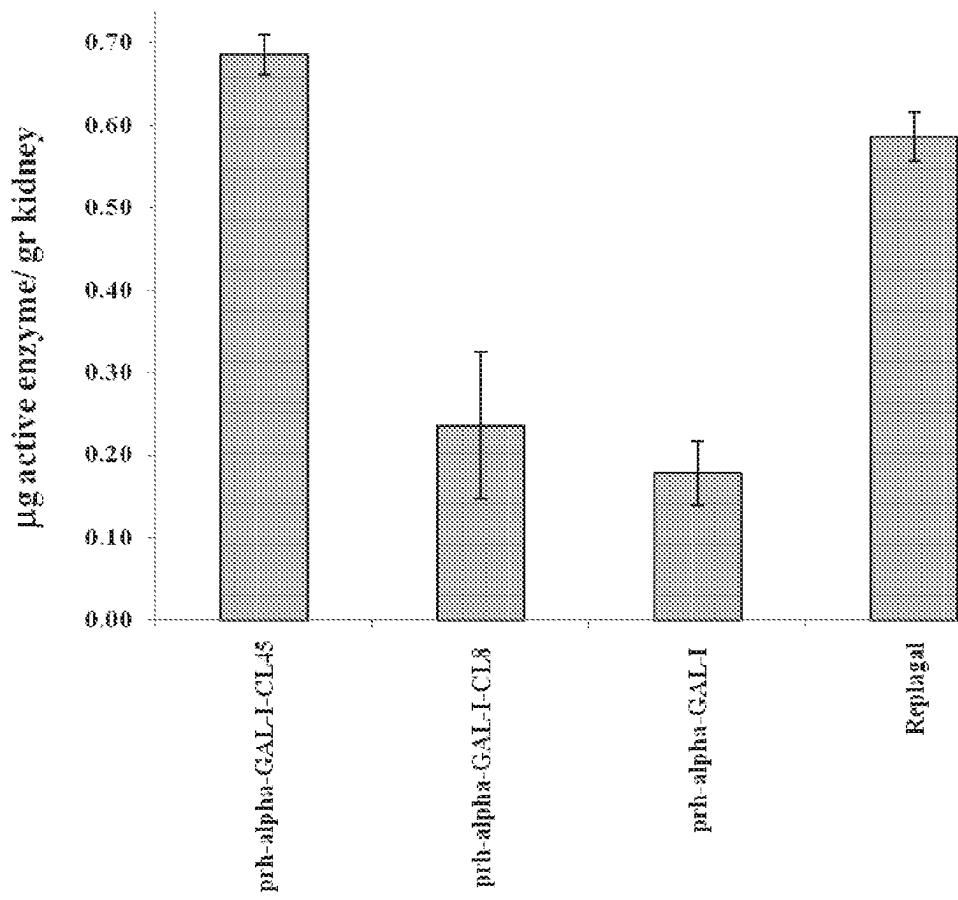


FIG. 17

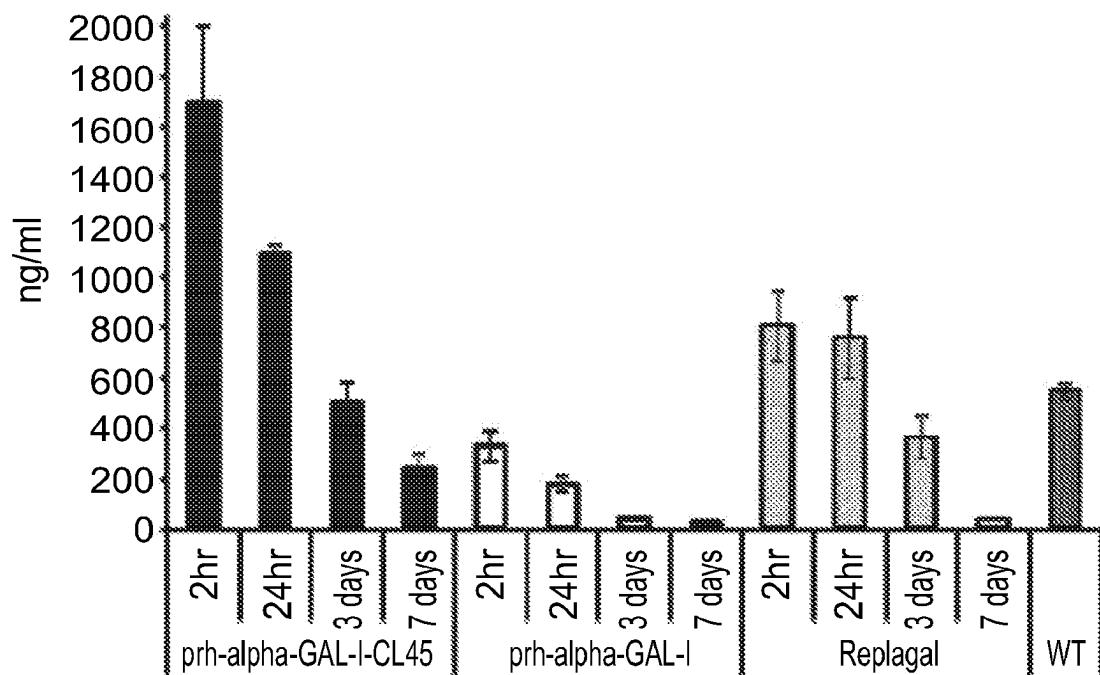


FIG. 18

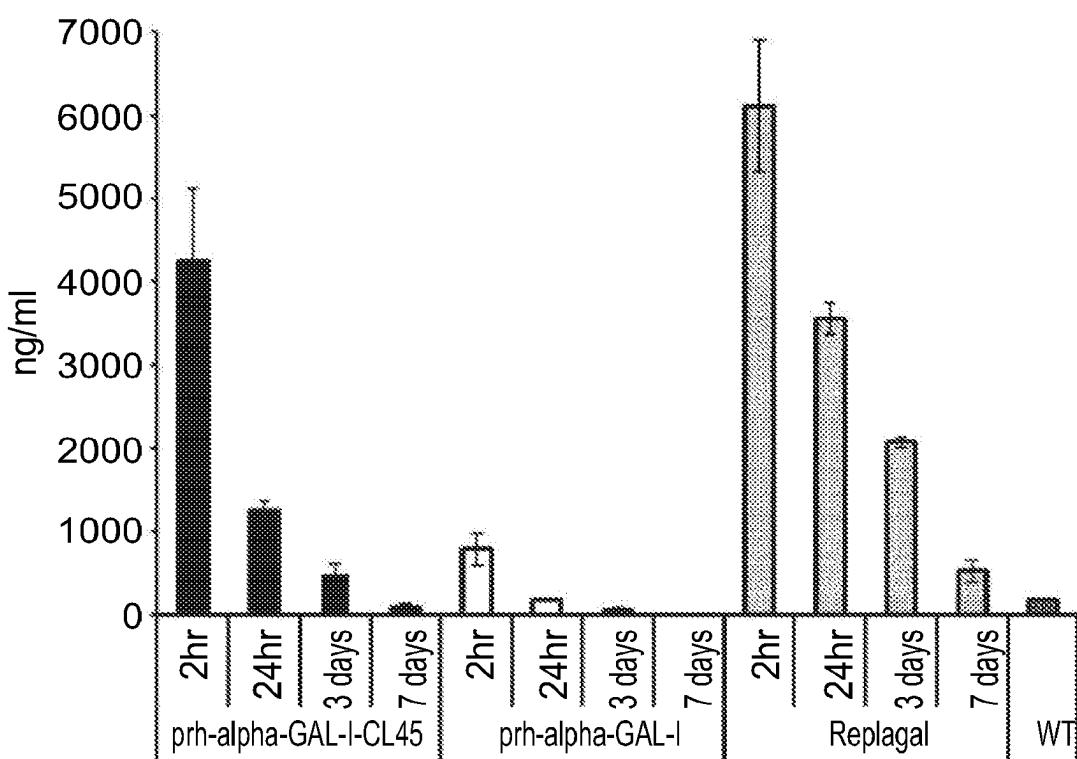


FIG. 19

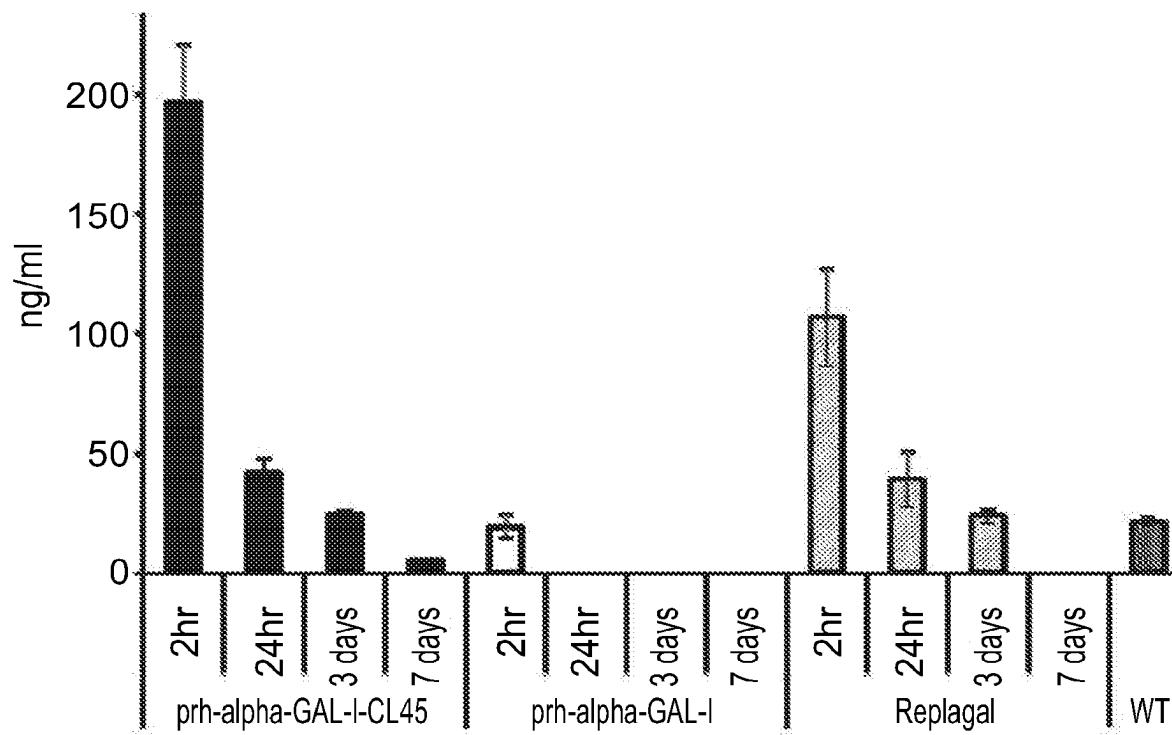


FIG. 20

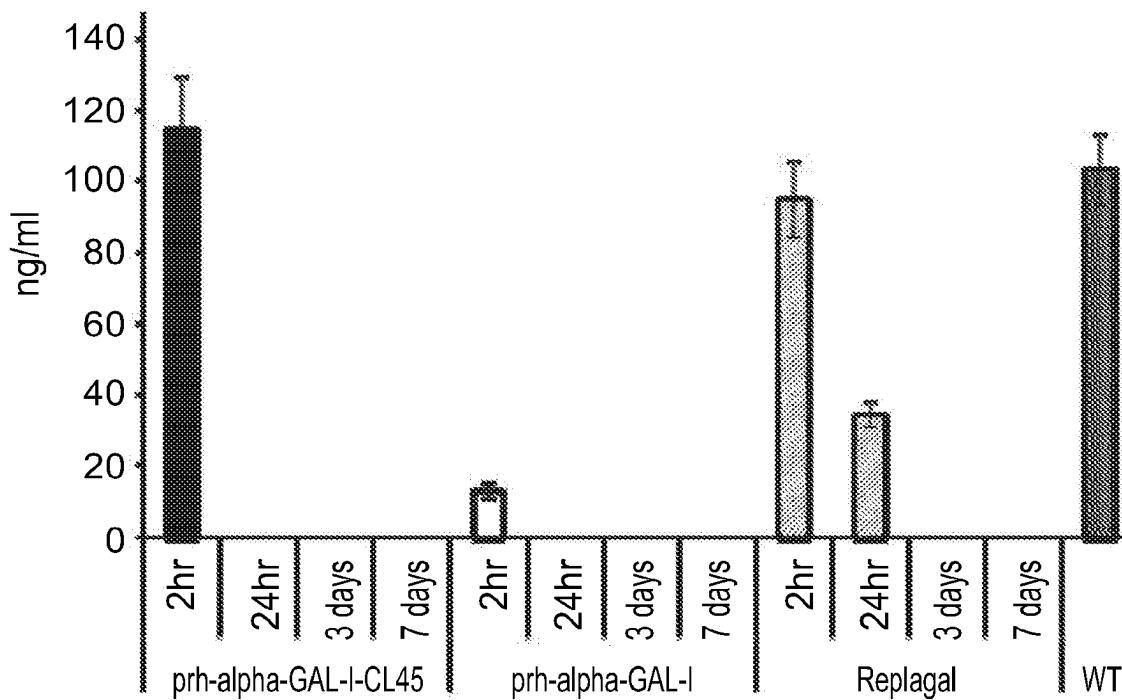


FIG. 21

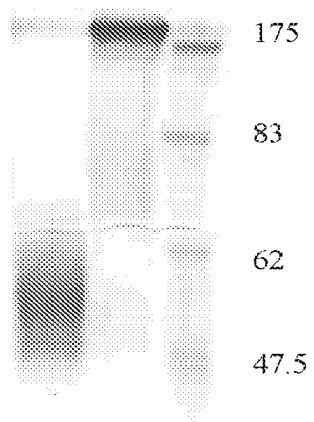


FIG. 22

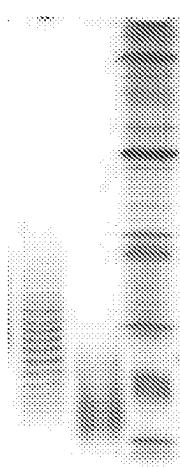


FIG. 23

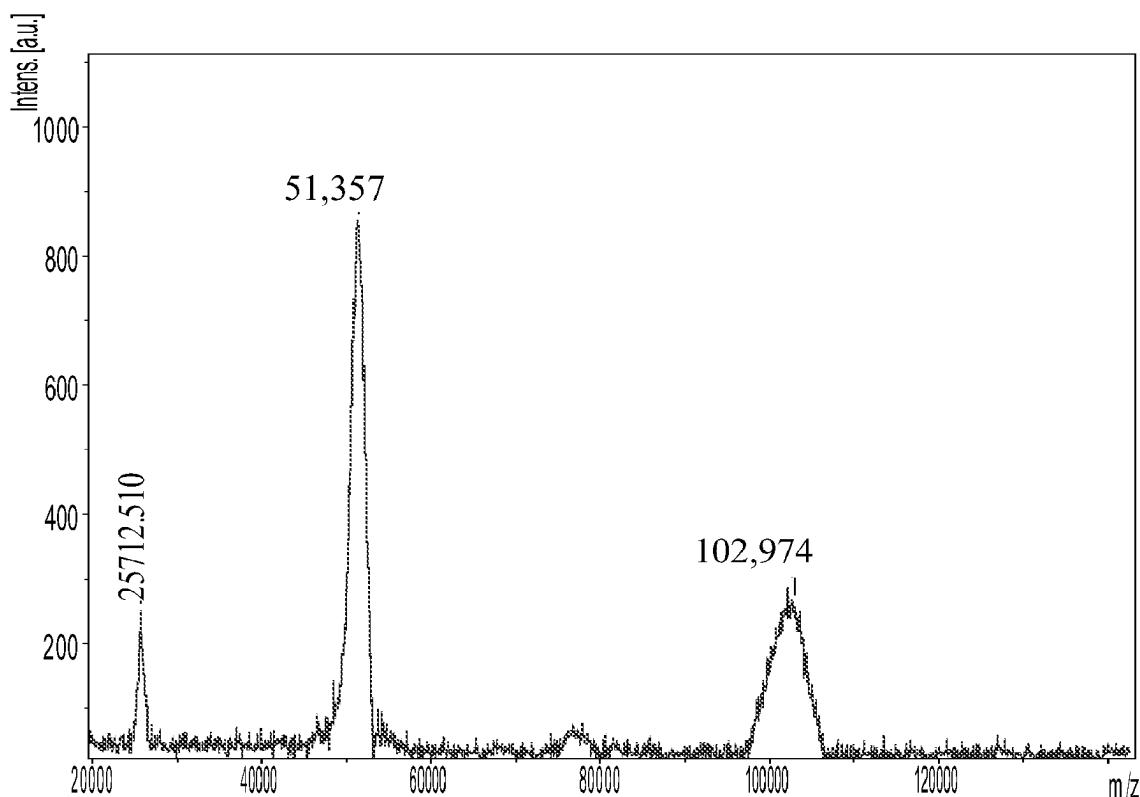


FIG. 24A

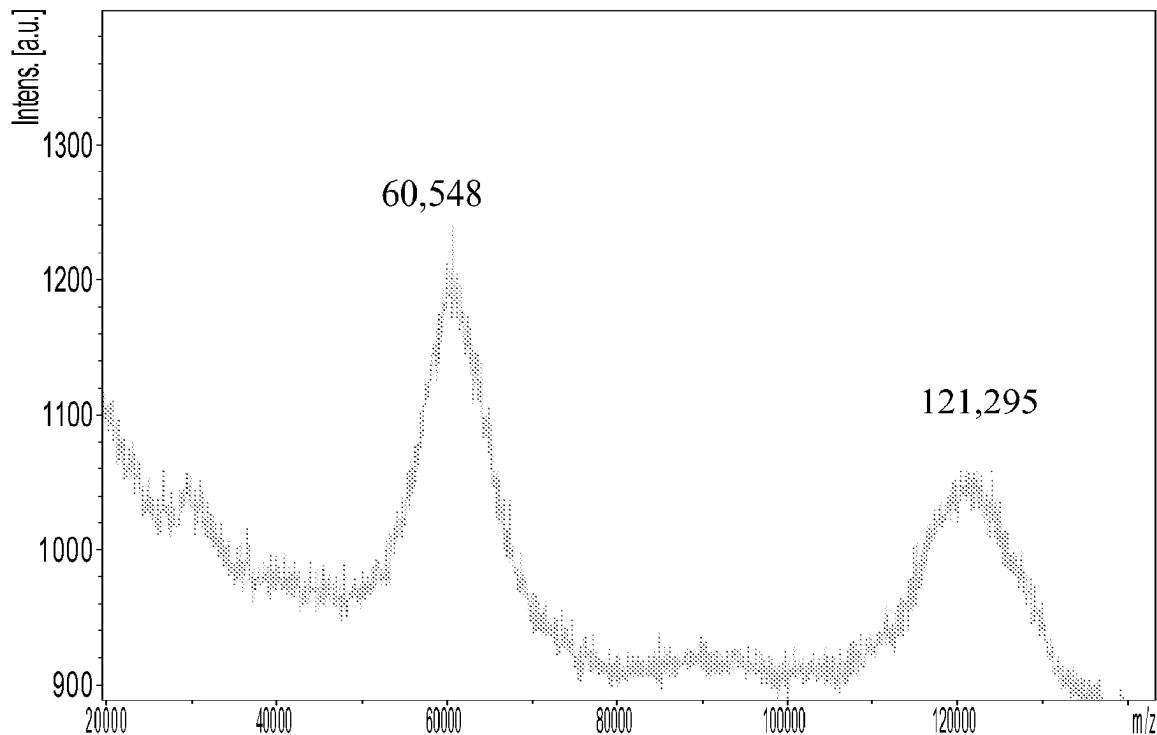


FIG. 24B

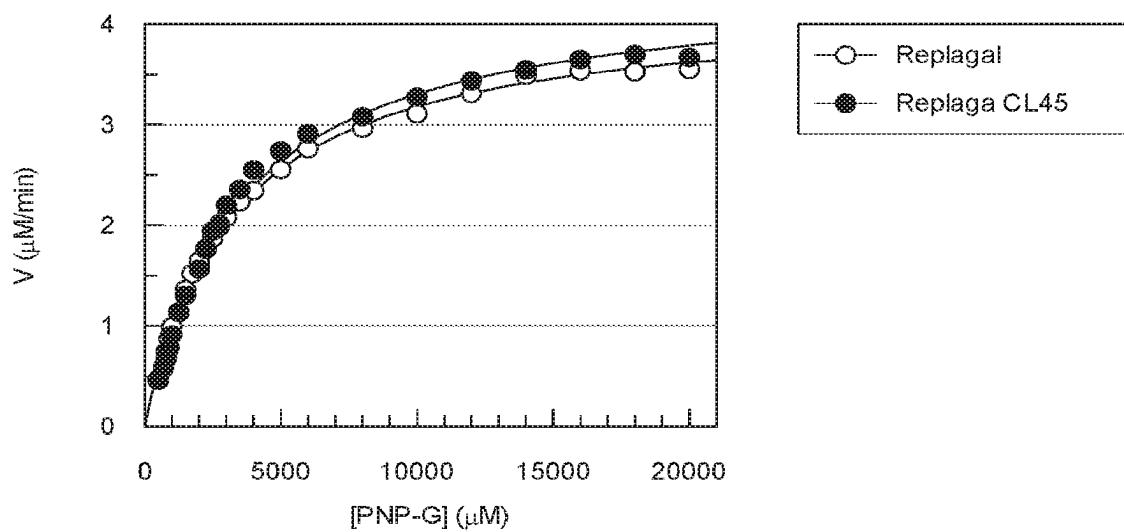


FIG. 25

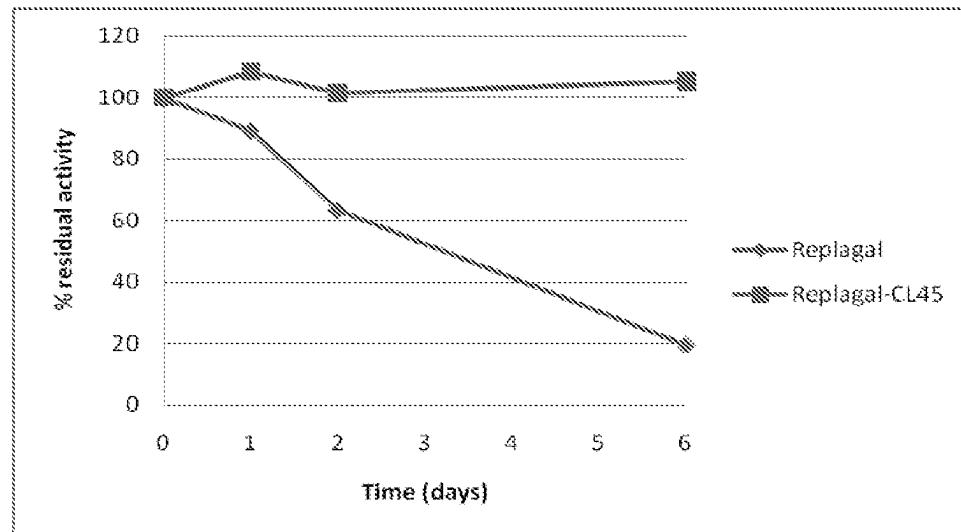


FIG. 26A

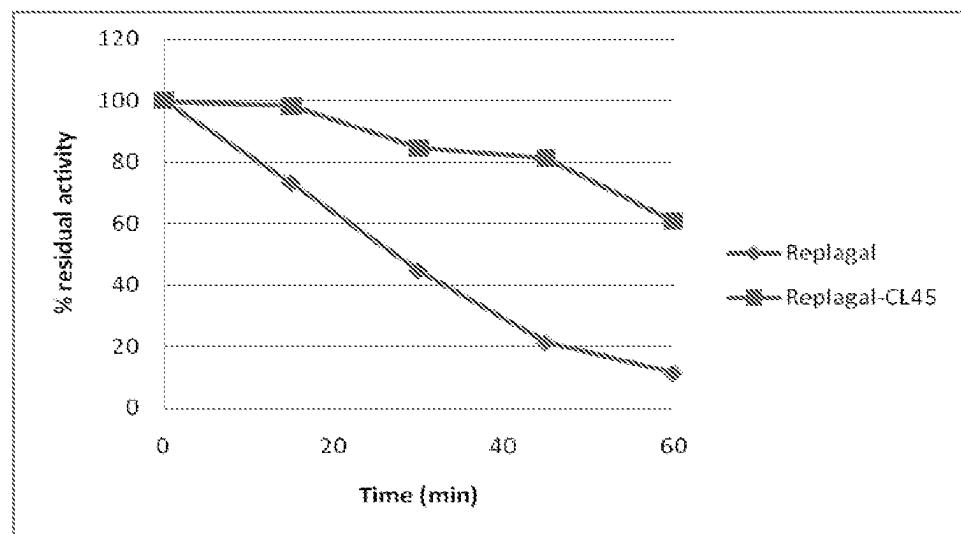


FIG. 26B

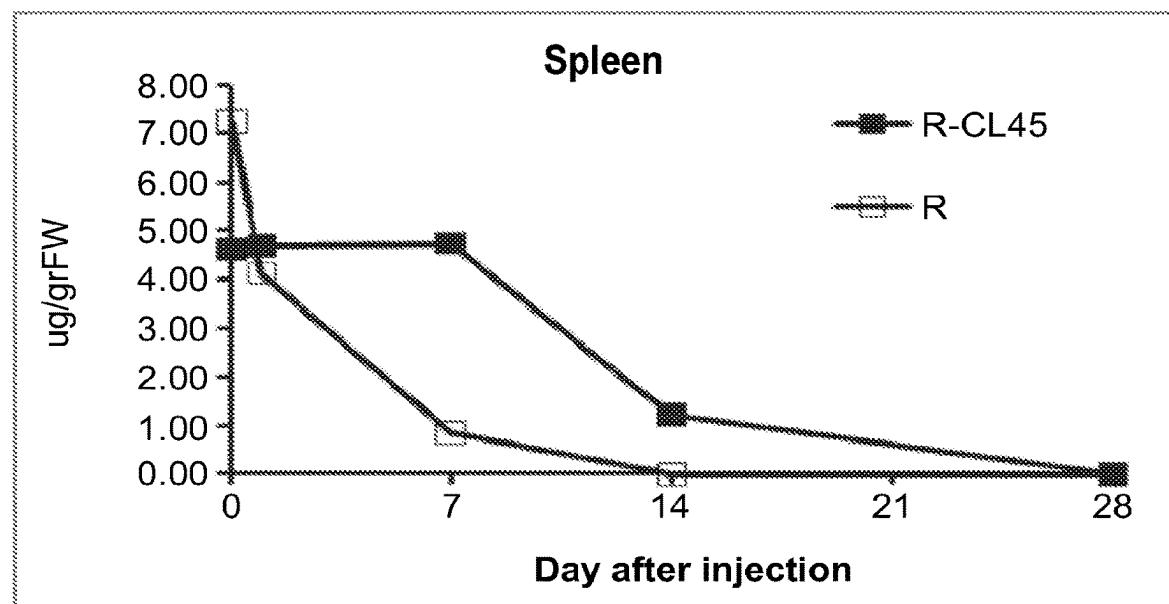


FIG. 27A

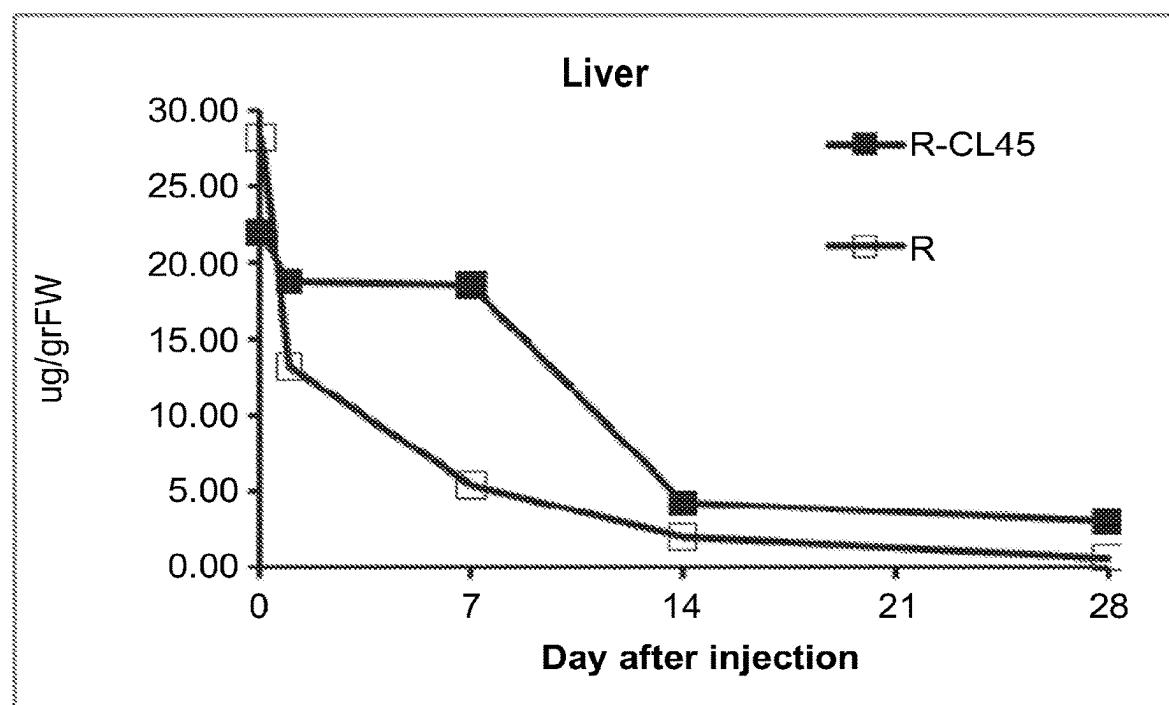


FIG. 27B

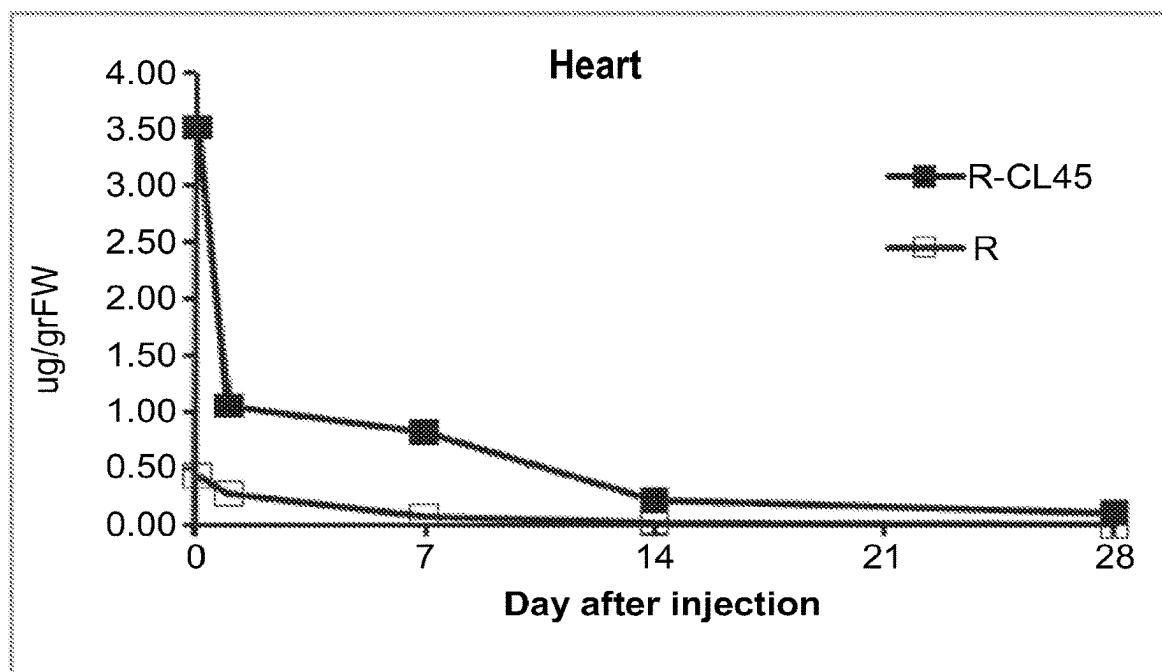


FIG. 27C

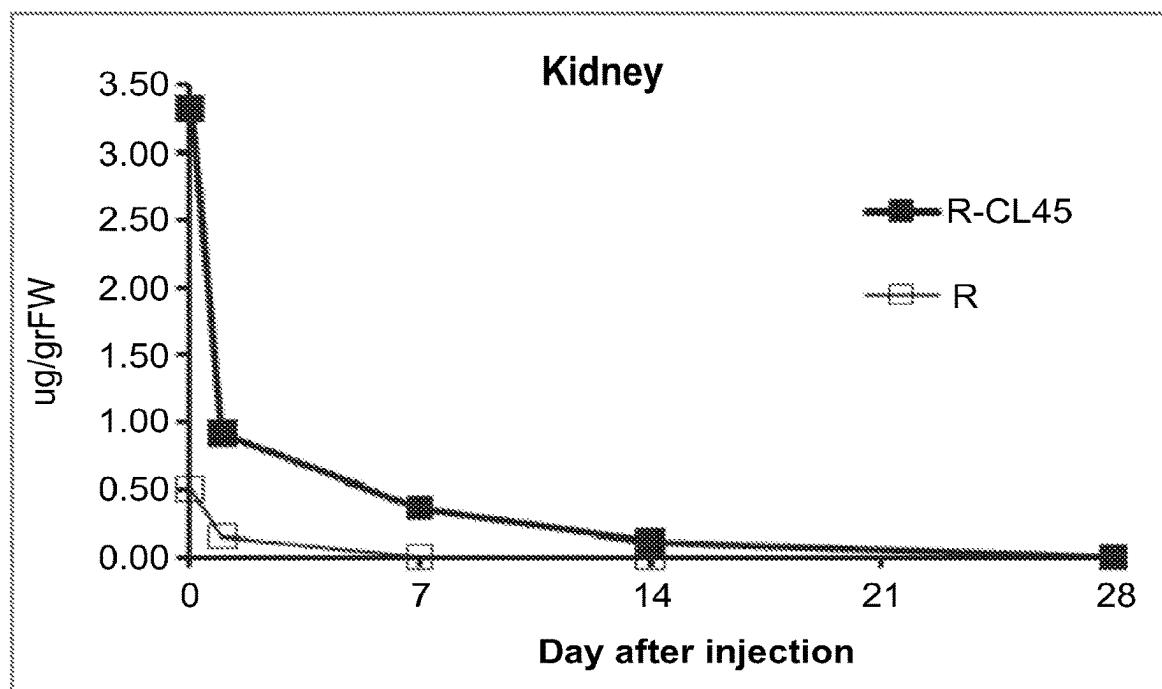
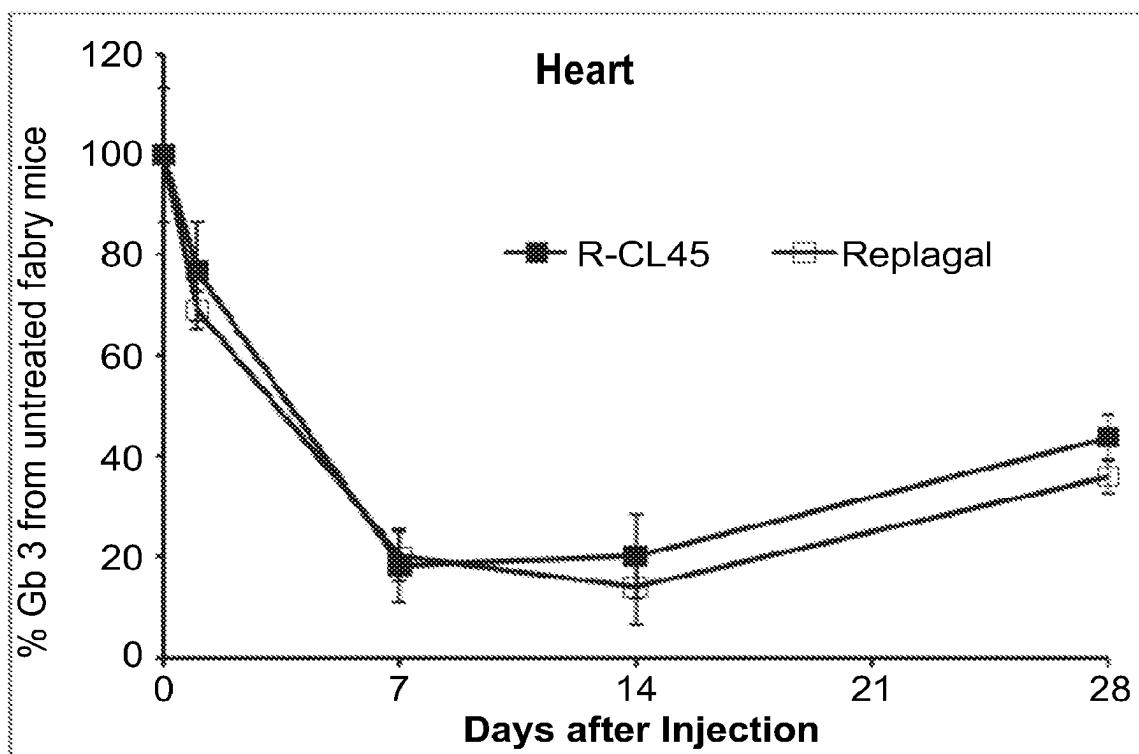
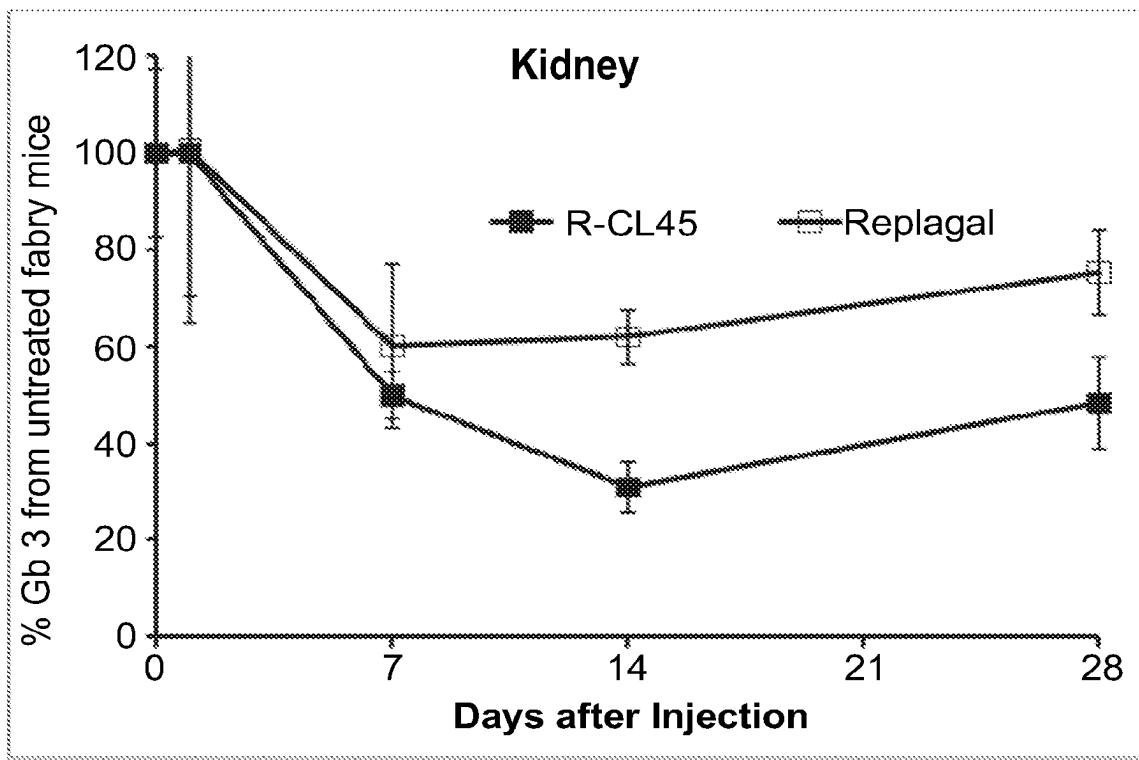


FIG. 27D



**FIG. 28A**



**FIG. 28B**

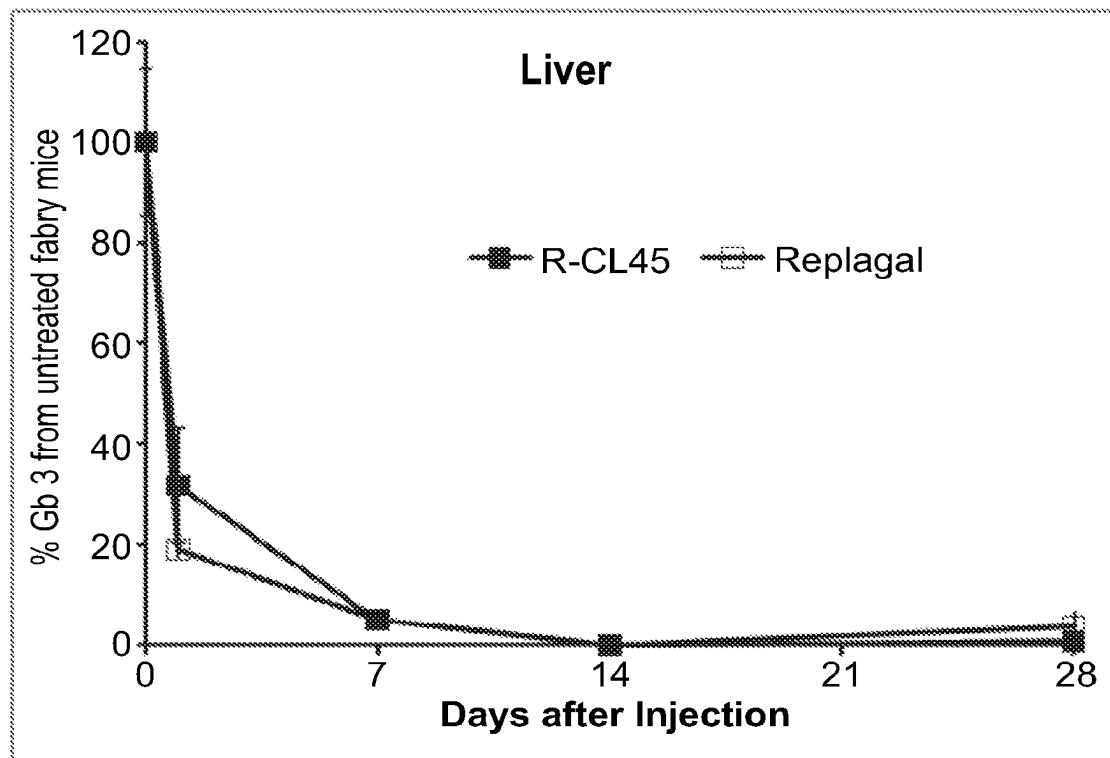


FIG. 28C

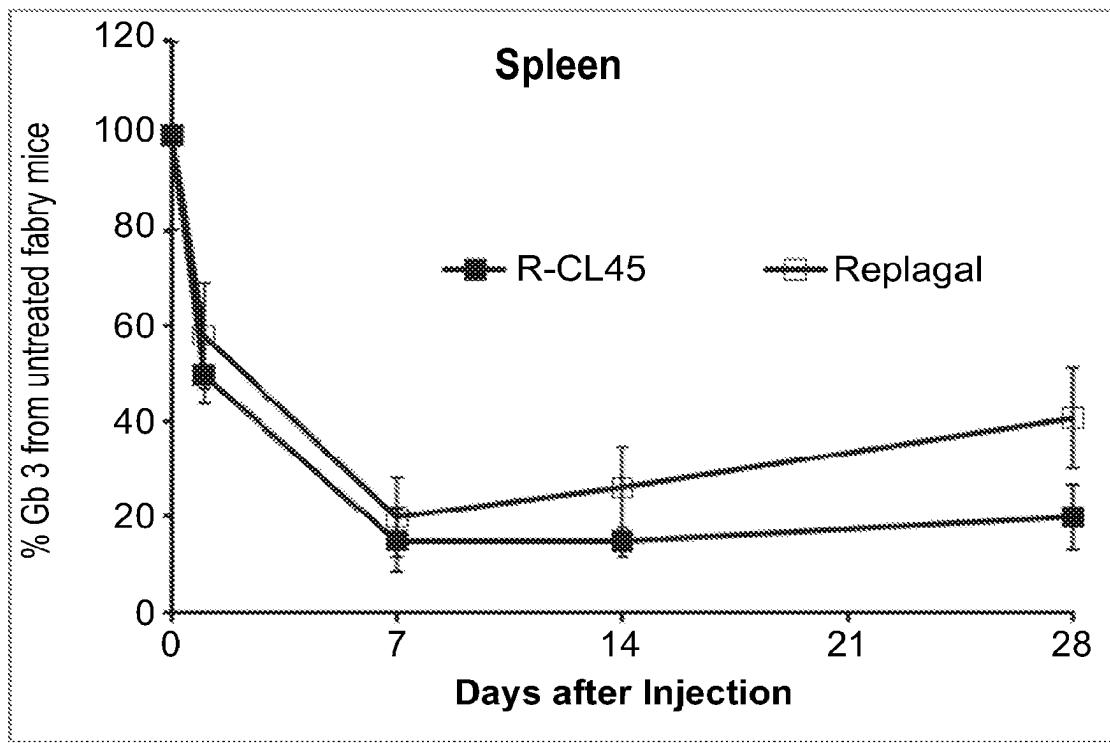


FIG. 28D

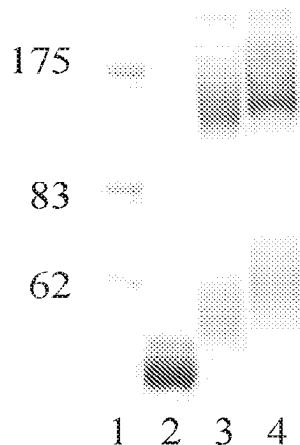


FIG. 29A

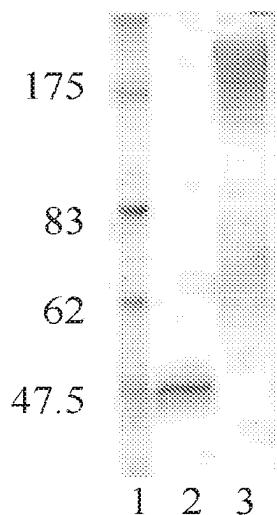
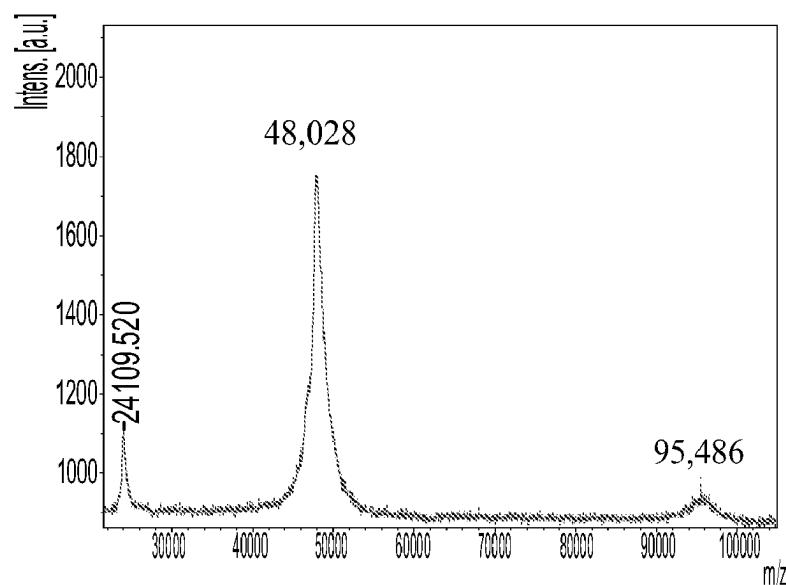
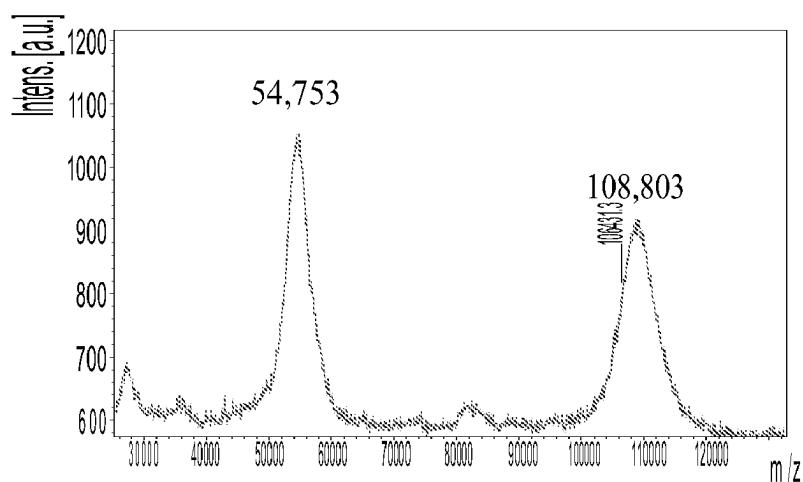
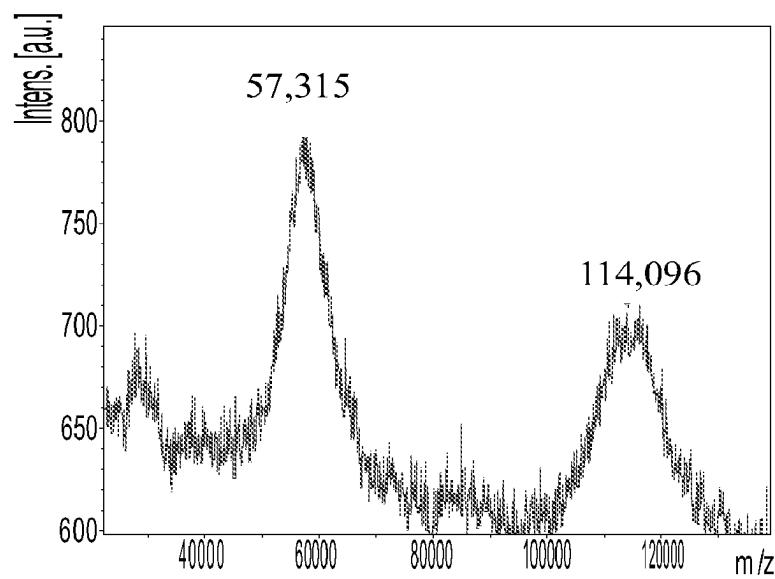


FIG. 29B

**FIG. 30A****FIG. 30B****FIG. 30C**

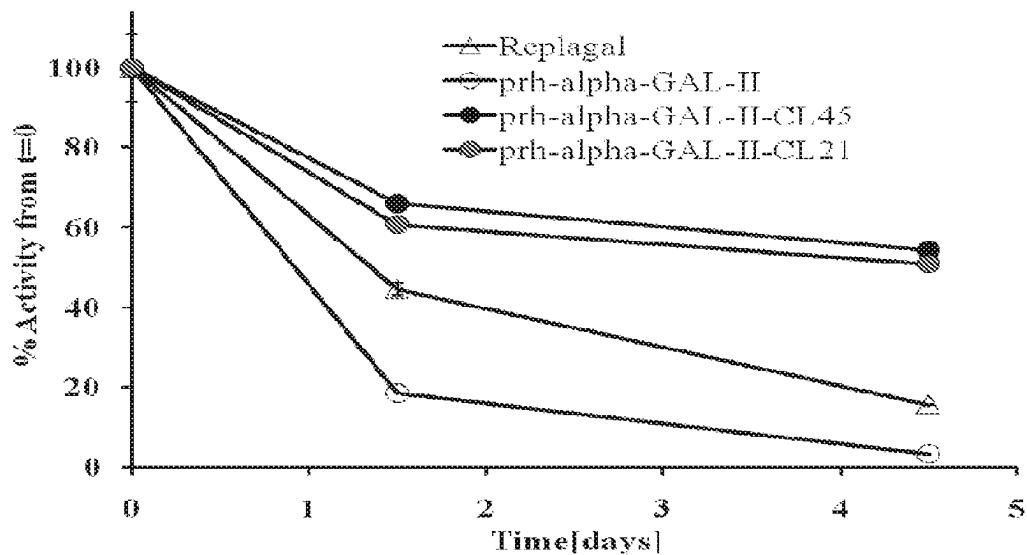


FIG. 31A

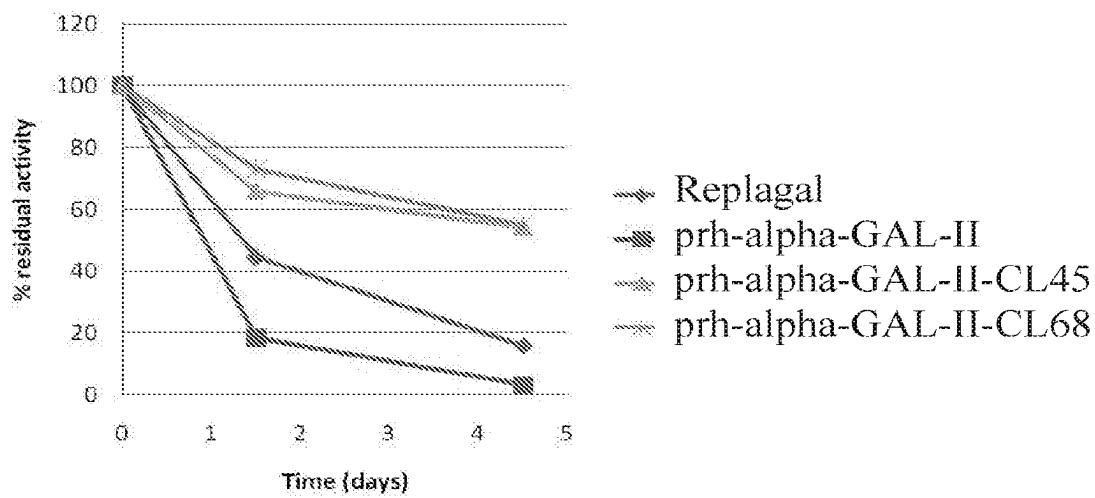


FIG. 31B

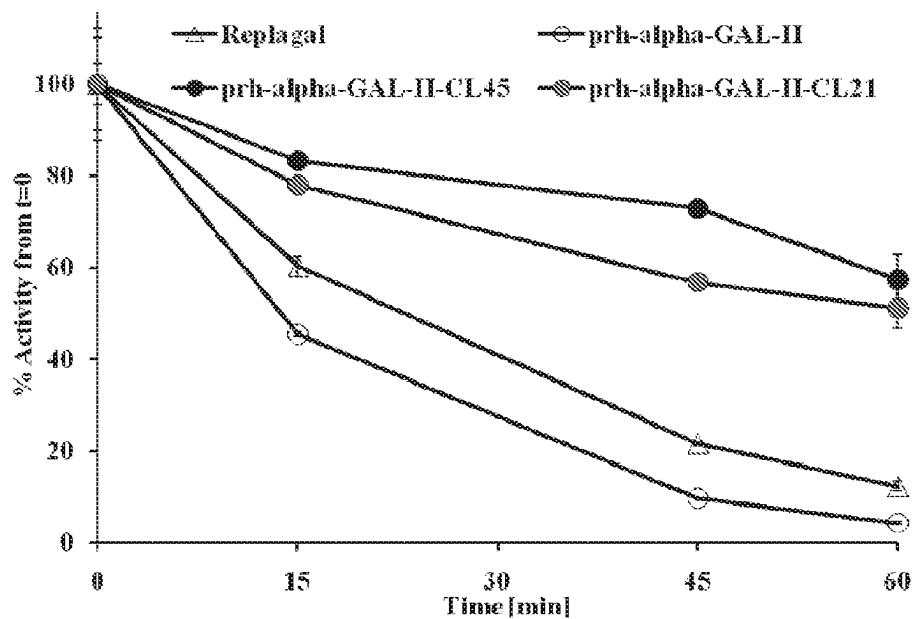


FIG. 31C

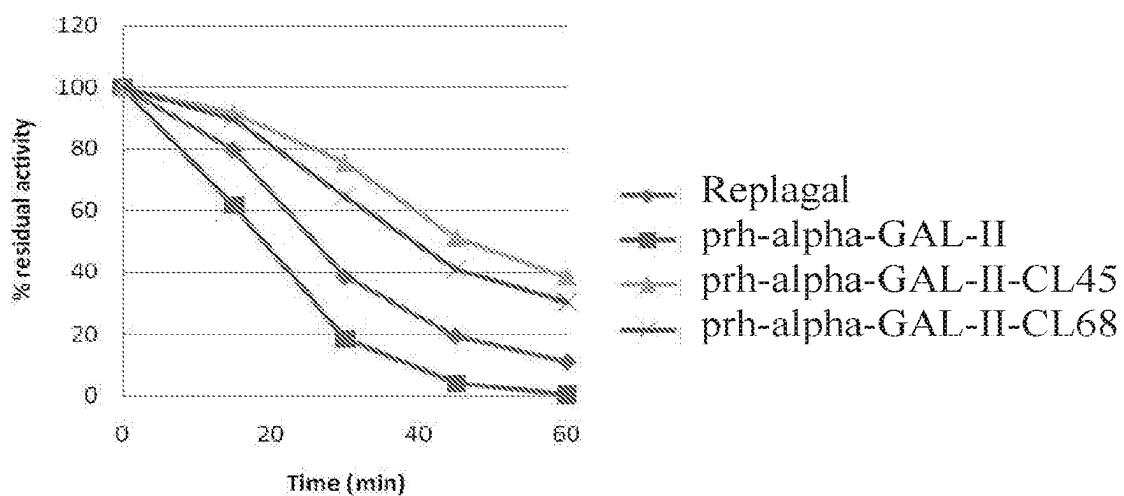


FIG. 31D

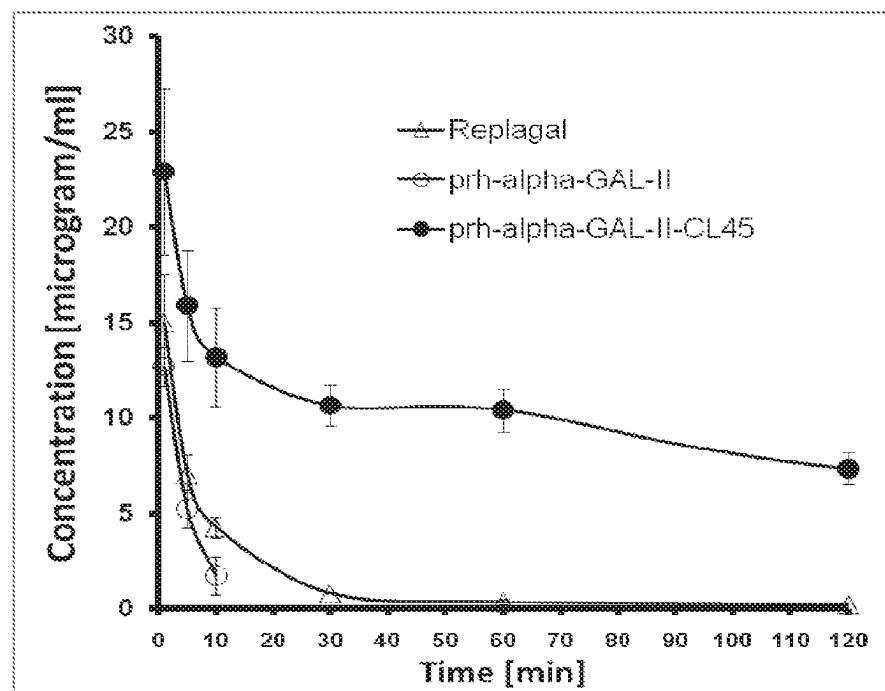


FIG. 32A

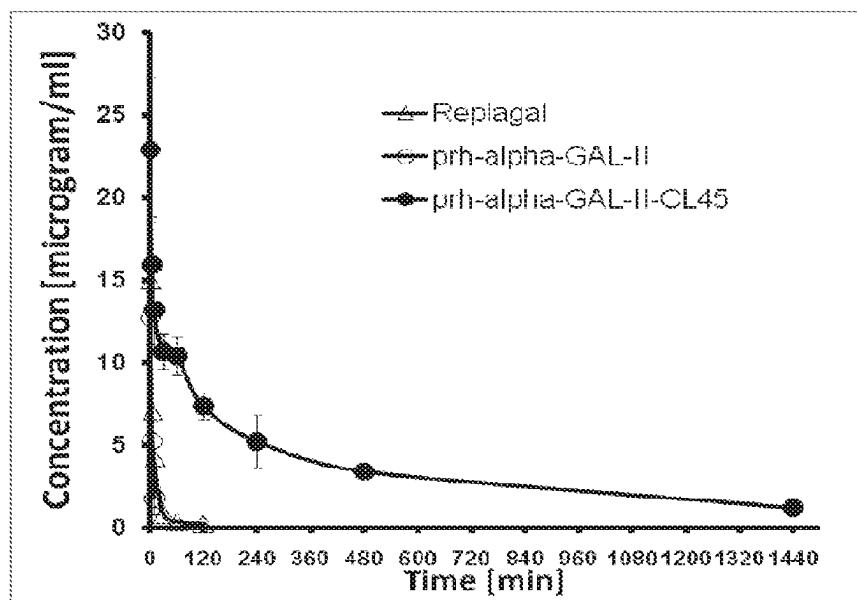


FIG. 32B

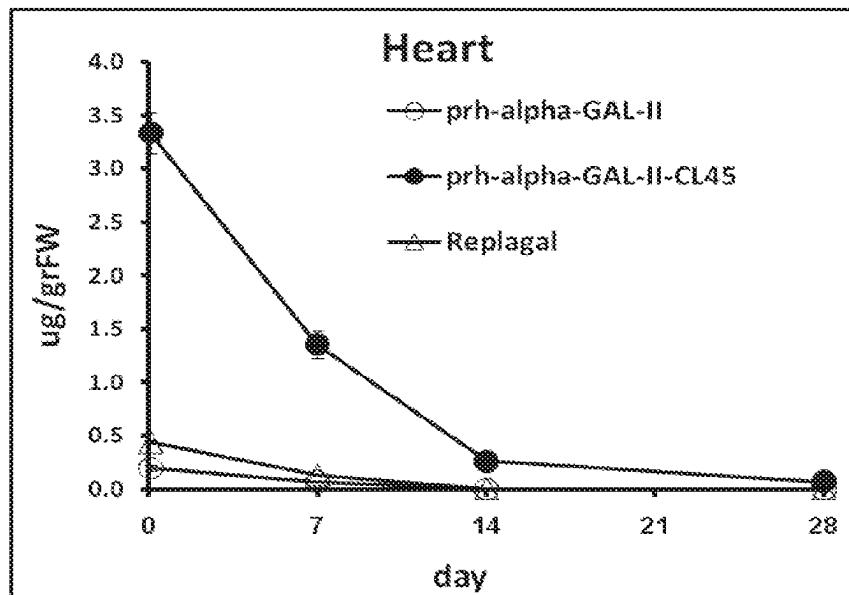


FIG. 33A

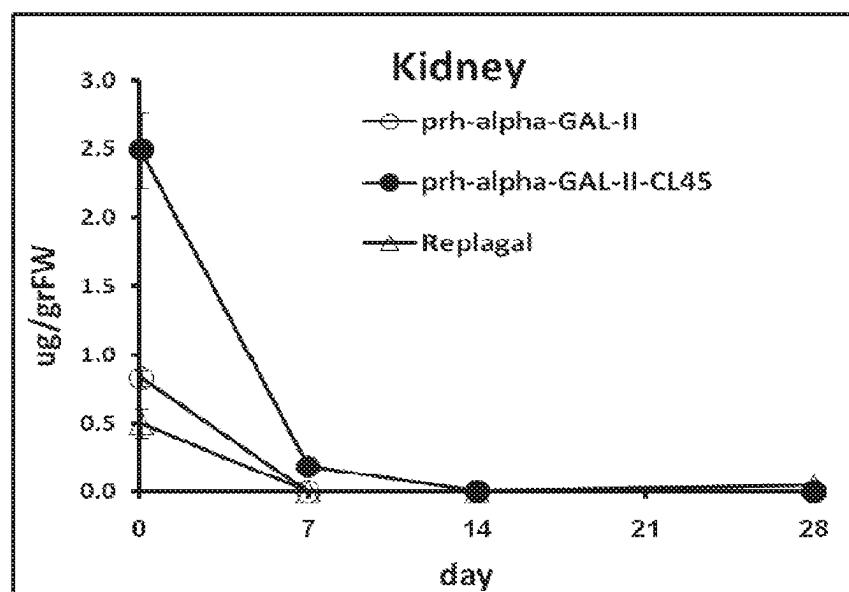


FIG. 33B

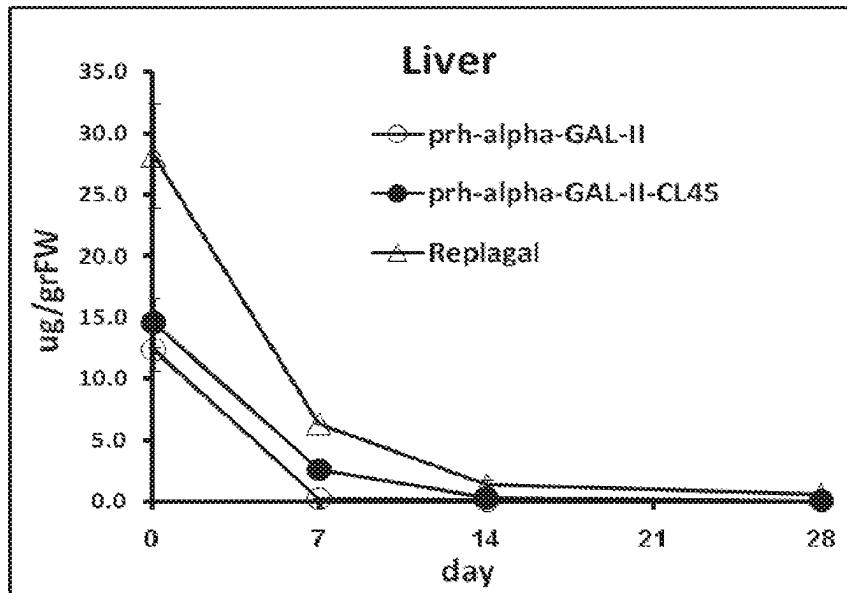


FIG. 33C

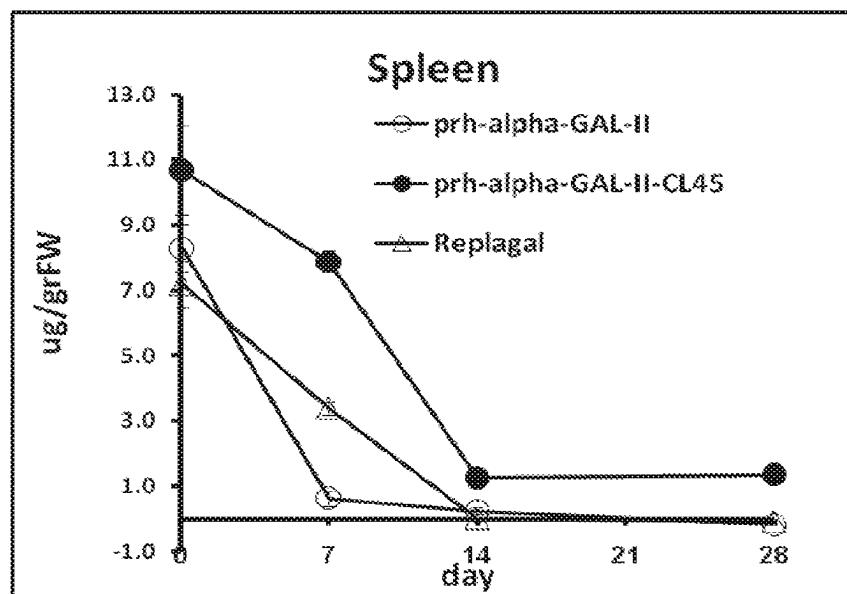


FIG. 33D

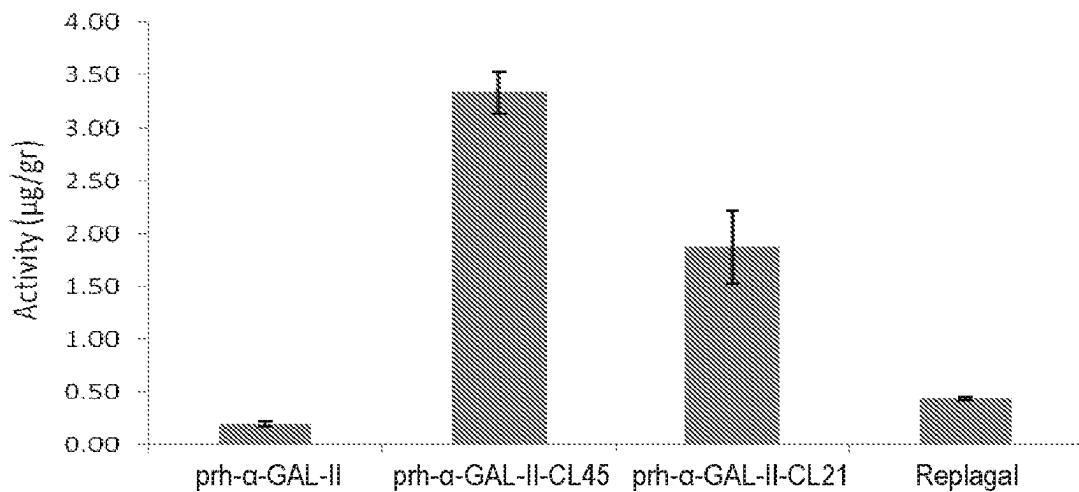


FIG. 33E

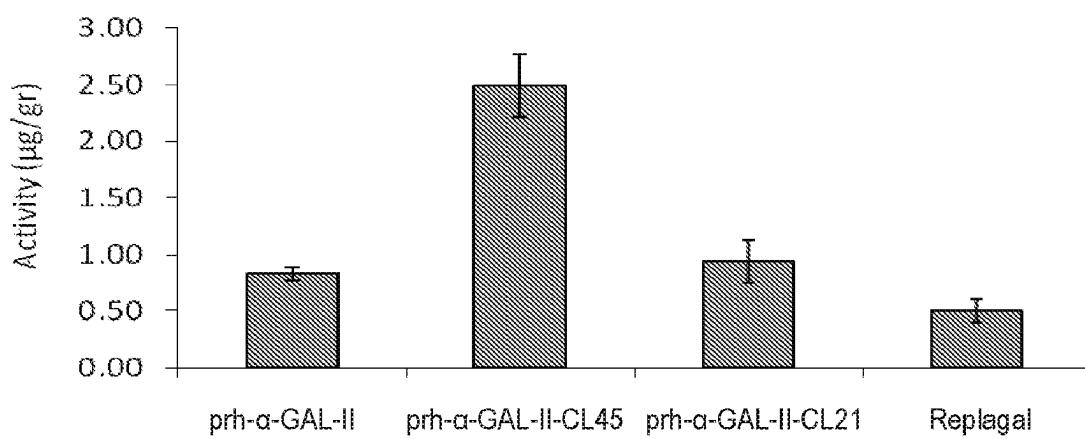


FIG. 33F

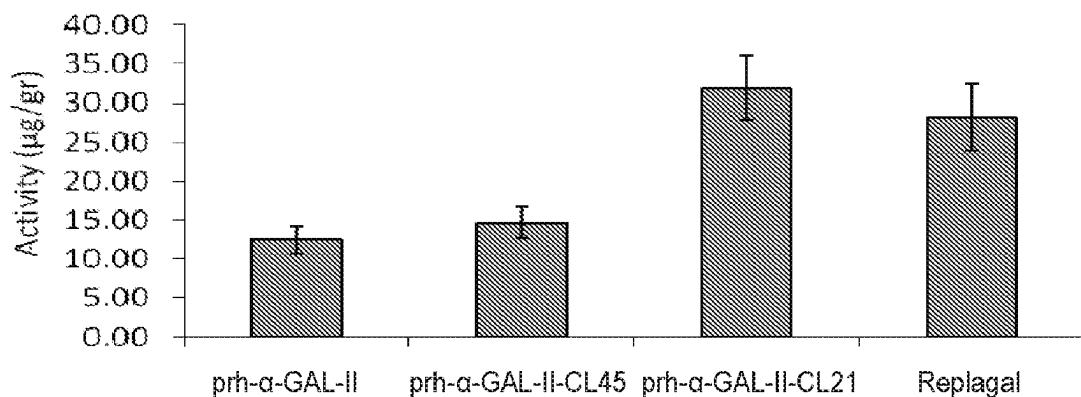


FIG. 33G

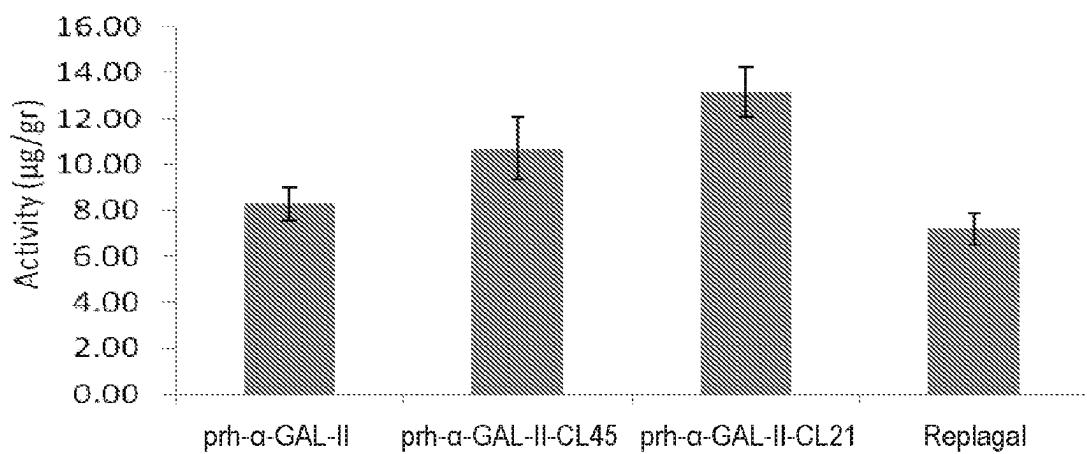


FIG. 33H

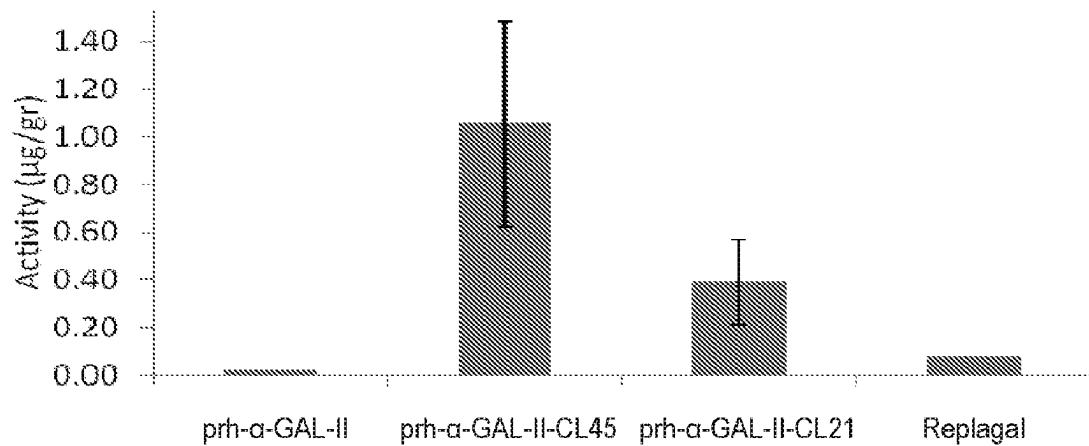


FIG. 33I

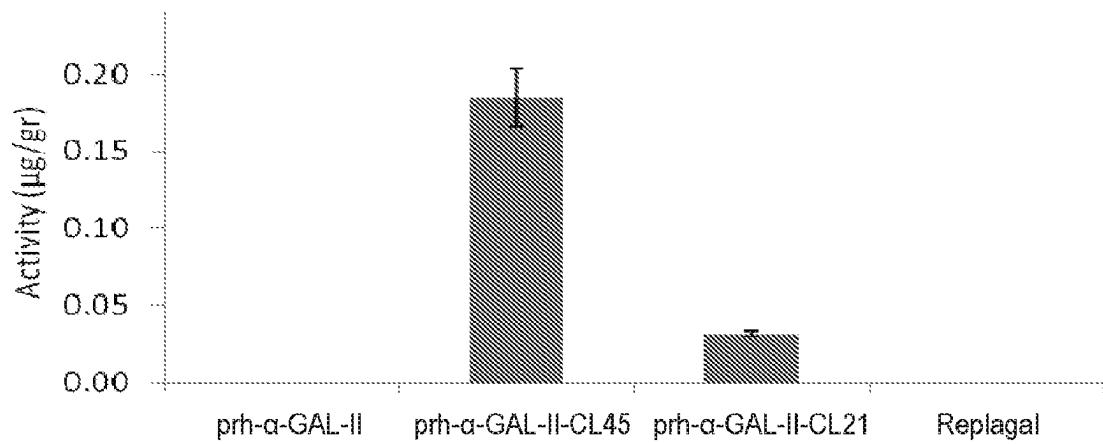


FIG. 33J

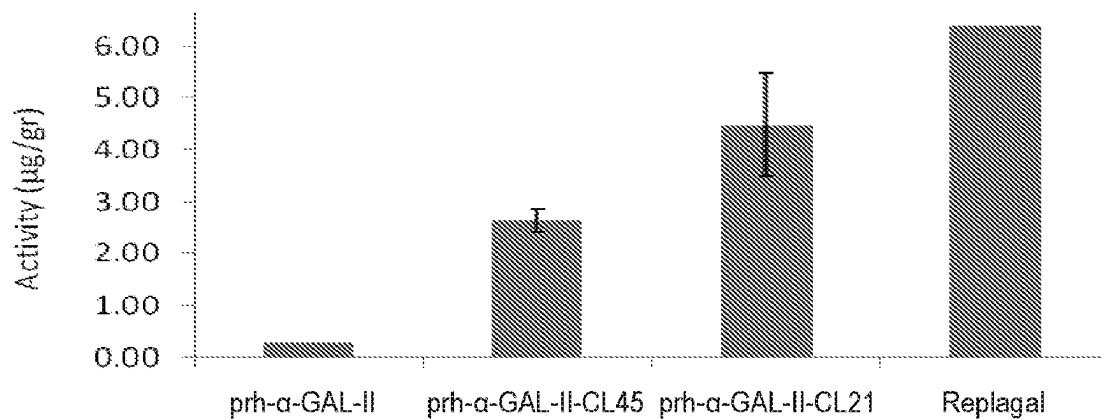


FIG. 33K

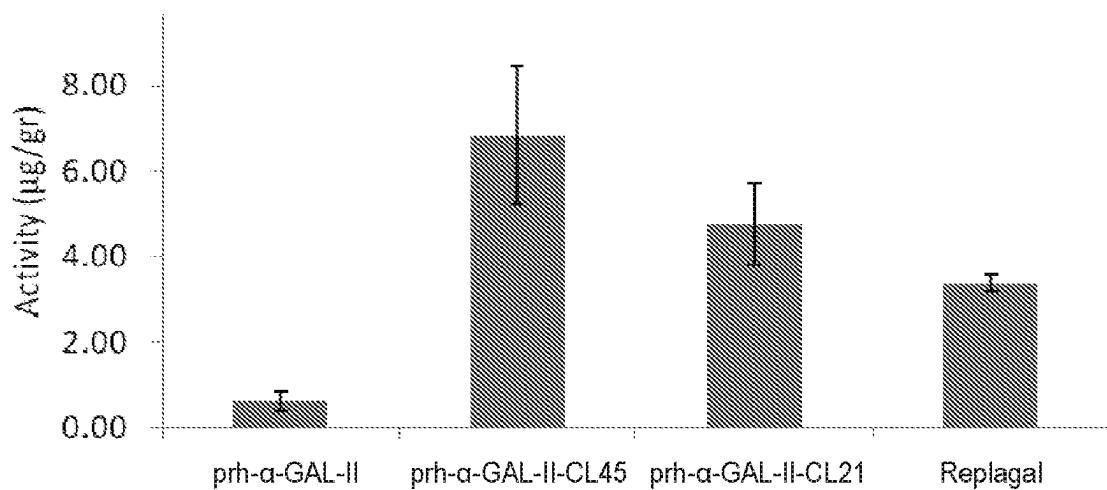


FIG. 33L

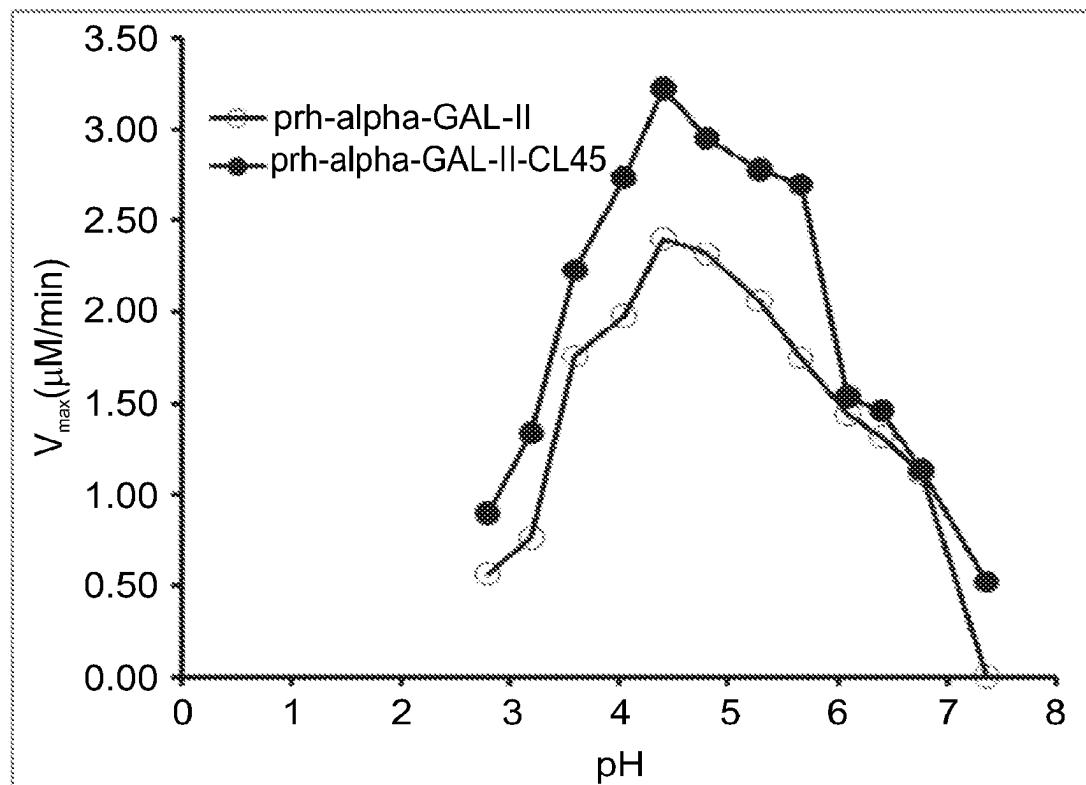


FIG. 34A

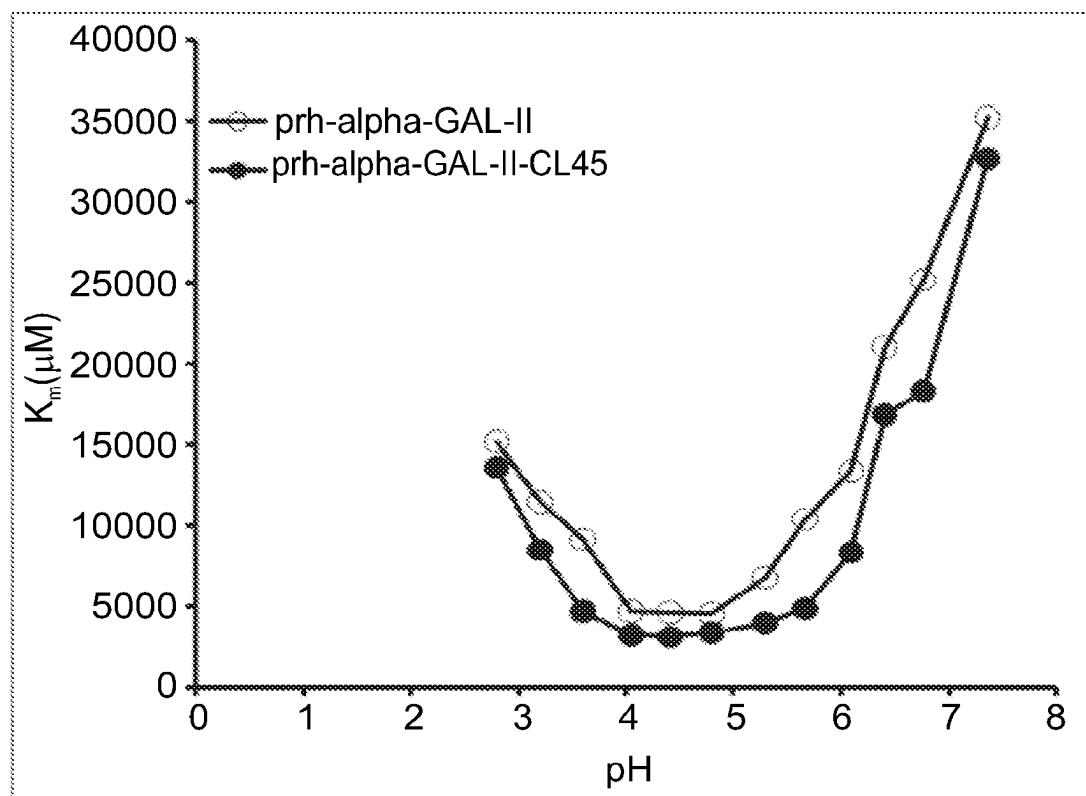


FIG. 34B

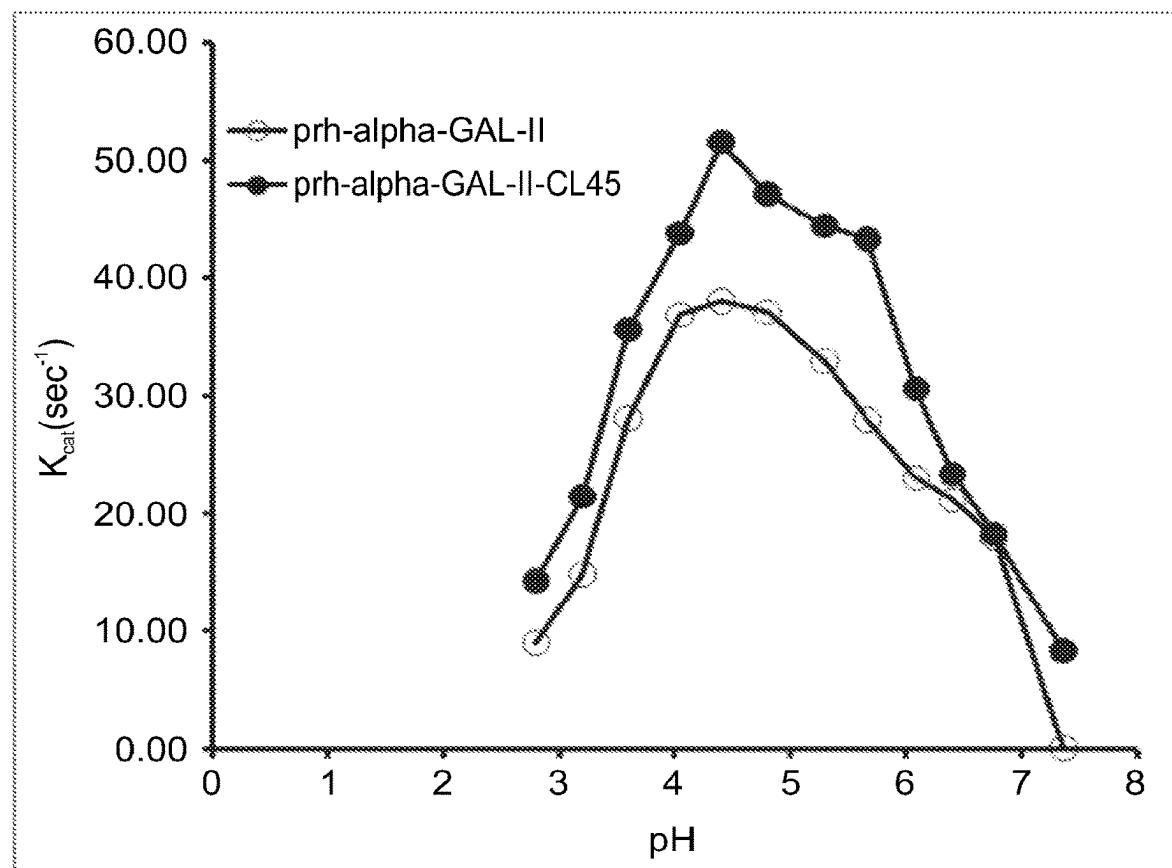


FIG. 34C

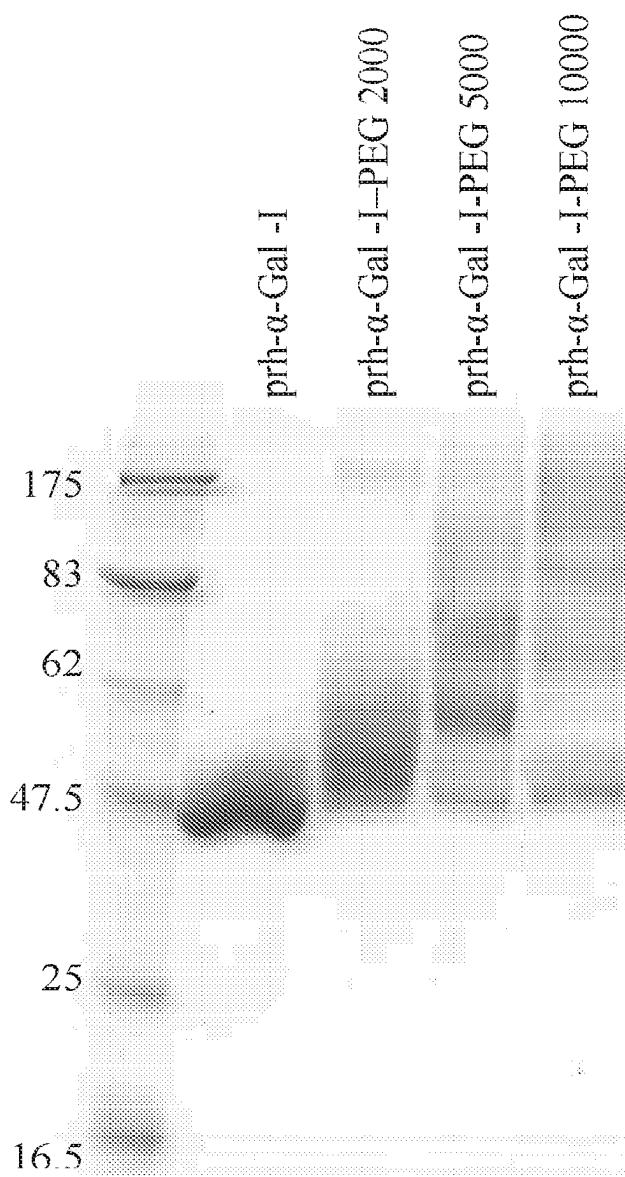


FIG. 35

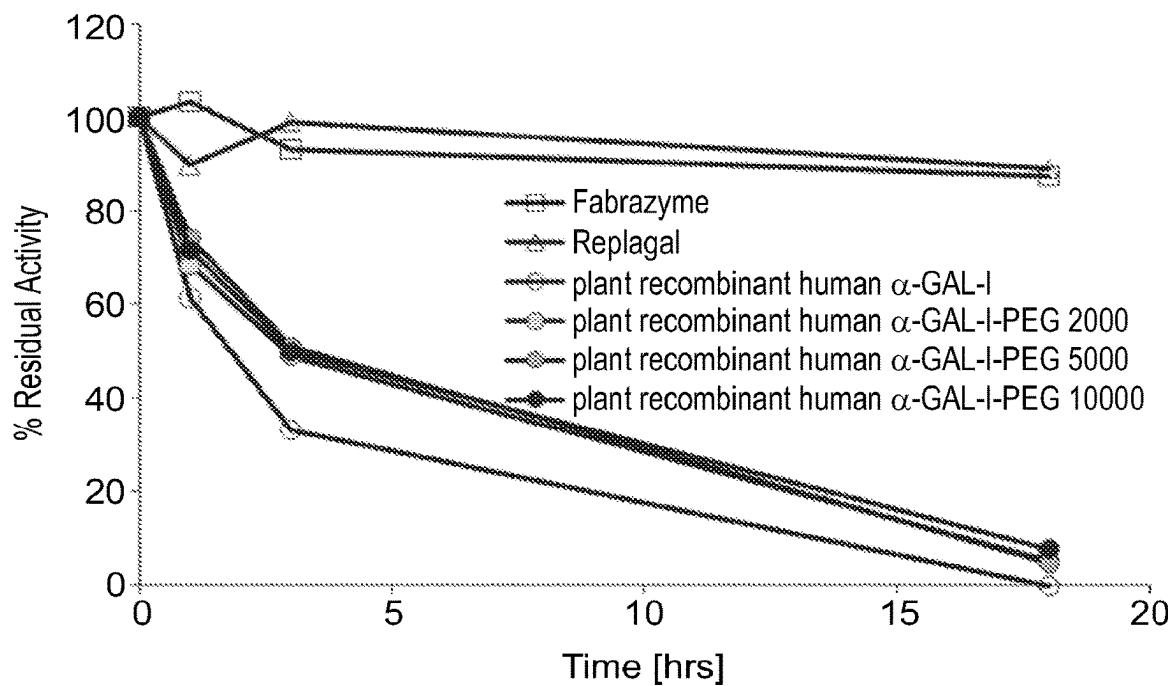


FIG. 36A

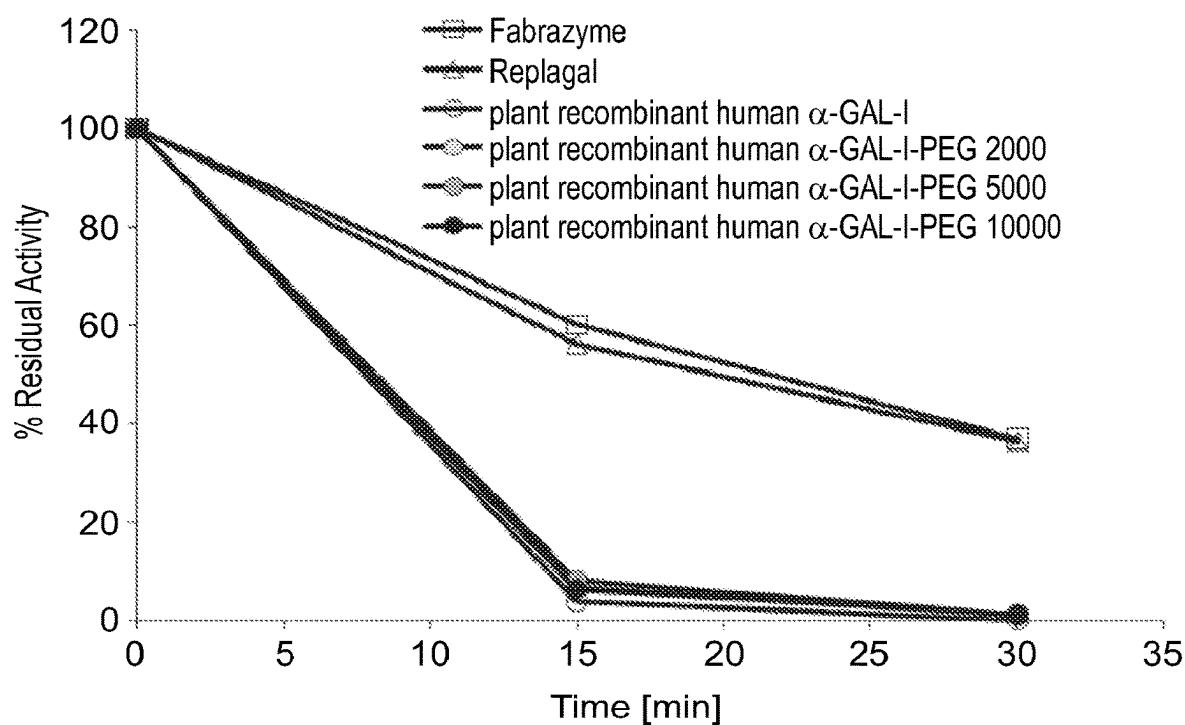


FIG. 36B

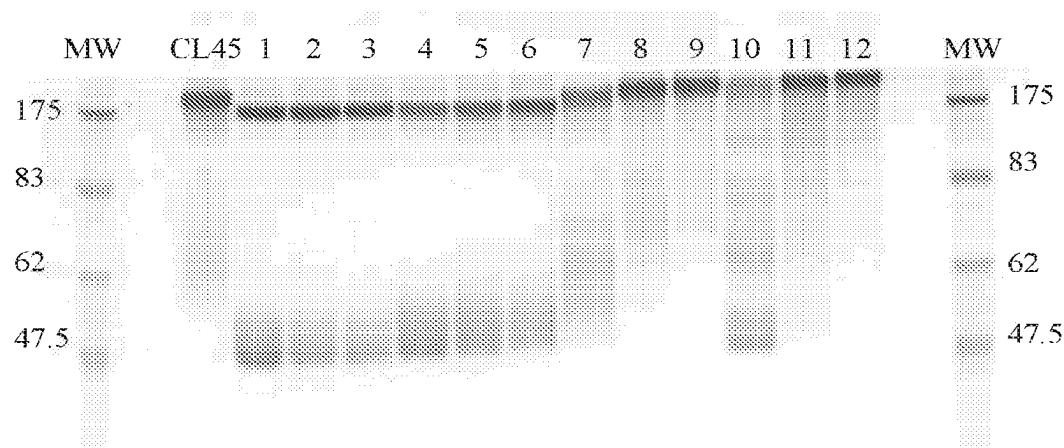


FIG. 37

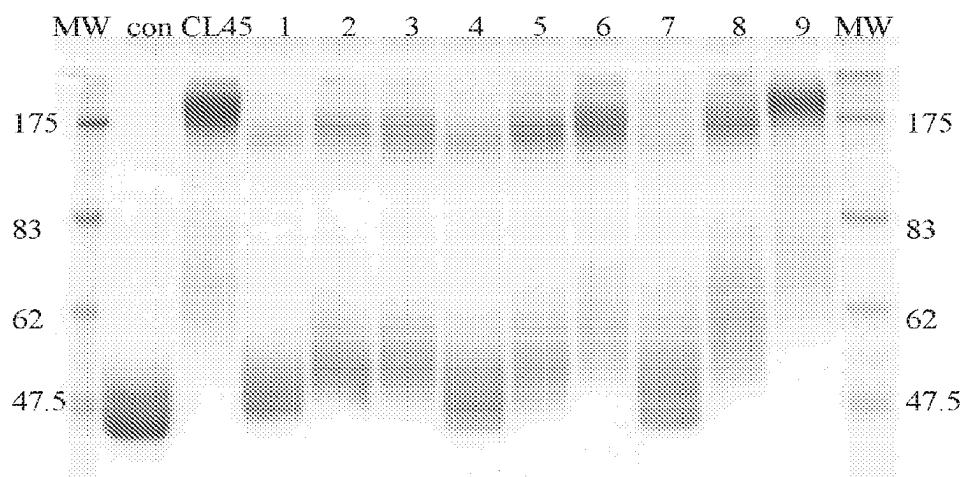


FIG. 38

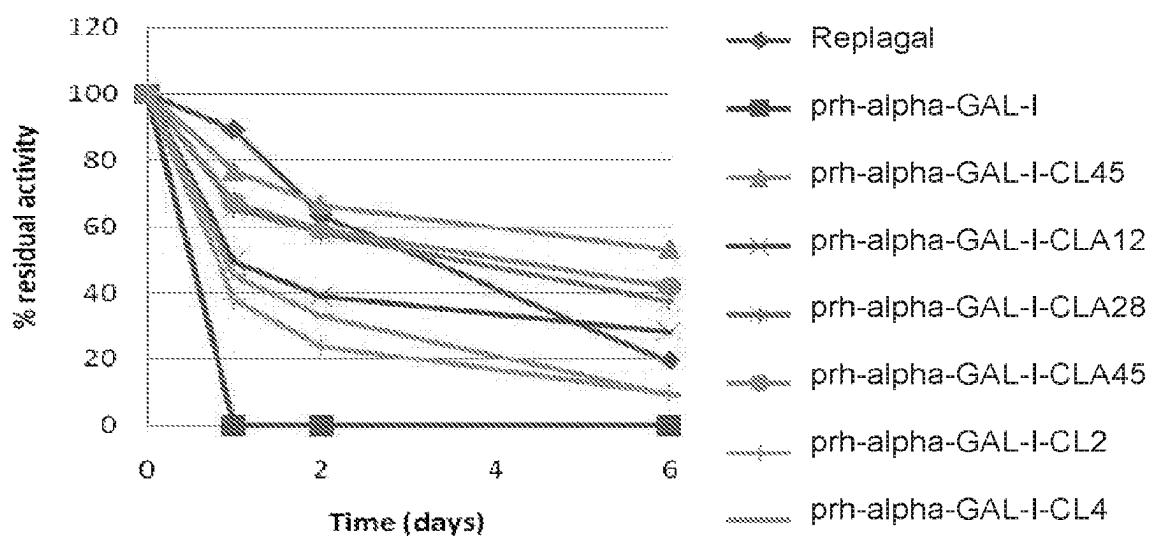


FIG. 39

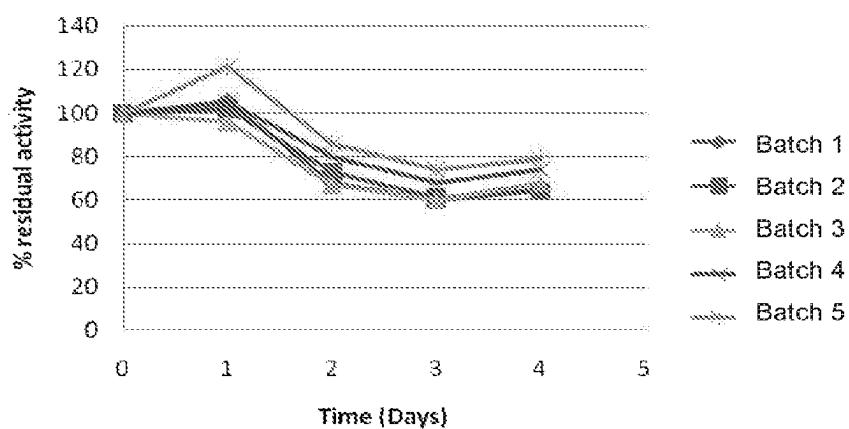


FIG. 40A

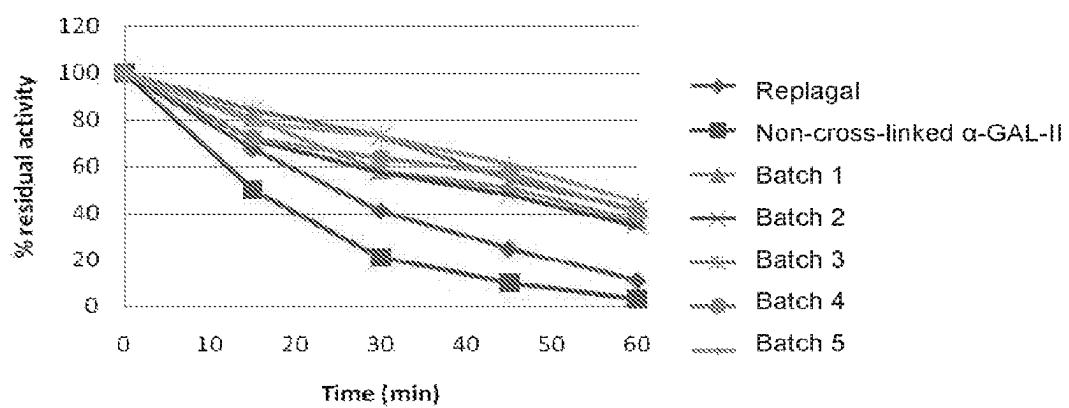


FIG. 40B

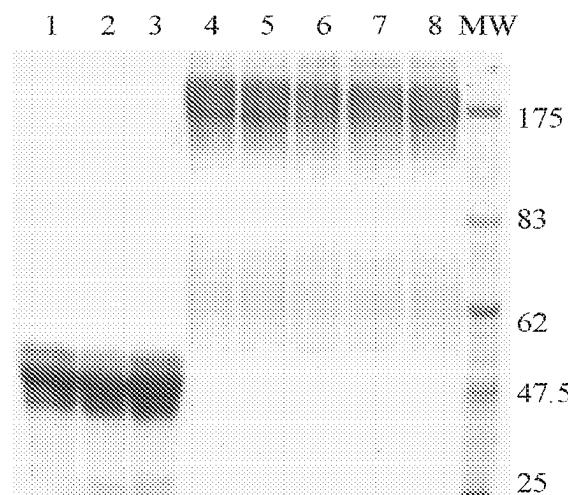


FIG. 41

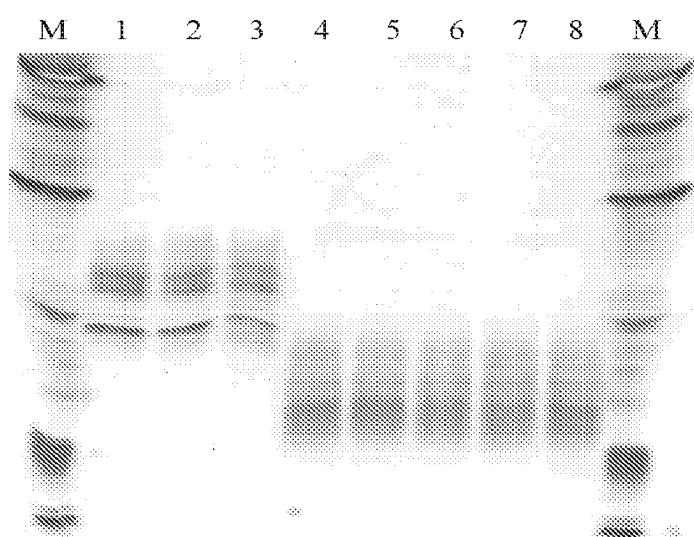
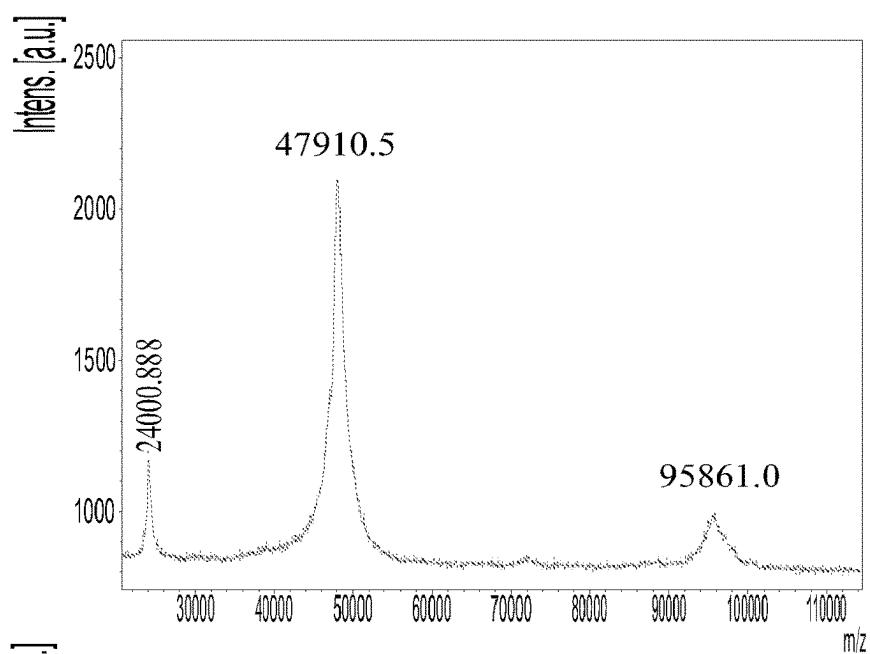
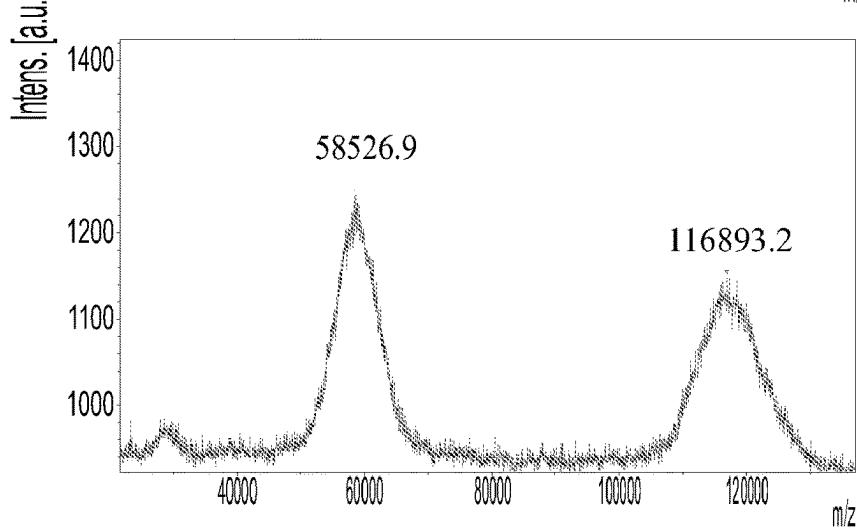
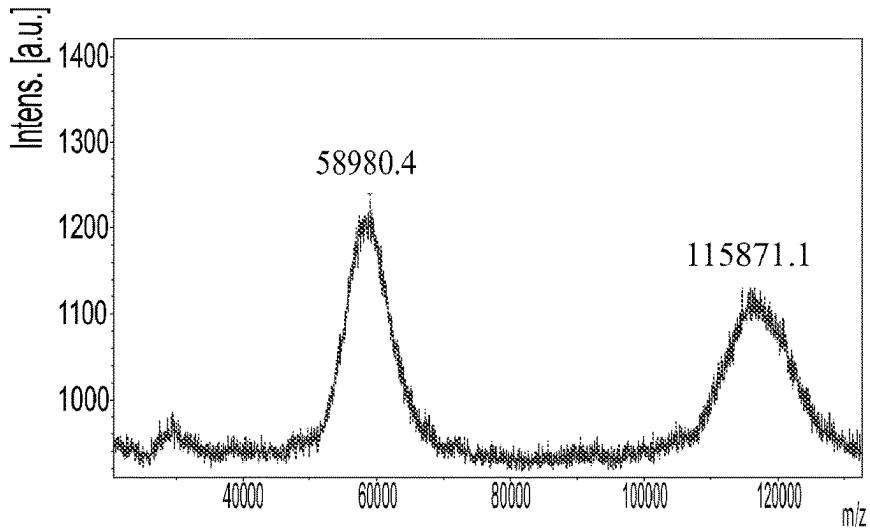
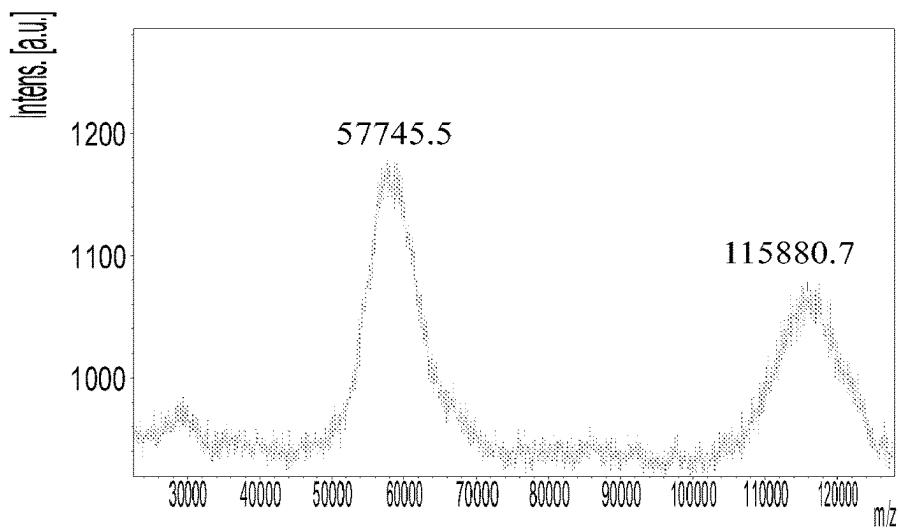
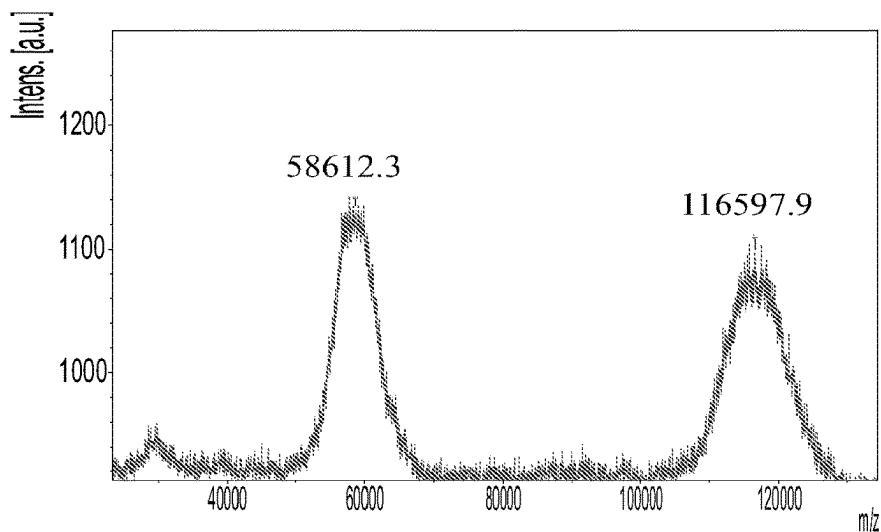
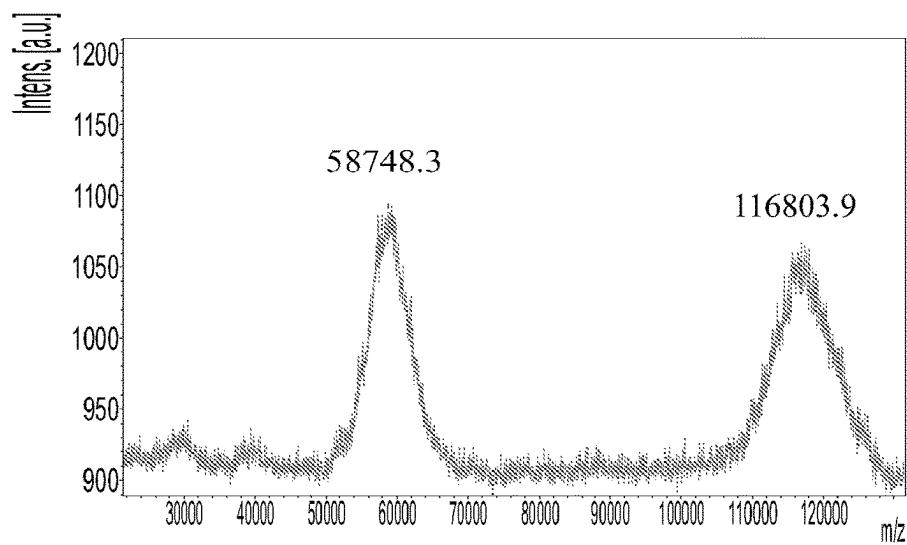


FIG. 42

**FIG. 43A****FIG. 43B****FIG. 43C**

**FIG. 43D****FIG. 43E****FIG. 43F**

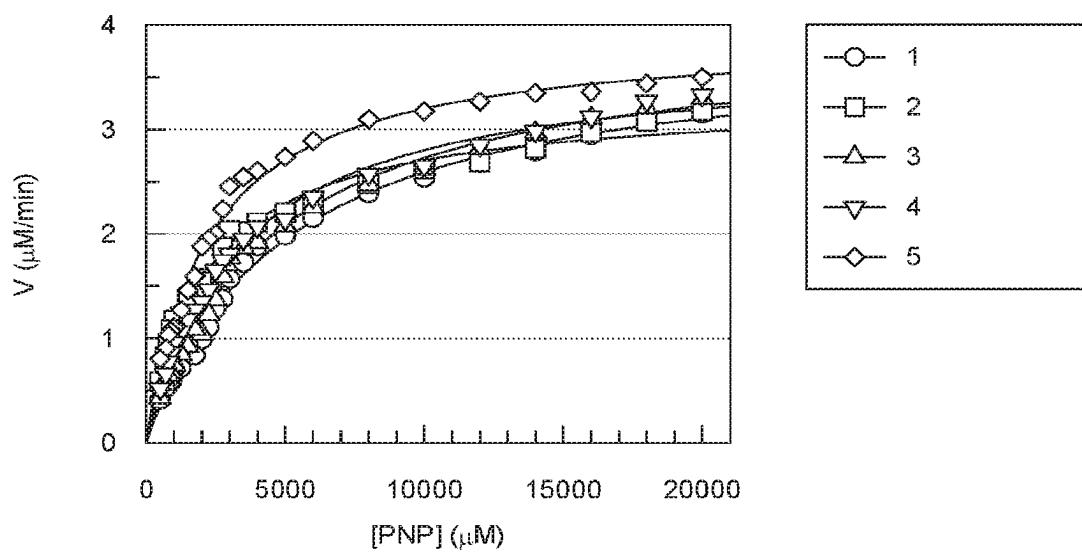


FIG. 44

**STABILIZED ALPHA-GALACTOSIDASE AND  
USES THEREOF**

**RELATED APPLICATIONS**

This application is a continuation of U.S. patent application Ser. No. 17/391,208, filed on Aug. 2, 2021; which is a continuation of U.S. patent application Ser. No. 17/111,464, filed on Dec. 3, 2020; which is a continuation of U.S. patent application Ser. No. 16/356,238, filed on Mar. 18, 2019, now U.S. Pat. No. 10,870,842, issued on Dec. 22, 2020; which is a continuation of U.S. patent application Ser. No. 15/636,753, filed on Jun. 29, 2017, now U.S. Pat. No. 10,280,414, issued on May 7, 2019; which is a continuation of U.S. patent application Ser. No. 14/936,720, filed on Nov. 10, 2015, now U.S. Pat. No. 9,708,595, issued on Jul. 18, 2017; which is a continuation of U.S. patent application Ser. No. 13/582,482, filed on Sep. 4, 2012, now U.S. Pat. No. 9,194,011, issued on Nov. 24, 2015; which is a National Phase of PCT Patent Application No. PCT/IL2011/000209 having International Filing Date of Mar. 2, 2011; which claims the benefit of priority of U.S. Provisional Patent Application Nos. 61/309,487, filed on Mar. 2, 2010; 61/434,499, filed on Jan. 20, 2011 and 61/434,503, filed on Jan. 20, 2011; and which is also a Continuation-in-Part (CIP) of PCT Patent Application No. PCT/IL2010/000956 having International Filing Date of Nov. 17, 2010.

PCT Patent Application No. PCT/IL2010/000956 claims the benefit of priority of U.S. Provisional Patent Application No. 61/261,787, filed on Nov. 17, 2009. The contents of each the above applications are all incorporated by reference as if fully set forth herein in their entirety.

**SEQUENCE LISTING STATEMENT**

The ASCII file, entitled “131219-00110\_Sequence\_Listing.txt”, created on Apr. 5, 2022, comprising 79,381 bytes, submitted concurrently with the filing of this application is incorporated herein by reference.

**FIELD AND BACKGROUND OF THE  
INVENTION**

The present invention, in some embodiments thereof, relates to novel multimeric protein structures and, more particularly, but not exclusively, to multimeric protein structures of  $\alpha$ -galactosidase and to uses thereof in treating Fabry disease.

The lysosomal enzyme  $\alpha$ -galactosidase-A ( $\alpha$ -GAL or  $\alpha$ -Gal A; EC 3.2.1.22) catalyzes the removal of galactose from oligosaccharides, glycoproteins and glycolipids during the catabolism of macromolecules. Deficiencies in lysosomal enzymes lead to the accumulation of their substrates in the tissues, conditions known as lysosomal storage diseases. In humans, the absence of functional  $\alpha$ -galactosidase-A leads to the accumulation of glycolipids containing terminal  $\alpha$ -galactose residues (primarily globotriaosylceramide, which is also referred to as “ceramide trihexoside”, “CTH” or “ $Gb_3$ ”) in the tissues, leading to Fabry disease. Fabry disease is an X-linked recessive disorder, first described in 1898, characterized by chronic pain, ocular opacities, liver and kidney impairment, skin lesions, vascular deterioration and/or cardiac deficiencies. Recombinant human  $\alpha$ -galactosidase-A has the ability to restore enzyme function in patients, and enzyme replacement therapy (ERT) using  $\alpha$ -GAL was approved in the United States in 2003 as a treatment for Fabry disease.  $\alpha$ -GAL became the second

recombinant protein approved for the treatment of a lysosomal storage disorder after (3-glucosidase, a treatment for Gaucher disease.

Endogenous and recombinant  $\alpha$ -GALs catalyze the hydrolysis of terminal galactosylated glycolipids in the lysosomes of cells of organs such as the liver, kidneys, spleen, heart, etc. This natural action site is characterized by its low pH, reaching as low as 4.5. Lysosomal enzymes, including  $\alpha$ -GAL, are hence designed to exert their maximal activity at these low pH levels.

Current Fabry ERT treatments are based on mammalian-cell derived recombinant  $\alpha$ -GAL which is considered to be a limited efficiency treatment. These treatments only decelerate the progress of the disease but are not able to stop its progress and do not offer a true and complete solution. Furthermore, in some cases, ERT with commercial recombinant  $\alpha$ -GALs must be ceased due to development of an immunogenic response to the treatment and in some cases the treatment cannot be initiated in light of immunogenicity problems.

X-ray structure analysis reveals that human  $\alpha$ -GAL is a homodimeric glycoprotein with each monomer composed of two domains, a  $(\beta/\alpha)_8$  domain containing the active site and a C-terminal domain containing eight antiparallel 13 strands on two sheets in a  $\beta$  sandwich [Garman & Garboczi, *J Mol Biol* 2004, 337:319-335]. The two monomers are arranged in a head-to-tail assembly and the dimerization is non-covalent. The two monomers pack with an interface that extends the 75 Å width of the dimer and buries 2200 Å<sup>2</sup> of surface area. In the dimer interface, 30 residues from each monomer contribute to the interface. The two active sites of the dimer are separated by approximately 50 Å.

The crystal structure of  $\alpha$ -Gal was solved for a non-liganded protein as well as for a galactose-ligated protein. These two structures exhibit little change between the liganded and non-liganded structures. Nevertheless, the use of galactose instead of the natural substrate, globotriaosylceramide ( $Gb_3$ ), the latter characterized by long lipidic chains able to interact with the hydrophobic domain of one monomer while the terminal galactose interacts with the active site of the second monomer, may not lead to evidence of active site cooperativity. Furthermore, biochemical evidence does suggest such cooperativity, exemplifying the importance of the homodimeric quaternary structure [Bishop & Desnick, *J Biol Chem* 1981, 256:1307-1316]. Thus, the kinetic properties of human  $\alpha$ -Gal were studied and cooperativity between the monomers of the homodimeric enzyme, each with an interacting catalytic site, was shown. It was therefore suggested that enzymatic activity and stability may be dependent on dimerization.

WO 2009/024977, by the present assignee, which is incorporated by reference as if fully set forth herein, teaches conjugates of a saccharide and a biomolecule, covalently linked therebetween via a non-hydrophobic linker, as well as medical uses utilizing such conjugates.

PCT International Patent Application No. PCT/IL2010/000956, by the present assignee, teaches methodologies which utilize  $\alpha$ -galactosidase which exhibits a lysosomal activity at pH levels higher than lysosomal pH.

Additional background art include Bendele et al. [*Toxicological Sciences* 1998, 42:152-157], U.S. Pat. Nos. 5,256,804, 5,580,757 and 5,766,897, International Patent Application PCT/NL2007/050684 (published as WO 2008/075957), and Seely & Richey [*J Chromatography A* 2001, 908:235-241].

**SUMMARY OF THE INVENTION**

According to an aspect of some embodiments of the present invention there is provided a multimeric protein

structure comprising at least two  $\alpha$ -galactosidase monomers being covalently linked to one another via a linking moiety, the multimeric protein structure featuring a characteristic selected from the group consisting of:

- (a) an  $\alpha$ -galactosidase activity upon subjecting the multimeric protein structure to human plasma conditions for one hour, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to human plasma conditions for one hour;
- (b) an  $\alpha$ -galactosidase activity which decreases upon subjecting the multimeric protein structure to human plasma conditions for one hour by a percentage which is at least 10% less than the percentage by which an activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to human plasma conditions for one hour;
- (c) an  $\alpha$ -galactosidase activity which remains substantially unchanged upon subjecting the multimeric protein structure to human plasma conditions for one hour;
- (d) an  $\alpha$ -galactosidase activity, upon subjecting the multimeric protein structure to lysosomal conditions for one week, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions for one week;
- (e) an  $\alpha$ -galactosidase activity which decreases upon subjecting the multimeric protein structure to lysosomal conditions for one day by a percentage which is at least 10% less than the percentage by which an activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions for one day;
- (f) an  $\alpha$ -galactosidase activity which remains substantially unchanged upon subjecting the multimeric protein structure to lysosomal conditions for one day;
- (g) an  $\alpha$ -galactosidase activity, immediately upon subjecting the multimeric protein structure to lysosomal conditions, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase immediately upon subjecting the native form of the protein to lysosomal conditions;
- (h) an  $\alpha$ -galactosidase activity, immediately upon subjecting the multimeric protein structure to an aqueous solution having a pH of 7 and a temperature of 37° C., which is at least 10% higher than an activity of native  $\alpha$ -galactosidase immediately upon subjecting the native  $\alpha$ -galactosidase to an aqueous solution having a pH of 7 and a temperature of 37° C.; and
- (i) a circulating half-life in a physiological system which is higher by at least 20% than the circulating half-life of the native  $\alpha$ -galactosidase.

According to an aspect of some embodiments of the present invention there is provided a multimeric protein structure comprising at least two  $\alpha$ -galactosidase monomers being covalently linked to one another via a linking moiety, wherein the linking moiety is not present in native  $\alpha$ -galactosidase.

According to an aspect of some embodiments of the present invention there is provided a pharmaceutical composition comprising a multimeric protein structure as described herein and a pharmaceutically acceptable carrier.

According to an aspect of some embodiments of the present invention there is provided a method of treating Fabry disease, the method comprising administering to a subject in need thereof a therapeutically effective amount of a multimeric protein structure as described herein, thereby treating the Fabry disease.

According to an aspect of some embodiments of the present invention there is provided a process of preparing a multimeric protein structure as described herein, the process comprising reacting  $\alpha$ -galactosidase with a cross-linking agent which comprises the linking moiety described herein and at least two reactive groups.

According to some embodiments of the invention, the linking moiety described herein is not present in native  $\alpha$ -galactosidase.

According to some embodiments of the invention, the multimeric protein structure features a characteristic selected from the group consisting of:

- (a) an  $\alpha$ -galactosidase activity, upon subjecting the multimeric protein structure to human plasma conditions for one hour, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to human plasma conditions for one hour;
- (b) an  $\alpha$ -galactosidase activity which decreases upon subjecting the multimeric protein structure to human plasma conditions for one hour by a percentage which is at least 10% less than the percentage by which an activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to human plasma conditions for one hour;
- (c) an  $\alpha$ -galactosidase activity which remains substantially unchanged upon subjecting the multimeric protein structure to human plasma conditions for one hour;
- (d) an  $\alpha$ -galactosidase activity, upon subjecting the multimeric protein structure to lysosomal conditions for one week, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions for one week;
- (e) an  $\alpha$ -galactosidase activity which decreases upon subjecting the multimeric protein structure to lysosomal conditions for one day by a percentage which is at least 10% less than the percentage by which an activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions for one day;
- (f) an  $\alpha$ -galactosidase activity which remains substantially unchanged upon subjecting the multimeric protein structure to lysosomal conditions for one day;
- (g) an  $\alpha$ -galactosidase activity, immediately upon subjecting the multimeric protein structure to lysosomal conditions, which is at least 10% higher than an activity of native  $\alpha$ -galactosidase immediately upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions;
- (h) an  $\alpha$ -galactosidase activity, immediately upon subjecting the multimeric protein structure to an aqueous solution having a pH of 7 and a temperature of 37° C., which is at least 10% higher than an activity of native  $\alpha$ -galactosidase immediately upon subjecting the native  $\alpha$ -galactosidase to an aqueous solution having a pH of 7 and a temperature of 37° C.; and
- (i) a circulating half-life in a physiological system which is higher than a circulating half-life of the native  $\alpha$ -galactosidase.

According to some embodiments of the invention, the  $\alpha$ -galactosidase activity of the multimeric protein structure which remains substantially unchanged upon subjecting the multimeric protein structure to lysosomal conditions for one day, further remains substantially unchanged upon subjecting the multimeric protein structure to lysosomal conditions for one week.

According to some embodiments of the invention, the circulating half-life of the multimeric protein structure

which is higher than a circulating half-life of the native  $\alpha$ -galactosidase, is higher by at least 20% than the circulating half-life of the native  $\alpha$ -galactosidase.

According to some embodiments of the invention, the circulating half-life of the multimeric protein structure which is higher than a circulating half-life of the native  $\alpha$ -galactosidase, is higher by at least 50% than the circulating half-life of the native  $\alpha$ -galactosidase.

According to some embodiments of the invention, the multimeric protein structure is characterized by an  $\alpha$ -galactosidase activity in an organ upon administration of the multimeric protein structure to a vertebrate, the organ being selected from the group consisting of a spleen, a heart and a kidney.

According to some embodiments of the invention, the multimeric protein structure comprises two  $\alpha$ -galactosidase monomers, the protein structure being a dimeric protein structure.

According to some embodiments of the invention, the  $\alpha$ -galactosidase is a human  $\alpha$ -galactosidase.

According to some embodiments of the invention, the  $\alpha$ -galactosidase is a plant recombinant  $\alpha$ -galactosidase.

According to some embodiments of the invention, the  $\alpha$ -galactosidase has an amino acids sequence selected from the group consisting of SEQ ID NO:1, SEQ ID NO:2 and SEQ ID NO:3.

According to some embodiments of the invention, the  $\alpha$ -galactosidase is an alkaline  $\alpha$ -galactosidase.

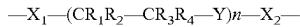
According to some embodiments of the invention, the  $\alpha$ -galactosidase is an acid  $\alpha$ -galactosidase.

According to some embodiments of the invention, the linking moiety comprises a poly(alkylene glycol).

According to some embodiments of the invention, the poly(alkylene glycol) comprises at least two functional groups, each functional group forming a covalent bond with one of the  $\alpha$ -galactosidase monomers.

According to some embodiments of the invention, the at least two functional groups are terminal groups of the poly(alkylene glycol).

According to some embodiments of the invention, the at least one linking moiety has a general formula:



wherein each of  $X_1$  and  $X_2$  is a functional group that forms a covalent bond with at least one  $\alpha$ -galactosidase monomer;

$Y$  is O, S or  $NR_5$ ;

$n$  is an integer from 1 to 200; and

each of  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$  and  $R_5$  is independently selected from the group consisting of hydrogen, alkyl, cycloalkyl, alkenyl, alkynyl, alkoxy, hydroxy, oxo, thiol and thioalkoxy.

According to some embodiments of the invention, at least one of the functional groups forms an amide bond with an  $\alpha$ -galactosidase monomer.

According to some embodiments of the invention,  $n$  is an integer from 5 to 150.

According to some embodiments of the invention,  $n$  is an integer from 40 to 70.

According to some embodiments of the invention, the pharmaceutical composition further comprises a galactose.

According to some embodiments of the invention, the multimeric protein structure is for use as a medicament.

According to some embodiments of the invention, the medicament is for treating Fabry disease.

According to some embodiments of the invention, the multimeric protein structure is for use in treating Fabry disease.

According to some embodiments of the invention, the process comprises reacting dimeric  $\alpha$ -galactosidase with the cross-linking agent.

According to some embodiments of the invention, the reactive groups comprise a leaving group.

According to some embodiments of the invention, the reactive group reacts with an amine group to form an amide bond.

According to some embodiments of the invention, each of the reactive groups is capable of forming a covalent bond between the linking moiety and at least one  $\alpha$ -galactosidase monomer.

According to some embodiments of the invention, a molar ratio of the cross-linking agent to monomers of  $\alpha$ -galactosidase is in a range of from 5:1 to 500:1.

According to some embodiments of the invention, the molar ratio is in a range of from 75:1 to 300:1.

Unless otherwise defined, all technical and/or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the invention, exemplary methods and/or materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be necessarily limiting.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Some embodiments of the invention are herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of embodiments of the invention. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the invention may be practiced.

In the drawings:

FIG. 1 is a graph showing the activity of Fabrazyme®  $\alpha$ -GAL, Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I, as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.);

FIG. 2 is a graph showing the activity of Fabrazyme®  $\alpha$ -GAL, Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I, and plant recombinant  $\alpha$ -GAL-I with galactose (100 mg/mL), as a function of incubation time under simulated physiological conditions (pH 7.4, 37° C.);

FIG. 3 is a graph showing the activity of Fabrazyme®  $\alpha$ -GAL, Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I, as a function of incubation time in human plasma at 37° C.;

FIG. 4 is a graph showing the activity of Fabrazyme®  $\alpha$ -GAL, Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I, and plant recombinant  $\alpha$ -GAL-I with galactose (100 mg/mL), as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.);

FIG. 5 is a scheme depicting the molecular structures of exemplary bis-N-hydroxysuccinimide-poly(ethylene glycol) (bis-NHS-PEG) cross-linking agents;

FIG. 6 is a scheme depicting a dimeric protein which has been reacted with bis-NHS-PEG cross-linking agents;

FIG. 7 presents a scan of an SDS-PAGE gel showing plant recombinant  $\alpha$ -GAL-I which was reacted with bis-NHS-PEG<sub>5</sub> (lanes 1-3), bis-NHS-PEG<sub>8</sub> (lanes 7-9), and bis-NHS-PEG<sub>45</sub> (lanes 4-6), at a molar ratio of 50:1 (lanes 1, 4 and 7), 100:1 (lanes 2, 5 and 8) and 200:1 (lanes 3, 6 and 9) bis-NHS-PEG: $\alpha$ -GAL, as well as molecular weight markers (Mw) and non-reacted plant recombinant  $\alpha$ -GAL-I standard (Std) (arrows show the band comprising an  $\alpha$ -GAL dimer);

FIG. 8 presents a scan of an isoelectric focusing gel showing plant recombinant  $\alpha$ -GAL-I which was reacted with bis-NHS-PEG<sub>5</sub> (lanes 1-3), bis-NHS-PEG<sub>8</sub> (lanes 7-9), and bis-NHS-PEG<sub>45</sub> (lanes 4-6), at a molar ratio of 50:1 (lanes 1, 4 and 7), 100:1 (lanes 2, 5 and 8) and 200:1 (lanes 3, 6 and 9) bis-NHS-PEG: $\alpha$ -GAL, as well as pH markers (M) and non-reacted plant recombinant  $\alpha$ -GAL-I standard (Std) (arrows show pH values for various bands);

FIG. 9 is a MALDI-TOF mass spectroscopy spectrum of plant recombinant  $\alpha$ -GAL-I cross-linked by bis-NHS-PEG<sub>45</sub> (x-axis indicates m/z values, and m/z values of peaks are shown);

FIG. 10 is a MALDI-TOF mass spectroscopy spectrum of plant recombinant  $\alpha$ -GAL-I cross-linked by bis-NHS-PEG<sub>8</sub> (x-axis indicates m/z values, and m/z values of peaks are shown);

FIG. 11 presents a photograph showing the  $\alpha$ -GAL substrate N-dodecanoyl-nitrobenzoxadiazole-ceramide trihexoside ( $G_b_3$ -NBD) and the  $\alpha$ -GAL reaction product lactosyl ceramide-nitrobenzoxadiazole (lactosyl ceramide-NBD), as visualized by irradiation under UV light (365 nm) following high performance thin layer chromatography, following incubation of the substrate  $G_b_3$ -NBD with plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (left lane), Replagal®  $\alpha$ -GAL (middle lane) and without  $\alpha$ -GAL (right lane);

FIGS. 12A, 12B and 12C, are graphs showing the activity of Fabrazyme®  $\alpha$ -GAL, Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I, and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>5</sub> (FIG. 12A), bis-NHS-PEG<sub>8</sub> (FIG. 12B) and bis-NHS-PEG<sub>45</sub> (FIG. 12C) at a molar ratio of 50:1 ("1" in FIG. 12A, "7" in FIG. 12B and "4" in FIG. 12C), 100:1 ("2" in FIG. 12A, "8" in FIG. 12B and "5" in FIG. 12C) and 200:1 ("3" in FIG. 12A, "9" in FIG. 12B and "6" in FIG. 12C) bis-NHS-PEG: $\alpha$ -GAL as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.);

FIG. 13 is a graph showing the pharmacokinetic profile of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I, and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> in the plasma of Fabry mice; the residual activity of each  $\alpha$ -GAL is presented as a percentage of the maximal residual activity of each  $\alpha$ -GAL, as a function of time following injection of the  $\alpha$ -GALs;

FIGS. 14A and 14B present a graph (FIG. 14A) showing the activity of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (prh-alpha-GAL-I-CL8) or bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the spleens of Fabry mice 2 hours following injection of  $\alpha$ -GAL, and a photograph of a Western blot (FIG. 14B) showing Replagal®  $\alpha$ -GAL (lanes 10-12 and 15), plant recombinant human  $\alpha$ -GAL-I (lanes 7-9 and 13), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (lanes 4-6) or bis-NHS-PEG<sub>45</sub> (lanes 1-3 and 14) in

the spleens of Fabry mice following injection of  $\alpha$ -GAL (lanes 1-12) or as a standard consisting of 50 ng  $\alpha$ -GAL (lanes 13-15);

FIGS. 15A and 15B present a graph (FIG. 15A) showing the activity of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (prh-alpha-GAL-I-CL8) or bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the livers of Fabry mice 2 hours following injection of  $\alpha$ -GAL, and a photograph of a Western blot (FIG. 15B) showing Replagal®  $\alpha$ -GAL (lanes 10-12 and 15), plant recombinant human  $\alpha$ -GAL-I (lanes 7-9 and 13), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (lanes 4-6) or bis-NHS-PEG<sub>45</sub> (lanes 1-3 and 14) in the livers of Fabry mice following injection of  $\alpha$ -GAL (lanes 1-12) or as a standard consisting of 50 ng  $\alpha$ -GAL (lanes 13-15);

FIG. 16 is a graph showing the activity of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (prh-alpha-GAL-I-CL8) or bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the hearts of Fabry mice 2 hours following injection of  $\alpha$ -GAL;

FIG. 17 is a graph showing the activity of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> (prh-alpha-GAL-I-CL8) or bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the kidneys of Fabry mice 2 hours following injection of  $\alpha$ -GAL;

FIG. 18 is a graph showing the activity of Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the spleens of Fabry mice 2 hours, 24 hours, 3 days and 7 days following injection of  $\alpha$ -GAL (endogenous wild type  $\alpha$ -GAL (WT) is shown as a standard);

FIG. 19 is a graph showing the activity of Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the livers of Fabry mice 2 hours, 24 hours, 3 days and 7 days following injection of  $\alpha$ -GAL (endogenous wild type  $\alpha$ -GAL (WT) is shown as a standard);

FIG. 20 is a graph showing the activity of Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the hearts of Fabry mice 2 hours, 24 hours, 3 days and 7 days following injection of  $\alpha$ -GAL (endogenous wild type  $\alpha$ -GAL (WT) is shown as a standard);

FIG. 21 is a graph showing the activity of Replagal®  $\alpha$ -GAL and plant recombinant human  $\alpha$ -GAL-I (prh-alpha-GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-I-CL45) in the kidneys of Fabry mice 2 hours, 24 hours, 3 days and 7 days following injection of  $\alpha$ -GAL (endogenous wild type  $\alpha$ -GAL (WT) is shown as a standard);

FIG. 22 presents a photograph of an image of an SDS-PAGE gel showing Replagal® mammalian recombinant human  $\alpha$ -GAL (left lane), and Replagal® mammalian recombinant human  $\alpha$ -GAL which was reacted with bis-NHS-PEG<sub>45</sub> (middle lane), as well as molecular weight markers (right lane; molecular weights of markers are indicated in KDa units);

FIG. 23 presents a photograph of an isoelectric focusing gel showing Replagal® mammalian recombinant human  $\alpha$ -GAL (left lane), and Replagal® mammalian recombinant

human  $\alpha$ -GAL which was reacted with bis-NHS-PEG<sub>45</sub> (middle lane), as well as pH markers (right lane);

FIGS. 24A and 24B are MALDI-TOF mass spectroscopy spectra of Replagal® mammalian recombinant human  $\alpha$ -GAL (FIG. 24A), and Replagal® mammalian recombinant human  $\alpha$ -GAL cross-linked by bis-NHS-PEG<sub>45</sub> (x-axis indicates m/z values, and m/z values (in Da units) of peaks are shown);

FIG. 25 is a Michaelis-Menten plot showing the velocity (V) of hydrolysis of p-nitrophenyl- $\alpha$ -D-galactopyranoside (pNP-G) by Replagal® mammalian recombinant human  $\alpha$ -GAL (Replagal) and Replagal® mammalian recombinant human  $\alpha$ -GAL cross-linked by bis-NHS-PEG<sub>45</sub> (Replagal CL45), as a function of pNP-G concentration;

FIGS. 26A and 26B are graphs showing the activity of Replagal® mammalian recombinant human  $\alpha$ -GAL (Replagal) and Replagal® mammalian recombinant human  $\alpha$ -GAL cross-linked by bis-NHS-PEG<sub>45</sub> (Replagal-CL45) as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.) (FIG. 26A) or in human plasma at 37° C. (FIG. 26B);

FIGS. 27A-27D are graphs showing the activity of Replagal®  $\alpha$ -GAL (R) and Replagal®  $\alpha$ -GAL cross-linked with bis-NHS-PEG<sub>45</sub> (R-CL45) in the spleens (FIG. 27A), livers (FIG. 27B), hearts (FIG. 27C) and kidneys (FIG. 27D) of Fabry mice 2 hours following injection of  $\alpha$ -GAL;

FIGS. 28A-28D are graphs showing Gb<sub>3</sub> levels in the hearts (FIG. 28A), kidneys (FIG. 28B), livers (FIG. 28C) and spleens (FIG. 28D) of Fabry mice, as a function of time following injection of Replagal®  $\alpha$ -GAL (R) or Replagal®  $\alpha$ -GAL cross-linked with bis-NHS-PEG<sub>45</sub> (R-CL45);

FIGS. 29A and 29B present scans of SDS-PAGE gels showing plant recombinant human  $\alpha$ -GAL-II (FIGS. 29A and 29B, lane 2), and plant recombinant human  $\alpha$ -GAL-II which was reacted with bis-NHS-PEG<sub>21</sub> (FIG. 29A, lane 3), bis-NHS-PEG<sub>45</sub> (FIG. 29A, lane 4) or bis-NHS-PEG<sub>68</sub> (FIG. 29B, lane 3), as well as molecular weight markers (FIGS. 29A and 29B, lane 1; molecular weights of markers are indicated in KDa units);

FIGS. 30A-30C are MALDI-TOF mass spectroscopy spectra of plant recombinant human  $\alpha$ -GAL-II (FIG. 30A), and plant recombinant human  $\alpha$ -GAL-II cross-linked by bis-NHS-PEG<sub>21</sub> (FIG. 30B) or bis-NHS-PEG<sub>45</sub> (FIG. 30C) (x-axis indicates m/z values, and m/z values (in Da units) of peaks are shown);

FIGS. 31A-31D are graphs showing the activity of Replagal® mammalian recombinant human  $\alpha$ -GAL (Replagal), plant recombinant human  $\alpha$ -GAL-II (prh-alpha-GAL-II) and plant recombinant human  $\alpha$ -GAL-II cross-linked by bis-NHS-PEG<sub>21</sub> (prh-alpha-GAL-II-CL21; FIGS. 31A and 31C), bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-II-CL45);

FIGS. 31A-31D) or bis-NHS-PEG<sub>68</sub> (prh-alpha-GAL-II-CL68; FIGS. 31B and 31D) as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.) (FIGS. 31A and 31B) or in human plasma at 37° C. (FIGS. 31C and 31D) (data shown in FIGS. 31C and 31D are from different experiments);

FIGS. 32A and 32B are graphs showing the pharmacokinetic profiles of Replagal®  $\alpha$ -GAL (Replagal), plant recombinant human  $\alpha$ -GAL-II (prh-alpha-GAL-II), and plant recombinant human  $\alpha$ -GAL-II cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-II-CL45) in the plasma of Fabry mice; concentration of each  $\alpha$ -GAL is presented as a function of time following injection of  $\alpha$ -GAL (FIGS. 32A and 32B present the same data at different time frames);

FIGS. 33A-33L are graphs showing the activity of Replagal®  $\alpha$ -GAL (Replagal), plant recombinant human  $\alpha$ -GAL-

II (prh-alpha-GAL-II) and plant recombinant human  $\alpha$ -GAL-II cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-II-CL45; FIGS. 33A-33L) or bis-NHS-PEG<sub>21</sub> (prh-alpha-GAL-II-CL21; FIGS. 33E-33L) in the hearts (FIGS. 33A, 33E and 33I), kidneys (FIGS. 33B, 33F and 33J), livers (FIGS. 33C, 33G and 33K) and spleens (FIGS. 33D, 33H and 33L) of Fabry mice 2 hours (FIGS. 33A-33H), 7 days (FIGS. 33A-33D and 33I-33L), 14 days (FIGS. 33A-33D) and 28 days (FIGS. 33A-33D) following injection of  $\alpha$ -GAL;

FIGS. 34A-34C are graphs showing the kinetic parameters V<sub>max</sub> (FIG. 34A), K<sub>M</sub> (FIG. 34B) and k<sub>cat</sub> (FIG. 34C) for plant recombinant human  $\alpha$ -GAL-II (prh-alpha-GAL-II) and plant recombinant human  $\alpha$ -GAL-II cross-linked with bis-NHS-PEG<sub>45</sub> (prh-alpha-GAL-II-CL45), as a function of pH;

FIG. 35 presents a scan of an SDS-PAGE gel showing plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -Gal-0, and plant recombinant human  $\alpha$ -GAL-I which was reacted with methoxy-capped NHS-PEG having a molecular weight of 2 KDa (prh- $\alpha$ -Gal-I-PEG 2000), 5 KDa (prh- $\alpha$ -Gal-I-PEG 5000) or 10 KDa (prh- $\alpha$ -Gal-I-PEG 10000), as well as molecular weight markers (left lane; molecular weights of markers are indicated in KDa units);

FIGS. 36A and 36B are graphs showing the activity of Fabrazyme® mammalian recombinant human  $\alpha$ -GAL (Fabrazyme), Replagal® mammalian recombinant human  $\alpha$ -GAL (Replagal), plant recombinant human  $\alpha$ -GAL-I which was reacted with methoxy-capped NHS-PEG having a molecular weight of 2 KDa ( $\alpha$ -Gal-I-PEG 2000), 5 KDa ( $\alpha$ -Gal-I-PEG 5000) or 10 KDa ( $\alpha$ -Gal-I-PEG 10000), as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.) (FIG. 36A) or in human plasma at 37° C. (FIG. 36B);

FIG. 37 presents a scan of an SDS-PAGE gel showing plant recombinant  $\alpha$ -GAL-I which was reacted with bis-NHS-PEG<sub>2</sub> (lanes 1-3), bis-NHS-PEG<sub>4</sub> (lanes 4-6), bis-NHS-PEG<sub>68</sub> (lanes 7-9), bis-NHS-PEG<sub>150</sub> (lanes 10-12) and bis-NHS-PEG<sub>45</sub> (CL45), at a molar ratio of 50:1 (lanes 1, 4, 7 and 10), 100:1 (lanes 2, 5, 8 and 11) and 200:1 (lanes 3, 6, 9 and 12) bis-NHS-PEG: $\alpha$ -GAL, as well as molecular weight markers (MW);

FIG. 38 presents a scan of an SDS-PAGE gel showing plant recombinant  $\alpha$ -GAL-I which was reacted with bis-COOH-PEG<sub>12</sub> (lanes 1-3), bis-COOH-PEG<sub>28</sub> (lanes 4-6), bis-COOH-PEG<sub>45</sub> (lanes 7-9), and bis-NHS-PEG<sub>45</sub> (CL45), at a molar ratio of 50:1 (lanes 1, 4 and 7), 100:1 (lanes 2, 5 and 8) and 200:1 (lanes 3, 6 and 9) bis-NHS-PEG: $\alpha$ -GAL, as well as molecular weight markers (MW), and non-crosslinked plant recombinant  $\alpha$ -GAL-I as a control (con);

FIG. 39 is a graph showing the activity of Replagal®  $\alpha$ -GAL, plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I), and plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> (prh- $\alpha$ -GAL-I-CL45), bis-NHS-PEG<sub>4</sub> (prh- $\alpha$ -GAL-I-CL4), bis-NHS-PEG<sub>2</sub> (prh- $\alpha$ -GAL-I-CL2), bis-COOH-PEG<sub>45</sub> (prh- $\alpha$ -GAL-I-CLA45) bis-COOH-PEG<sub>28</sub> (prh- $\alpha$ -GAL-I-CLA28) or bis-COOH-PEG<sub>12</sub> (prh- $\alpha$ -GAL-I-CLA12) as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.);

FIGS. 40A and 40B are graphs showing the activity of plant recombinant human  $\alpha$ -GAL-II cross-linked by bis-NHS-PEG<sub>45</sub> as a function of incubation time under simulated lysosomal conditions (citrate phosphate buffer, pH 4.6, 37° C.) (FIG. 40A) or in human plasma at 37° C. (FIG. 40B) (FIG. 40B shows the activity of Replagal® mammalian

## 11

recombinant  $\alpha$ -GAL and non-cross-linked plant recombinant human  $\alpha$ -GAL-II for comparison);

FIG. 41 presents a scan of an SDS-PAGE gel showing plant recombinant  $\alpha$ -GAL-II from 3 different batches (lanes 1-3) and plant recombinant  $\alpha$ -GAL-II which was reacted with bis-NHS-PEG<sub>45</sub> from 5 different batches (lanes 4-8), as well as molecular weight markers (MW);

FIG. 42 presents a scan of an isoelectric focusing gel showing plant recombinant  $\alpha$ -GAL-II from 3 different batches (lanes 1-3) and plant recombinant  $\alpha$ -GAL-II which was reacted with bis-NHS-PEG<sub>45</sub> from 5 different batches (lanes 4-8), as well as pH markers (M);

FIGS. 43A-43F are MALDI-TOF mass spectroscopy spectra of plant recombinant human  $\alpha$ -GAL-II (FIG. 43A), and plant human  $\alpha$ -GAL-II cross-linked by bis-NHS-PEG<sub>45</sub> from 5 different batches (FIGS. 43B-43F, respectively) (x-axis indicates m/z values, and m/z values (in Da units) of peaks are shown); and

FIG. 44 is a graph showing the catalytic velocity (V) of  $\alpha$ -GAL activity exhibited by plant human  $\alpha$ -GAL-II cross-linked by bis-NHS-PEG<sub>45</sub> from 5 different batches, as a function of substrate (p-nitrophenyl- $\alpha$ -D-galactopyranoside) concentration.

#### DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

The present invention, in some embodiments thereof, relates to novel multimeric protein structures and, more particularly, but not exclusively, to multimeric protein structures of  $\alpha$ -galactosidase and to uses thereof in treating Fabry disease.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details set forth in the following description or exemplified by the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

Deficiencies of a lysosomal protein (e.g., defects in a lysosomal protein or absence of a lysosomal protein) can cause considerable harm to the health of a subject (a lysosomal storage disease). Enzyme replacement therapy (ERT), in which the deficient protein is administered to a patient, has been used in attempts to treat lysosomal storage diseases. However, administration of the deficient protein does not necessarily result in a considerable and/or persistent increase in the activity of the protein in vivo.

Fabry disease is an example of an X-linked recessive (inherited) lysosomal storage disease which can cause a wide range of systemic symptoms. A deficiency of the lysosomal enzyme  $\alpha$ -galactosidase A due to mutation causes a glycolipid known as globotriaosylceramide (also known as Gb<sub>3</sub> or ceramide trihexose) to accumulate within the blood vessels, other tissues, and organs. This accumulation leads to an impairment of their proper function. Two enzyme replacement therapies (ERTs) are available to functionally compensate for  $\alpha$ -galactosidase deficiency. Agalsidase alpha (Replagal®, Shire) and agalsidase beta (Fabrazyme®, Genzyme) are both recombinant forms of the human  $\alpha$ -galactosidase A enzyme. These enzymes are difficult to manufacture and as such are expensive. Recently, contamination at Genzyme's Allston, MA, plant caused a worldwide shortage of agalsidase beta, and supplies were rationed to patients at one-third the recommended dose.

As shown herein,  $\alpha$ -galactosidases exert their maximal activity at low pH levels characteristic of lysosomes, while their activity at higher pH levels is compromised. Thus, for

## 12

example,  $\alpha$ -galactosidase used in ERT would have little ability to hydrolyze terminal galactosylated glycolipids in the serum of Fabry patients.

Moreover, as further shown herein, even under lysosomal conditions, the activity of  $\alpha$ -galactosidases is gradually compromised, although at a slower rate than at higher pH levels.

Motivated by a need to solve the compromised activity of  $\alpha$ -galactosidases, the present inventors have searched for stabilized forms of  $\alpha$ -galactosidase ( $\alpha$ -GAL). More specifically, the present inventors have envisioned that a stabilized form of  $\alpha$ -galactosidase would exhibit longer lasting activity in general, including longer lasting activity in serum. The present inventors have thus designed and successfully prepared and practiced stabilized forms of native  $\alpha$ -galactosidase and have indeed shown that such stabilized forms exhibit an improved performance, in terms of enhanced activity and/or a longer lasting activity under both lysosomal conditions and in a serum environment, which allows for an enhanced activity of the protein in vivo.

The present inventors have demonstrated a formation of stabilized forms of  $\alpha$ -galactosidase which exhibit an improved performance by means of cross-linking native  $\alpha$ -galactosidase, via formation of new covalent linkage between  $\alpha$ -galactosidase monomers.

Referring now to the drawings, FIGS. 1 and 4 show the decline of enzyme activity under lysosomal conditions for plant recombinant human  $\alpha$ -GAL I (prh- $\alpha$ -GAL I) and Fabrazyme® and Replagal®  $\alpha$ -GAL. FIGS. 2 and 3 show the decline of enzyme activity under simulated physiological conditions or in human plasma, for the same  $\alpha$ -GAL varieties. FIGS. 2 and 4 show that galactose decreases the rate of the decline in  $\alpha$ -GAL activity.

FIG. 5 shows exemplary PEG (polyethylene glycol) cross-linking agents, according to optional embodiments of the invention. FIG. 6 depicts a cross-linked  $\alpha$ -GAL dimer according to optional embodiments of the invention.

FIGS. 7-10 and 37 show that prh- $\alpha$ -GAL-I reacted with exemplary cross-linking agents comprising N-hydroxysuccinimide moieties. FIG. 38 shows that prh- $\alpha$ -GAL-I reacted with exemplary cross-linking agents comprising carboxyl groups, following in situ activation with N-hydroxysuccinimide. FIGS. 7, 37 and 38 show that the reaction with the cross-linking agent resulted in  $\alpha$ -GAL appearing primarily in a dimeric form rather than a monomeric form under denaturing conditions, indicating that the quaternary structure of the  $\alpha$ -GAL was maintained by covalent cross-linking. FIG. 11 shows that the cross-linked  $\alpha$ -GAL retained its enzymatic activity.

FIGS. 12A-12C and 39 show that the cross-linked prh  $\alpha$ -GAL-I exhibits a longer lasting activity than non-cross-linked  $\alpha$ -GAL under simulated lysosomal conditions. The increase in stability is stronger for PEG<sub>28</sub> and PEG<sub>45</sub> linkers than for shorter PEG linkers. FIG. 13 shows that the cross-linked prh- $\alpha$ -GAL-I exhibits a longer lasting activity than non-cross-linked  $\alpha$ -GAL in plasma in vivo. FIGS. 14A-21 show that cross-linked prh- $\alpha$ -GAL-I exhibits an enhanced activity in vivo in the spleen, liver, heart and kidneys. The enhancement of  $\alpha$ -GAL activity is stronger for PEG<sub>45</sub> linkers than for shorter PEG linkers. FIGS. 15A, 15B and 19 show that although cross-linked prh- $\alpha$ -GAL-I exhibits an enhanced activity in vivo, the enhanced activity is not as concentrated in the liver as is Replagal®  $\alpha$ -GAL activity.

The above results indicate that cross-linking plant recombinant human  $\alpha$ -GAL-I results in a dimer with improved stability, which allows for a more effective increase of  $\alpha$ -GAL activity when administered in vivo.

## 13

Similarly, FIGS. 22-28D show that cross-linking mammalian recombinant human  $\alpha$ -GAL results in a covalently-linked dimer (FIGS. 22-24B), which exhibits normal enzymatic activity (FIG. 25), as well as longer lasting activity under both lysosomal conditions and in plasma (FIGS. 26A-26B), and enhanced activity in vivo in the spleen, liver, heart and kidneys (FIGS. 27A-28D).

Similarly, FIGS. 29A-33L show that cross-linking plant recombinant human  $\alpha$ -GAL II results in a covalently-linked dimer (FIGS. 29-30), which exhibits longer lasting activity under both lysosomal conditions and in plasma (FIGS. 31A-31B), and enhanced activity in vivo in plasma and in the spleen, liver, heart and kidneys (FIGS. 32A-33L). As shown in FIGS. 33A-33L, cross-linking with a PEG<sub>45</sub> linker was particularly effective at enhancing in vivo activity.

These results indicate that the advantageous effects of cross-linking are applicable to a variety of  $\alpha$ -GAL proteins.

FIGS. 34A-34C show that cross-linking  $\alpha$ -GAL enhances parameters of  $\alpha$ -GAL enzymatic catalysis, broadens the pH range for  $\alpha$ -GAL activity, and allows for  $\alpha$ -GAL activity at a pH of about 7 or more.

FIGS. 35-36B show that PEGylation without cross-linking has no significant effect on  $\alpha$ -GAL activity, indicating that the advantageous effects of cross-linking are specifically due to cross-linking, rather than to an effect of PEGylation.

FIGS. 40-44 show that cross-linking of  $\alpha$ -GAL according to embodiments of the invention allows for good reproducibility of the stability (FIGS. 40A-40B), degree of covalent cross-linking (FIGS. 41-43F) and enzymatic properties (FIG. 44) of the to cross-linked  $\alpha$ -GAL.

The results presented herein show that covalently cross-linked, multimeric protein structures of  $\alpha$ -galactosidase are characterized by a higher stability and enhanced activity under physiologically relevant conditions, as compared to the native forms of  $\alpha$ -galactosidase.

Thus, the covalently-linked multimeric protein structure may exhibit an activity which is higher than an activity of a native form of  $\alpha$ -galactosidase, as a result of the activity of the native form decaying more rapidly over time than the activity of the cross-linked multimeric protein structure, which is stabilized by the covalent cross-linking.

The covalently cross-linked multimeric protein structure may exhibit an activity which is higher than an activity of a native form of  $\alpha$ -galactosidase, also due to a higher initial activity (e.g., due to different parameters of activity), i.e., independently of any decay of activity over time.

Hence, according to an aspect of some embodiments of the present invention there is provided a multimeric protein structure comprising at least two  $\alpha$ -galactosidase monomers being covalently linked to one another via a linking moiety. According to some embodiments, the multimeric protein structure features a stability higher than that of native  $\alpha$ -galactosidase and/or an initial activity higher than that of native  $\alpha$ -galactosidase, as described in detail below.

Herein, the term "monomer" with respect to  $\alpha$ -galactosidase refers to an individual polypeptide of  $\alpha$ -galactosidase. The polypeptide may include non-peptidic substituents (e.g., one or more saccharide moieties).

Herein, the term "native" with respect to  $\alpha$ -galactosidase encompasses proteins comprising an amino acid sequence substantially identical (i.e., at least 95% homology, optionally at least 99% homology, and optionally 100%) to an amino acid sequence of a naturally occurring  $\alpha$ -galactosidase protein. A native  $\alpha$ -galactosidase may be a protein isolated from a natural source, or a recombinantly produced protein (e.g., derived from mammalian cells, plant cells, yeast cells, bacterial cells, insect cells).

## 14

The term "native", when used in reference to a quaternary structure of  $\alpha$ -galactosidase (e.g., an  $\alpha$ -galactosidase dimer), further comprises a quaternary structure substantially identical to that of a naturally occurring protein.

5 Herein, the phrase "naturally occurring protein" refers to a protein in a form which occurs in nature (e.g., in an organism), with respect to the protein's amino acid sequence, as well as the protein's quaternary structure if the protein is in a multimeric form.

10 Post-translational modifications (e.g., glycosylation) of naturally occurring  $\alpha$ -galactosidase proteins (e.g., in an organism which expresses the naturally occurring  $\alpha$ -galactosidase protein) may be present, absent or modified in the native form of  $\alpha$ -galactosidase referred to herein. A native form of  $\alpha$ -galactosidase (e.g., a recombinantly produced  $\alpha$ -galactosidase) may optionally comprise different post-translational modifications than those of the naturally occurring  $\alpha$ -galactosidase, provided that the native form of the  $\alpha$ -galactosidase retains a substantially similar amino acid sequence and structure as the naturally occurring  $\alpha$ -galactosidase, as described hereinabove.

15 Herein, the native form of a protein may refer to a monomeric structure (e.g., an  $\alpha$ -galactosidase monomer) and/or a multimeric structure (e.g., an  $\alpha$ -galactosidase dimer).

20 For example, a dimeric protein can be described as a native form of  $\alpha$ -galactosidase, and a monomeric polypeptide in a dimeric protein can be described as a native form of the  $\alpha$ -galactosidase monomer.

25 Optionally, the multimeric protein structure described herein is a dimeric structure, as is the native form of  $\alpha$ -galactosidase.

30 Alternatively, the multimeric protein structure comprises more than two  $\alpha$ -galactosidase monomers. For example, the multimeric protein structure may be a tetramer, a hexamer, or an octamer comprised of  $\alpha$ -galactosidase monomers.

35 The multimeric protein structures described herein comprise covalent bonds which link the  $\alpha$ -galactosidase monomers therein, and which are absent from the native form of the  $\alpha$ -galactosidase.

40 Optionally, the linking moiety which links the  $\alpha$ -galactosidase monomers is a moiety which is not present in a native form of  $\alpha$ -galactosidase (e.g., a synthetic linking moiety).

45 Thus, for example, the linking moiety is optionally a moiety which is covalently attached to a side chain, an N-terminus or a C-terminus, or a moiety related to post-translational modifications (e.g., a saccharide moiety) of an  $\alpha$ -galactosidase monomer, as well as to a side chain, an N-terminus or a C-terminus, or a moiety related to post-translational modifications (e.g., a saccharide moiety) of another  $\alpha$ -galactosidase monomer. Exemplary such linking moieties are described in detail hereinunder.

50 Alternatively, the linking moiety forms a part of the  $\alpha$ -galactosidase monomers being linked (e.g., a part of a side chain, N-terminus or C-terminus, or a moiety related to post-translational modifications (e.g., a saccharide moiety) of an  $\alpha$ -galactosidase monomer, as well as of a side chain, an N-terminus or a C-terminus, or a moiety related to post-translational modifications (e.g., a saccharide moiety) of another  $\alpha$ -galactosidase monomer).

55 Thus, for example, the linking moiety can be a covalent bond (e.g., an amide bond) between a functional group of a side chain, N-terminus, C-terminus or moiety related to post-translational modifications of a monomer (e.g., an amine), and a complementary functional group of a side chain, N-terminus, C-terminus or moiety related to post-translational modifications of another monomer (e.g., car-

boxyl), wherein such a covalent bond is absent from the native form of the  $\alpha$ -galactosidase. Other covalent bonds, such as, for example, an ester bond (between a hydroxy group and a carboxyl); a thioester bond; an ether bond (between two hydroxy groups); a thioether bond; an anhydride bond (between two carboxyls); a thioamide bond; a carbamate or thiocarbamate bond, are also contemplated.

Optionally, the linking moiety is devoid of a disulfide bond. However, a linking moiety which includes a disulfide bond at a position which does not form a link between monomers (e.g., cleavage of the disulfide bond does not cleave the link between the monomers) is within the scope of this embodiment of the invention. A potential advantage of linking moiety devoid of a disulfide bond is that it is not susceptible to cleavage by mildly reducing conditions, as are disulfide bonds.

Optionally, the linking moiety is a non-peptidic moiety (e.g., the linking moiety does not consist of an amide bond, an amino acid, a dipeptide, a tripeptide, an oligopeptide or a polypeptide).

Alternatively, the linking moiety may be, or may comprise, a peptidic moiety (e.g., an amino acid, a dipeptide, a tripeptide, an oligopeptide or a polypeptide).

Optionally, the linking moiety is not merely a linear extension of any of the  $\alpha$ -galactosidase monomers attached thereto (i.e., the N-terminus and C-terminus of the peptidic moiety is not attached directly to the C-terminus or N-terminus of any of the  $\alpha$ -galactosidase monomers).

Alternatively, the linking moiety is formed by direct covalent attachment of an N-terminus of an  $\alpha$ -galactosidase monomer with a C-terminus of another  $\alpha$ -galactosidase monomer, so as to produce a fused polypeptide. Such a polypeptide will not be a native form of  $\alpha$ -galactosidase, although it may comprise two  $\alpha$ -galactosidase monomers essentially in their native form.

However, the covalent linking of  $\alpha$ -galactosidase monomers described herein is preferably in a form other than direct linkage of an N-terminus to a C-terminus.

The linking moiety is also referred to herein as a cross-linking moiety. The linking of  $\alpha$ -galactosidase monomers by a linking moiety is referred to herein as "cross-linking".

The cross-linking moiety can be a covalent bond, a chemical atom or group (e.g., a  $C(=O)-O-$  group,  $-O-$ ,  $-S-$ ,  $NR-$ ,  $N=N-$ ,  $NH-C(=O)-NH-$ , and the like) or a bridging moiety (composed of a chain of chemical groups).

A bridging moiety can be, for example, a polymeric or oligomeric group.

The bridging moiety is a multifunctional moiety (e.g., biradical, triradical, etc.) that is attached to side chains, moieties related to post-translational modifications (e.g., saccharide moieties) and/or termini (i.e., N-termini, C-termini) of two or more of the monomers.

As exemplified herein in the Examples section, relatively short linking moieties (e.g., PEG<sub>2</sub>, PEG<sub>4</sub>, PEG<sub>5</sub>) may be less effective than longer linking moieties (e.g., PEG<sub>28</sub>, PEG<sub>45</sub>) at cross-linking between different  $\alpha$ -galactosidase monomers.

Hence, according to some embodiments, the linking moiety is not a covalent bond, a chemical atom or group, but is rather a bridging moiety.

Hence, according to some embodiments, the linking moiety is at least 10 atoms long, optionally at least 20 atoms long, optionally at least 30 atoms long, optionally at least 50 atoms long, optionally at least 100 atoms long, and optionally at least 200 atoms long.

Herein, the length of a linking moiety (when expressed as a number of atoms) refers to length of the backbone of the linking moiety, i.e., the number atoms forming a linear chain between residues of each of two monomers linked via the linking moiety.

Optionally, the linking moiety is below a certain size, so as to avoid an unnecessarily excessive part of the linking moiety in the formed cross-linked protein, which may interfere with the function of the protein.

10 Hence, according to some embodiments, each linking moiety is characterized by a molecular weight of less than 20 KDa, optionally less than 10 KDa, optionally less than 5 KDa, and optionally less than 3 KDa.

In order to facilitate cross-linking, the linking moiety is 15 optionally substantially flexible, wherein the bonds in the backbone of the linking moiety are mostly rotationally free, for example, single bonds which are not coupled to a double bond (e.g., unlike an amide bond) and wherein rotation is not sterically hindered. Optionally, at least 70%, optionally at least 80%, and optionally at least 90% (e.g., 100%) of the bonds in the backbone of the linking moiety are rotationally free.

In some embodiments, the linking moiety comprises a poly(alkylene glycol) chain.

The phrase "poly(alkylene glycol)", as used herein, encompasses a family of polyether polymers which share the following general formula:  $-\text{O}-[(\text{CH}_2)_m-\text{O}-]_n-$ , wherein m represents the number of methylene groups present in each alkylene glycol unit, and n represents the number of repeating units, and therefore represents the size or length of the polymer. For example, when m=2, the polymer is referred to as a polyethylene glycol, and when m=3, the polymer is referred to as a polypropylene glycol.

In some embodiments, m is an integer greater than 1 (e.g., 35 m=2, 3, 4, etc.).

Optionally, m varies among the units of the poly(alkylene glycol) chain. For example, a poly(alkylene glycol) chain may comprise both ethylene glycol (m=2) and propylene glycol (m=3) units linked together.

The poly(alkylene glycol) optionally comprises at least two functional groups (e.g., as described herein), each functional group forming a covalent bond with one of the  $\alpha$ -galactosidase monomers. The functional groups are optionally terminal groups of the poly(alkylene glycol), such that the entire length of the poly(alkylene glycol) lies between the two functional groups.

The phrase "poly(alkylene glycol)" also encompasses analogs thereof, in which the oxygen atom is replaced by another heteroatom such as, for example, S, —NH— and the like. This term further encompasses derivatives of the above, in which one or more of the methylene groups composing the polymer are substituted. Exemplary substituents on the methylene groups include, but are not limited to, alkyl, cycloalkyl, alkenyl, alkynyl, alkoxy, hydroxy, oxo, thiol and thioalkoxy, and the like.

The phrase "alkylene glycol unit", as used herein, encompasses a  $-(\text{CH}_2)_m-\text{O}-$  group or an analog thereof, as described hereinabove, which forms the backbone chain of the poly(alkylene glycol), wherein the  $(\text{CH}_2)_m$  (or analog thereof) is bound to a heteroatom belonging to another alkylene glycol unit or to an  $\alpha$ -galactosidase monomer moiety (in cases of a terminal unit), and the O (or heteroatom analog thereof) is bound to the  $(\text{CH}_2)_m$  (or analog thereof) of another alkylene glycol unit, or to a functional group which forms a bond with an  $\alpha$ -galactosidase monomer.

An alkylene glycol unit may be branched, such that it is linked to 3 or more neighboring alkylene glycol units,

wherein each of the 3 or more neighboring alkylene glycol units are part of a poly(alkylene glycol) chain. Such a branched alkylene glycol unit is linked via the heteroatom thereof to one neighboring alkylene glycol unit, and heteroatoms of the remaining neighboring alkylene glycol units are each linked to a carbon atom of the branched alkylene glycol unit. In addition, a heteroatom (e.g., nitrogen) may bind more than one carbon atom of an alkylene glycol unit of which it is part, thereby forming a branched alkylene glycol unit (e.g.,  $[(-\text{CH}_2)_m]_2\text{N}$ —and the like).

In exemplary embodiments, at least 50% of alkylene glycol units are identical, e.g., they comprise the same heteroatoms and the same m values as one another. Optionally, at least 70%, optionally at least 90%, and optionally 100% of the alkylene glycol units are identical. In exemplary embodiments, the heteroatoms bound to the identical alkylene glycol units are oxygen atoms. In further exemplary embodiments, m is 2 for the identical units.

In one embodiment, the linker is a single, straight chain linker, preferably being polyethylene glycol (PEG).

As used herein, the term “poly(ethylene glycol)” describes a poly(alkylene glycol), as defined hereinabove, wherein at least 50%, at least 70%, at least 90%, and preferably 100%, of the alkylene glycol units are  $-\text{CH}_2\text{CH}_2-\text{O}-$ . Similarly, the phrase “ethylene glycol units” is defined herein as units of  $-\text{CH}_2\text{CH}_2\text{O}-$ .

According to optional embodiments, the linking moiety comprises a poly(ethylene glycol) or analog thereof, having a general formula:



wherein each of  $\text{X}_1$  and  $\text{X}_2$  is a functional group (e.g., as described herein) that forms a covalent bond with at least one  $\alpha$ -galactosidase monomer;

$\text{Y}$  is O, S or  $\text{NR}_5$  (optionally 0);

n is an integer, optionally from 1 to 200 (optionally from 5 to 150, and optionally from 40 to 70), although higher values of n are also contemplated; and

each of  $\text{R}_1$ ,  $\text{R}_2$ ,  $\text{R}_3$ ,  $\text{R}_4$ , and  $\text{R}_5$  is independently selected from the group consisting of hydrogen, alkyl, cycloalkyl, alkenyl, alkynyl, alkoxy, hydroxy, oxo, thiol and thioalkoxy.

In some embodiments, n is at least 5, optionally at least 8, optionally at least 15, optionally at least 25, and optionally at least 40.

In some embodiments, n is no more than 200, optionally no more than 150, and optionally no more than 70.

The poly(ethylene glycol) or analog thereof may optionally comprise a copolymer, for example, wherein the  $\text{CR}_1\text{R}_2-\text{CR}_3\text{R}_4-\text{Y}$  units in the above formula are not all identical to one another.

In some embodiments, at least 50% of  $\text{CR}_1\text{R}_2-\text{CR}_3\text{R}_4-\text{Y}$  units are identical. Optionally, at least 70%, optionally at least 90%, and optionally 100% of the  $\text{CR}_1\text{R}_2-\text{CR}_3\text{R}_4-\text{Y}$  units are identical.

Optionally, the linking moiety is branched, for example, such that for one or more  $\text{CR}_1\text{R}_2-\text{CR}_3\text{R}_4-\text{Y}$  units in the above formula, at least of one of  $\text{R}_1$ ,  $\text{R}_2$ ,  $\text{R}_3$ ,  $\text{R}_4$ , and  $\text{R}_5$  is  $-(\text{CR}_1\text{R}_2-\text{CR}_3\text{R}_4-\text{Y})_p-\text{X}_3-$ , wherein  $\text{R}_1-\text{R}_4$  and  $\text{Y}$  are as defined hereinabove, p is an integer as defined herein for n (e.g., from 1 to 200), and  $\text{X}_3$  is as defined herein for  $\text{X}_1$  and  $\text{X}_2$ .

The functional groups may optionally form a bond such as, but not limited to, an amide bond, an amide bond, an ester bond, and/or an ether bond.

For example, the functional group may optionally comprise a carbonyl group which forms an amide bond with a

nitrogen atom in a polypeptide (e.g., in a lysine residue or N-terminus), or an ester bond with an oxygen atom in a polypeptide (e.g., in a serine, threonine or tyrosine residue).

Alternatively or additionally, the functional group may 5 optionally comprise a heteroatom (e.g., N, S, O) which forms an amide bond, ester bond or thioester bond with a carbonyl group in a polypeptide (e.g., in a glutamate or aspartate residue or in a C-terminus).

Alternative or additionally, the functional group may 10 comprise an alkyl or aryl group attached to a polypeptide (e.g., to a heteroatom in the polypeptide).

Alternatively or additionally, the functional group may 15 optionally comprise a nitrogen atom which forms an amine bond with an alkyl group in an  $\alpha$ -galactosidase monomer, or an  $\alpha$ -galactosidase monomer may optionally comprise a nitrogen atom which forms an amine bond with an alkyl group in the functional group. Such an amine bond may be formed by reductive amination (e.g., as described hereinbelow).

20 In some embodiments, at least one of the functional groups forms an amide bond with a polypeptide (e.g., with a lysine residue therein).

The functional groups may be identical to one another or different.

25 In some embodiments, at least one of the functional groups is attached to one functionality of a polypeptide (e.g., an amine group of a lysine residue or N-terminus), and at least one of the functional groups is attached to a different functionality of a polypeptide (e.g., a thiol group of a cysteine residue).

According to optional embodiments, the multimeric protein structure described herein exhibits a high stability in human plasma conditions and/or in lysosomal conditions.

As used herein, the phrase “human plasma conditions” 30 refers to human plasma as a medium, at a temperature of 37° C.

As used herein, the phrase “lysosomal conditions” refers to an aqueous solution having a pH of 4.6 as a medium (e.g., a citrate phosphate buffer described herein), at a temperature of 37° C.

Enhanced stability under lysosomal conditions is advantageous because the lysosome is a target for replacement therapy for  $\alpha$ -galactosidase, as lysosomes are the normal location for  $\alpha$ -galactosidase activity in a body, and lysosomal conditions (e.g., acidic pH) represent optimal conditions for activity of  $\alpha$ -galactosidase.

Without being bound by any particular theory, it is believed that enhanced stability in serum-like conditions (e.g., the human plasma conditions described herein) is also advantageous because stable  $\alpha$ -galactosidase in the blood can act on metabolites (e.g.,  $\text{Gb}_3$ ) present in the blood due to efflux from cells. A serum-active multimeric protein structure could optionally be efficient in removing and preventing glycosphinglipids deposited within blood vessel walls which promote inflammation [Bodary et al., TCM 55 17(4):129-133]. For example, in Fabry disease, the major pathogenesis results from the accumulation of  $\text{Gb}_3$  in the vascular endothelium, leading to vascular occlusion of small vessels, ischemia and infarction of these vessels and ischemia and infarction of the kidney, heart and brain [Desnick et al., 2003, Annals of Internal Medicine, 138(4):338-346].

Additionally, enhanced stability in serum can negate the need for lysosomal trafficking. ERT can thereby become much more accessible, as robust cost-effective host systems e.g., plants, can be employed.

According to optional embodiments, the high stability of the multimeric protein structure in human plasma conditions

is such that the multimeric protein structure exhibits, upon being subjected to human plasma conditions for one hour, an  $\alpha$ -galactosidase activity which is at least 10% higher, optionally 20% higher, optionally 50% higher, and optionally 100% higher, than an  $\alpha$ -galactosidase activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to the human plasma conditions for one hour.

Alternatively or additionally, the high stability of the multimeric protein structure in human plasma conditions is such that an  $\alpha$ -galactosidase activity of the multimeric protein structure decreases more slowly in human plasma conditions than a corresponding activity of the native  $\alpha$ -galactosidase. Optionally, the multimeric protein structure exhibits an activity which decreases upon subjecting the protein structure to human plasma conditions for one hour by a percentage which is at least 10% less, optionally 20% less, optionally 50% less, and optionally 80% less, than the percentage by which a corresponding activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to human plasma conditions for one hour.

It is to be understood that herein, a decrease which is "10% less" than a decrease of 50% refers to a decrease of 45% (45 being 10% less than 50), and not to a decrease of 40% (50%-10%).

Alternatively or additionally, the high stability of the multimeric protein structure in human plasma conditions is such that an  $\alpha$ -galactosidase activity of the multimeric protein structure remains substantially unchanged upon subjecting the multimeric protein structure to human plasma conditions for one hour, and optionally for 2, 4 or even 6 hours.

As used herein, the phrase "substantially unchanged" refers to a level (e.g., of activity) which remains in a range of from 50% to 150% of the initial level, and optionally a level which remains at least 60%, optionally at least 70%, optionally at least 80%, and optionally at least 90% of the initial level.

Optionally, the high stability of the multimeric protein structure in lysosomal conditions is such that the multimeric protein structure exhibits, upon being subjected to lysosomal conditions for a predetermined time period (e.g., one day, two days, 3 days, one week), an  $\alpha$ -galactosidase activity which is at least 10% higher, optionally 20% higher, optionally 50% higher, and optionally 100% higher, than an activity of native  $\alpha$ -galactosidase upon subjecting the native  $\alpha$ -galactosidase to the lysosomal conditions for the same predetermined time period.

Alternatively or additionally, the high stability of the multimeric protein structure in lysosomal conditions is such that an  $\alpha$ -galactosidase activity of the multimeric protein structure decreases more slowly in lysosomal conditions than a corresponding activity of the native  $\alpha$ -galactosidase. Optionally, the multimeric protein structure exhibits an activity which decreases upon subjecting the protein structure to lysosomal conditions for a predetermined time period (e.g., one day, 2 days, 3 days, one week), by a percentage which is at least 10% less, optionally 20% less, optionally 50% less, and optionally 80% less, than the percentage by which a corresponding activity of the native  $\alpha$ -galactosidase decreases upon subjecting the native  $\alpha$ -galactosidase to lysosomal conditions for the same time period.

Alternatively or additionally, the high stability of the multimeric protein structure in lysosomal conditions is such that an  $\alpha$ -galactosidase activity of the multimeric protein structure remains substantially unchanged upon subjecting

the multimeric protein structure to lysosomal conditions for one day, for 2 days, for 3 days, for one week, for two weeks, and/or for one month.

As exemplified in the Examples section herein, in addition to exhibiting more stability over time, the multimeric protein structure may exhibit parameters of  $\alpha$ -galactosidase activity which are different than those of the native  $\alpha$ -galactosidase.

Hence, according to optional embodiments, the multimeric protein structure is characterized as exhibiting, independently of any decay of activity over time, an  $\alpha$ -galactosidase activity which is higher than an  $\alpha$ -galactosidase activity of a native form of the protein. Optionally, the activity is 10% higher, and optionally 20% higher, than the corresponding activity of the native form.

In order to characterize such an activity, the activity is preferably determined immediately (e.g., within 1 hour, within 15 minutes) upon subjecting the native  $\alpha$ -galactosidase or multimeric protein structure to conditions (e.g., as described herein) in which the activity decreases substantially, so that the measured activity will reflect the activity per se, and not a degree of stability.

Optionally, the multimeric protein structure is characterized as exhibiting an  $\alpha$ -galactosidase activity in lysosomal conditions which is higher than a corresponding activity of native  $\alpha$ -galactosidase.

Alternatively or additionally, the multimeric protein structure is characterized as exhibiting an  $\alpha$ -galactosidase activity in simulated physiological conditions at a neutral pH which is higher than a corresponding activity of native  $\alpha$ -galactosidase. The simulated physiological conditions comprise an aqueous solution (e.g., phosphate buffer saline) at a temperature of 37° C. The pH is optionally 7. Alternatively, the pH is 7.4.

The  $\alpha$ -galactosidase activity described herein is a biological activity which is characteristic of  $\alpha$ -galactosidase (e.g., a catalytic activity characteristic of  $\alpha$ -galactosidase, such as hydrolysis of a terminal  $\alpha$ -galactosyl moiety of a substrate).

In some embodiments, a catalytic activity of  $\alpha$ -galactosidase is characterized by a rate of catalysis at saturation (i.e., a  $V_{max}$  value).

Alternatively, the  $\alpha$ -galactosidase activity is a therapeutic activity (e.g., an enzymatic activity having a therapeutic effect), such as a therapeutic activity in the context of Fabry disease. Optionally, the therapeutic activity is determined in experimental animals (e.g., Fabry mice), and optionally in human Fabry patients.

Techniques for determining an activity of  $\alpha$ -galactosidase will be known to a skilled person. Typically, the  $\alpha$ -galactosidase (i.e., the native form or a multimeric protein structure described herein) is contacted with a compound recognized in the art as a substrate of  $\alpha$ -galactosidase, and the degree of activity is then determined quantitatively. Compounds which allow for particularly convenient detection of  $\alpha$ -galactosidase activity are known in the art and are commercially available.

In some embodiments,  $\alpha$ -galactosidase activity is determined by assaying hydrolysis of 4-methylumbelliferyl- $\alpha$ -D-galactopyranoside (e.g., as described in the Examples section herein).

In some embodiments,  $\alpha$ -galactosidase activity is determined by assaying hydrolysis of p-nitrophenyl- $\alpha$ -D-galactopyranoside (e.g., as described in the Examples section herein).

When comparing an activity of a multimeric protein structure described herein with an activity of native  $\alpha$ -ga-

lactosidase, the native  $\alpha$ -galactosidase preferably comprises  $\alpha$ -galactosidase monomers substantially identical (e.g., with respect to amino acid sequence and glycosylation pattern) to the  $\alpha$ -galactosidase monomers of the multimeric structure.

According to some embodiments, the multimeric protein structure is characterized by a circulating half-life in a physiological system (e.g., blood, serum and/or plasma of a human or laboratory animal) which is higher (e.g., at least 20%, at least 50% higher, at least 100% higher, at least 400% higher, at least 900% higher) than a circulating half-life of native  $\alpha$ -galactosidase.

An increased circulating half-life may optionally be associated with a higher in vitro stability (e.g., as described herein), a higher in vivo stability (e.g., resistance to metabolism) and/or with other factors (e.g., reduced renal clearance).

Circulating half-lives can be determined by taking samples (e.g., blood samples, tissue samples) from physiological systems (e.g., humans, laboratory animals) at various intervals, and determining a level of  $\alpha$ -galactosidase in the sample, using techniques known in the art.

Optionally, the half-life is calculated as a terminal half-life (e.g., as described in the Examples section), wherein half-life is the time required for a concentration (e.g., a blood concentration) to decrease by 50% after pseudo-equilibrium of distribution has been reached. The terminal half-life may be calculated from a terminal linear portion of a time vs. log concentration, by linear regression of time vs. log concentration (see, for example, Toutain & Bousquet-Melou [J Vet Pharmacol Ther 2004, 27:427-39]). Thus, the terminal half-life is a measure of the decrease in drug plasma concentration due to drug elimination and not of decreases due to other reasons, and is not necessarily the time necessary for the amount of the administered drug to fall by one half.

Determining a level of  $\alpha$ -galactosidase (e.g., the multimeric protein structure or the native  $\alpha$ -galactosidase) may comprise detecting the physical presence of  $\alpha$ -galactosidase (e.g., via an antibody against  $\alpha$ -galactosidase) and/or detecting a level of an  $\alpha$ -galactosidase activity (e.g., as described herein).

According to some embodiments, the multimeric protein structure is characterized by an  $\alpha$ -galactosidase activity in an organ (e.g., spleen, heart, kidney, brain, liver) upon administration (e.g., intravenous administration) of the protein structure to a vertebrate (e.g., a human, a mouse), for example, a vertebrate with an  $\alpha$ -galactosidase deficiency (e.g., a human Fabry disease patient, a Fabry mouse). Optionally, the  $\alpha$ -galactosidase activity in the organ is higher than an  $\alpha$ -galactosidase activity of native  $\alpha$ -galactosidase in the organ, upon an equivalent administration to a vertebrate.

The activity in an organ may be a function of uptake of the  $\alpha$ -galactosidase and/or retention of  $\alpha$ -galactosidase activity following uptake.

Optionally,  $\alpha$ -galactosidase activity in the organ is determined 2 hours after administration, and optionally 24 hours, optionally 3 days, optionally 7 days, and optionally 14 days, after administration.

As increased activity of  $\alpha$ -galactosidase in a liver may in some cases be associated with a lower activity in other parts of a body, and hence, with a reduced biological effect of the  $\alpha$ -galactosidase.

Hence, in some embodiments, the multimeric protein structure is characterized by an enhanced  $\alpha$ -galactosidase activity in an organ other than a liver. Exemplary organs include the spleen, heart and kidneys.

In some embodiments, the multimeric protein structure is characterized by an enhanced  $\alpha$ -galactosidase activity in an organ after administration (as described herein) which is at least 20% higher, optionally at least 50% higher, optionally at least 100% higher, and optionally at least 300% higher, than the activity of native  $\alpha$ -galactosidase after an equivalent administration. As noted hereinabove, the present inventors have devised and successfully prepared and practiced stabilized forms of  $\alpha$ -galactosidase by means of multimeric structures of cross-linked  $\alpha$ -galactosidase monomers.

Optionally, the  $\alpha$ -galactosidase is a human  $\alpha$ -galactosidase (e.g., a recombinant human  $\alpha$ -galactosidase), for example, in order to facilitate optimal biocompatibility for administration to human subjects. Human  $\alpha$ -galactosidase is commercially available, for example, as Replagal® (agalsidase alpha, Shire) and Fabrazyme® (agalsidase beta, Genzyme).

Herein, “human  $\alpha$ -galactosidase” refers to an  $\alpha$ -galactosidase comprising an amino acid sequence substantially identical (e.g., as described hereinabove) to an amino acid sequence of an  $\alpha$ -galactosidase protein which naturally occurs in humans.

In some embodiments, the  $\alpha$ -galactosidase is a plant recombinant  $\alpha$ -galactosidase. Exemplary  $\alpha$ -galactosidases include plant recombinant human  $\alpha$ -galactosidases.

Examples of  $\alpha$ -GAL include, without limitation,  $\alpha$ -GAL having an amino acid sequence selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2, and SEQ ID NO: 3. Optionally, the  $\alpha$ -GAL has an amino acid sequence selected from the group consisting of SEQ ID NO: 2 and SEQ ID NO: 3.

As used herein, “ $\alpha$ -galactosidase” refers to any protein which exhibits an enzymatic activity (e.g., hydrolysis) towards galactose moieties in  $\text{Gb}_3$  (e.g.,  $\alpha$ -galactosidase A). Optionally, “ $\alpha$ -galactosidase” refers to E.C. 3.2.1.22.

The  $\alpha$ -galactosidase of embodiments of the invention can be purified (e.g., from plants or animal tissue) or generated by recombinant DNA technology.

As described herein, activity of  $\alpha$ -galactosidase in serum may be highly advantageous, for example, for reducing  $\text{Gb}_3$  levels in serum.

Hence, in some embodiments, the  $\alpha$ -galactosidase is an alkaline  $\alpha$ -galactosidase.

As used herein the phrase “alkaline  $\alpha$ -galactosidase” refers to  $\alpha$ -GAL characterized by an ability to hydrolyse terminal-linked  $\alpha$ -galactose moieties from galactose-containing oligosaccharides under neutral to basic pH conditions (e.g., about pH 7-7.5), particularly at a normal serum pH (e.g., about 7.35-7.45).

It will be appreciated that an alkaline  $\alpha$ -GAL of some embodiments of the invention may be active under neutral to basic pH conditions but may still display activity under acidic pH conditions (i.e., about 4.6).

In a specific embodiment the enzyme is active under acidic to basic pH conditions (i.e., about pH 4.2-7.5).

In yet another specific embodiment the enzyme is active under pH of about 6.5-7.5.

Specific examples of alkaline  $\alpha$ -galactosidases which can be used in accordance with the present teachings are provided in US Patent Application 20070036883, WO03/097791, and in PCT/IL2010/000956, each of which is hereby incorporated by reference in its entirety.

Thus, alkaline  $\alpha$ -galactosidase can be a member of the plant family selected from the group consisting of Cucurbitaceae, Lamiaceae, Piperaceae, Solanaceae, Leguminosae, Cruciferae and Gramineae families.

23

According to a specific embodiment, the alkaline  $\alpha$ -galactosidase is from melon. P.-R. Gaudreault and J. A. Webb have described in several publications, (such as "Alkaline alpha-galactosidase in leaves of *Cucurbita pepo*", Plant Sci. Lett. 24, 281-288, 1982, "Partial purification and properties of an alkaline alpha-galactosidase from mature leaves of *Cucurbita pepo*", Plant Physiol., 71, 662-668, 1983, and "Alkaline alpha-galactosidase activity and galactose metabolism in the family Cucurbitaceae", Plant Science, 45, 71-75, 1986), a novel  $\alpha$ -galactosidase purified from young leaves of *Cucurbita pepo*, that has an optimal activity at alkaline conditions (pH 7.5). In addition to the alkaline  $\alpha$ -galactosidase, they also reported three acid forms of the enzyme, and distinct substrate preferences were found for the acid and alkaline forms.

$\alpha$ -Galactosidase activity at alkaline pH has been observed in other cucurbit tissue, such as cucumber fruit pedicels, young squash fruit and young melon fruit ("Melons: Biochemical and Physiological Control of Sugar Accumulation", In: Encyclopedia of Agricultural Science, vol. 3, pp. 25-37, Arntzen, C. J., et al., eds. Academic Press, New York, 1994).

Bachmann et al. ("Metabolism of the raffinose family oligosaccharides in leaves of *Ajuga reptans* L.", Plant Physiology 105:1335-1345, 1994) that *Ajuga reptans* plants (common bugle), a stachyose translocator from the unrelated Lamiaceae family also contains an alkaline  $\alpha$ -galactosidase. This enzyme was partially characterized and found to have high affinity to stachyose. Also, leaves of the *Peperomia camptotricha* L. plant, from the family Piperaceae, show  $\alpha$ -galactosidase activity at alkaline pH, suggesting that they also contain an alkaline  $\alpha$ -galactosidase enzyme (Madore, M., "Catabolism of raffinose family oligosaccharides by vegetative sink tissues", In: Carbon Partitioning and Source-Sink Interactions in Plants, Madore, M. and Lucas, W. J. (eds.) pp. 204-214, 1995, American Society of Plant Physiologists, Maryland). Similarly, Gao and Schaffer (Plant Physiol. 1999; 119:979-88, which is incorporated fully herein by reference) have reported an  $\alpha$ -galactosidase activity with alkaline pH optimum in crude extracts of tissues from a variety of species including members of the Cucurbit and Coleus (Lamiaceae) families.

Specific examples of plant alkaline  $\alpha$ -galactosidase sequences are provided in SEQ ID NOS: 4, 5 and 13 (*Cucumis melo*), 6 (*T. tetragonoides*), 7 and 12 (*Cucumis sativus*), 8 and 9 (*Zea mays*), 10 (*Oruza sativa*), 11 (*Pisum sativum*) and 14 (*Coffea arabica*).

In some embodiments, the  $\alpha$ -galactosidase is an acid  $\alpha$ -galactosidase.

As used herein, "acid  $\alpha$ -galactosidase" refers to  $\alpha$ -galactosidase characterized by an ability to hydrolyse terminal-linked  $\alpha$ -galactose moieties from galactose-containing oligosaccharides under acidic pH conditions (e.g., about pH 4.2-5), such as occur in a lysosome.

The  $\alpha$ -galactosidase of embodiments of the invention can be of any human, animal or plant source, provided no excessively adverse immunological reaction is induced upon *in vivo* administration (e.g., plant to human).

To reduce immunological reaction, a non-human  $\alpha$ -galactosidase preparation (e.g., of plant  $\alpha$ -galactosidase) can be co-administered with a human  $\alpha$ -galactosidase (i.e., acid human  $\alpha$ -galactosidase).

Optionally, the multimeric protein structure further comprises at least one mannose-6-phosphate (M6P) moiety. The M6P moiety (or moieties) may be linked to one or more of the  $\alpha$ -galactosidase monomers of the multimeric protein structure (e.g., via a linker).

24

Techniques and reagents for introducing M6P-containing moieties to a biomolecule (e.g., a polypeptide) are described in WO 2009/024977.

As exemplified in the Examples section herein, a multimeric protein structure described herein may be conveniently prepared by reacting  $\alpha$ -galactosidase with a cross-linking agent.

Hence, according to another aspect of embodiments of the invention, there is provided a process of preparing a multimeric protein structure described herein. The process comprises reacting  $\alpha$ -galactosidase, so as to introduce at least one linking moiety which covalently links at least two  $\alpha$ -galactosidase monomers.

Optionally, the linking moiety is a bond (e.g., an amide bond, a disulfide bond) which links one  $\alpha$ -galactosidase monomer to another  $\alpha$ -galactosidase monomer. Optionally, the bond is introduced by using suitable conditions and/or reagents. For example, reagents which are suitable for forming an amide bond from a carboxylic acid group and an amine group are known in the art.

Optionally, the linking moiety is a moiety which is not derived from a part of the  $\alpha$ -galactosidase. For example, the linking moiety may be an oligomer, a polymer, a residue of a small molecule (e.g., an amino acid).

In some embodiments, the linking moiety is introduced by reacting the  $\alpha$ -galactosidase with a cross-linking agent which comprises the linking moiety (e.g., as described herein) and at least two reactive groups.

Optionally, the  $\alpha$ -galactosidase is reacted under conditions in which the native  $\alpha$ -galactosidase is in a dimeric form.

In some embodiments, the cross-linking agent is reacted with the  $\alpha$ -galactosidase at a molar ratio in a range of from 5:1 to 500:1 (cross-linking agent:  $\alpha$ -galactosidase monomer), optionally in a range of from 50:1 to 400:1, and optionally in a range of 75:1 to 300:1 (e.g., about 100:1, about 200:1).

The process optionally further comprises purifying the cross-linked protein, for example, removing excess cross-linking agent. Common purification methods may be used, such as dialysis and/or ultra-filtration using appropriate cut-off membranes and/or additional chromatographic steps, including size exclusion chromatography, ion exchange chromatography, affinity chromatography, hydrophobic interaction chromatography, and the like.

The reactive group is selected suitable for undergoing a chemical reaction that leads to a bond formation with a complementary functionality in the  $\alpha$ -galactosidase monomer. Optionally, each reactive group is capable of forming a covalent bond between the linking moiety described herein and at least one polypeptide (e.g., so as to form a functional group bound to the polypeptide, as described herein).

The reactive groups of a cross-linking agent may be identical to one another or different.

As used herein, the phrase "reactive group" describes a chemical group that is capable of undergoing a chemical reaction that typically leads to a bond formation. The bond, according to the present embodiments, is preferably a covalent bond (e.g., for each of the reactive groups). Chemical reactions that lead to a bond formation include, for example, nucleophilic and electrophilic substitutions, nucleophilic and electrophilic addition reactions, alkylations, addition-elimination reactions, cycloaddition reactions, rearrangement reactions and any other known organic reactions that involve a functional group, as well as combinations thereof.

The reactive group may optionally comprise a non-reactive portion (e.g., an alkyl) which may serve, for example,

to attach a reactive portion of the reactive group to a linking moiety (e.g., poly(alkylene glycol) or analog thereof) described herein.

The reactive group is preferably selected so as to enable its conjugation to  $\alpha$ -galactosidase. Exemplary reactive groups include, but are not limited to, carboxylate (e.g.,  $-\text{CO}_2\text{H}$ ), thiol ( $-\text{SH}$ ), amine ( $-\text{NH}_2$ ), halo, azide ( $-\text{N}_3$ ), isocyanate ( $-\text{NCO}$ ), isothiocyanate ( $-\text{N}=\text{C}=\text{S}$ ), hydroxy ( $-\text{OH}$ ), carbonyl (e.g., aldehyde), maleimide, sulfate, phosphate, sulfonyl (e.g. mesyl, tosyl), etc. as well as activated groups, such as N-hydroxysuccinimide (NHS) (e.g. NHS esters), sulfo-N-hydroxysuccinimide, anhydride, acyl halide ( $-\text{C}(=\text{O})\text{-halogen}$ ) etc.

In some embodiments, the reactive group comprises a leaving group, such as a leaving group susceptible to nucleophilic substitution (e.g., halo, sulfate, phosphate, carboxylate, N-hydroxysuccinimide).

Optionally, the reactive group may be in an activated form thereof.

As used herein, the phrase "activated form" describes a derivative of a chemical group (e.g., a reactive group) which is more reactive than the chemical group, and which is thus readily capable of undergoing a chemical reaction that leads to a bond formation. The activated form may comprise a particularly suitable leaving group, thereby facilitating substitution reactions. For example, a  $-\text{C}(=\text{O})\text{-NHS}$  group (N-hydroxysuccinimide ester, or  $-\text{C}(=\text{O})\text{-O-succinimide}$ ) is a well-known activated form of  $-\text{C}(=\text{O})\text{OH}$ , as NHS (N-hydroxysuccinimide) can be reacted with a  $-\text{C}(=\text{O})\text{OH}$  to form  $-\text{C}(=\text{O})\text{-NHS}$ , which readily reacts to form products characteristic of reactions involving  $-\text{C}(=\text{O})\text{OH}$  groups, such as amides and esters.

The reactive group can be attached to the rest of the linking moiety (e.g., a poly(alkylene glycol) or analog thereof) via different groups, atoms or bonds. These may include an ether bond [e.g.,  $-\text{O-alkyl-}$ ], an ester bond [e.g.,  $-\text{O-C}(=\text{O})\text{-alkyl-}$ ], a carbamate [e.g.,  $\text{O-C}(=\text{O})\text{-NH-alkyl-}$ ], etc. Thus, a variety of terminal groups can be employed.

The following are non-limiting examples of the different groups that may constitute a reactive group as described herein:  $-\text{CH}_2\text{CO}_2\text{H}$ ,  $-\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$ ,  $-\text{CH}_2\text{CH}_2\text{SH}$ ,  $-\text{CH}_2\text{CH}_2\text{NH}_2$ ,  $-\text{CH}_2\text{CH}_2\text{N}_3$ ,  $-\text{CH}_2\text{CH}_2\text{NCO}$ ,  $-\text{CH}_2\text{C}(=\text{O})\text{-NHS}$ ,  $-\text{CH}_2\text{CH}_2\text{C}(=\text{O})\text{-NHS}$ ,  $-\text{C}(=\text{O})\text{-CH}_2\text{C}(=\text{O})\text{-NHS}$ ,  $-\text{CH}_2\text{CH}_2\text{NHC}(=\text{O})\text{CH}_2\text{CH}_2\text{-maleimide}$ , etc.

The number of methylene groups in each of the above reactive groups is merely exemplary, and may be varied.

The reactive group may also comprise the heteroatom at the end of a poly(alkylene glycol) chain (e.g.,  $-\text{OH}$ ).

In exemplary embodiments of the present invention, the reactive group comprises a carboxylate (e.g., an activated carboxylate such as an N-hydroxysuccinimide ester).

Optionally, the reactive group reacts with an amine group in the  $\alpha$ -galactosidase (e.g., in a lysine residue and/or an N-terminus) to form an amide bond.

In some embodiments, the reaction of the reactive group comprises reductive amination, wherein an amine group reacts with an aldehyde group to form an imine, and the imine is reduced (e.g., by addition of a reducing agent, such as sodium cyanoborohydride) to form an amine bond. The reactive group may be an amine group which reacts with an aldehyde group of the  $\alpha$ -galactosidase (e.g., on a saccharide moiety attached to the polypeptide of the protein), or the reactive group may be an aldehyde group which reacts with an amine group of the  $\alpha$ -galactosidase (e.g., on a lysine residue). Optionally, a saccharide moiety of  $\alpha$ -galactosidase

is oxidized by an oxidizing agent to form an aldehyde group, prior to reaction of the reactive group with the  $\alpha$ -galactosidase. For example, reaction of a saccharide with sodium periodate may be used to produce a pair of aldehyde groups in a saccharide moiety.

In some embodiments, at least one of the reactive groups is selected so as to react with one functionality of an  $\alpha$ -galactosidase monomer (e.g., an amine group of a lysine residue or N-terminus), and at least one of the reactive groups is selected so as to react with a different functionality of an  $\alpha$ -galactosidase monomer (e.g., a thiol group of a cysteine residue).

Optionally, one or more polypeptides described herein are reacted with a glycosylation reagent for introducing one or more M6P moieties, in order to obtain an M6P-containing multimeric protein structure (e.g., as described herein). Suitable M6P-containing glycosylation reagents and their use are described, for example, in WO 2009/024977.

As used herein, the terms "amine" and "amino" refer to either a  $-\text{NRR}'$  group, wherein R' and R" are selected from the group consisting of hydrogen, alkyl, cycloalkyl, heteroalicyclic (bonded through a ring carbon), aryl and heteroaryl (bonded through a ring carbon). R' and R" are bound via a carbon atom thereof. Optionally, R' and R" are selected from the group consisting of hydrogen and alkyl comprising 1 to 4 carbon atoms. Optionally, R' and R" are hydrogen.

As used herein throughout, the term "alkyl" refers to a saturated aliphatic hydrocarbon including straight chain and branched chain groups. Preferably, the alkyl group has 1 to 20 carbon atoms. Whenever a numerical range; e.g., "1-20", is stated herein, it implies that the group, in this case the alkyl group, may contain 1 carbon atom, 2 carbon atoms, 3 carbon atoms, etc., up to and including 20 carbon atoms. More preferably, the alkyl is a medium size alkyl having 1 to 10 carbon atoms. Most preferably, unless otherwise indicated, the alkyl is a lower alkyl having 1 to 4 carbon atoms. The alkyl group may be substituted or unsubstituted.

When substituted, the substituent group can be, for example, cycloalkyl, alkenyl, alkynyl, aryl, heteroaryl, heteroalicyclic, halo, hydroxy, alkoxy, aryloxy, thiohydroxy, thioalkoxy, thioaryloxy, sulfinyl, sulfonyl, cyano, nitro, azide, phosphonyl, phosphinyl, oxo, carbonyl, thiocarbonyl, urea, thiourea, O-carbamyl, N-carbamyl, O-thiocarbamyl, N-thiocarbamyl, C-amido, N-amido, C-carboxy, O-carboxy, sulfonamido, and amino, as these terms are defined herein.

A "cycloalkyl" group refers to an all-carbon monocyclic or fused ring (i.e., rings which share an adjacent pair of carbon atoms) group wherein one or more of the rings does not have a completely conjugated pi-electron system. Examples, without limitation, of cycloalkyl groups are cyclopropane, cyclobutane, cyclopentane, cyclopentene, cyclohexane, cyclohexadiene, cycloheptane, cycloheptatriene, and adamantane. A cycloalkyl group may be substituted or unsubstituted.

When substituted, the substituent group can be, for example, alkyl, alkenyl, alkynyl, aryl, heteroaryl, heteroalicyclic, halo, hydroxy, alkoxy, aryloxy, thiohydroxy, thioalkoxy, thioaryloxy, sulfinyl, sulfonyl, cyano, nitro, azide, phosphonyl, phosphinyl, oxo, carbonyl, thiocarbonyl, urea, thiourea, O-carbamyl, N-carbamyl, O-thiocarbamyl, N-thiocarbamyl, C-amido, N-amido, C-carboxy, O-carboxy, sulfonamido, and amino, as these terms are defined herein.

An "alkenyl" group refers to an alkyl group which consists of at least two carbon atoms and at least one carbon-carbon double bond.

An "alkynyl" group refers to an alkyl group which consists of at least two carbon atoms and at least one carbon-carbon triple bond.

An "aryl" group refers to an all-carbon monocyclic or fused-ring polycyclic (i.e., rings which share adjacent pairs of carbon atoms) groups having a completely conjugated pi-electron system. Examples, without limitation, of aryl groups are phenyl, naphthalenyl and anthracenyl. The aryl group may be substituted or unsubstituted. When substituted, the substituent group can be, for example, alkyl, alkenyl, alkynyl, cycloalkyl, aryl, heteroaryl, heteroalicyclic, halo, hydroxy, alkoxy, aryloxy, thiohydroxy, thioalkoxy, thioaryloxy, sulfinyl, sulfonyl, cyano, nitro, azide, phosphonyl, phosphinyl, oxo, carbonyl, thiocarbonyl, urea, thiourea, O-carbamyl, N-carbamyl, O-thiocarbamyl, N-thiocarbamyl, C-amido, N-amido, C-carboxy, O-carboxy, sulfonamido, and amino, as these terms are defined herein.

A "heteroaryl" group refers to a monocyclic or fused ring (i.e., rings which share an adjacent pair of atoms) group having in the ring(s) one or more atoms, such as, for example, nitrogen, oxygen and sulfur and, in addition, having a completely conjugated pi-electron system. Examples, without limitation, of heteroaryl groups include pyrrole, furane, thiophene, imidazole, oxazole, thiazole, pyrazole, pyridine, pyrimidine, quinoline, isoquinoline and purine. The heteroaryl group may be substituted or unsubstituted. When substituted, the substituent group can be, for example, alkyl, alkenyl, alkynyl, cycloalkyl, aryl, heteroaryl, heteroalicyclic, halo, hydroxy, alkoxy, aryloxy, thiohydroxy, thioalkoxy, thioaryloxy, sulfinyl, sulfonyl, cyano, nitro, azide, phosphonyl, phosphinyl, oxo, carbonyl, thiocarbonyl, urea, thiourea, O-carbamyl, N-carbamyl, O-thiocarbamyl, N-thiocarbamyl, C-amido, N-amido, C-carboxy, O-carboxy, sulfonamido, and amino, as these terms are defined herein.

A "heteroalicyclic" group refers to a monocyclic or fused ring group having in the ring(s) one or more atoms such as nitrogen, oxygen and sulfur. The rings may also have one or more double bonds. However, the rings do not have a completely conjugated pi-electron system. The heteroalicyclic may be substituted or unsubstituted. When substituted, the substituent group can be, for example, lone pair electrons, alkyl, alkenyl, alkynyl, cycloalkyl, aryl, heteroaryl, heteroalicyclic, halo, hydroxy, alkoxy, aryloxy, thiohydroxy, thioalkoxy, thioaryloxy, sulfinyl, sulfonyl, cyano, nitro, azide, phosphonyl, phosphinyl, oxo, carbonyl, thiocarbonyl, urea, thiourea, O-carbamyl, N-carbamyl, O-thiocarbamyl, N-thiocarbamyl, C-amido, N-amido, C-carboxy, O-carboxy, sulfonamido, and amino, as these terms are defined herein. Representative examples are piperidine, piperazine, tetrahydrafuran, tetrahydropyran, morpholine and the like.

A "hydroxy" group refers to an —OH group.

An "azide" group refers to a —N=N<sup>+</sup>=N<sup>-</sup> group.

An "alkoxy" group refers to both an —O-alkyl and an —O-cycloalkyl group, as defined herein.

An "aryloxy" group refers to both an —O-aryl and an —O-heteroaryl group, as defined herein.

An "ether" refers to both an alkoxy and an aryloxy group, wherein the group is linked to an alkyl, alkenyl, alkynyl, cycloalkyl, aryl, heteroaryl or heteroalicyclic group.

An ether bond describes a —O— bond.

A "thiohydroxy" or "thiol" group refers to a —SH group.

A "thioalkoxy" group refers to both an —S-alkyl group, and an —S-cycloalkyl group, as defined herein.

A "thioaryloxy" group refers to both an —S-aryl and an —S-heteroaryl group, as defined herein.

A "thioether" refers to both a thioalkoxy and a thioaryloxy group, wherein the group is linked to an alkyl, alkenyl, alkynyl, cycloalkyl, aryl, heteroaryl or heteroalicyclic group.

5 A thioether bond describes a —S— bond.

A "disulfide" group refers to both a —S-thioalkoxy and a —S-thioaryloxy group.

A disulfide bond describes a —S—S— bond.

10 A "carbonyl" group refers to a —C(=O)—R' group, where R' is defined as hereinabove.

A "thiocarbonyl" group refers to a —C(=S)—R' group, where R' is as defined herein.

A "carboxyl" refers to both "C-carboxy" and O-carboxy".

15 A "C-carboxy" group refers to a —C(=O)—O—R' groups, where R' is as defined herein.

An "O-carboxy" group refers to an R'C(=O)—O— group, where R' is as defined herein.

An "oxo" group refers to a =O group.

20 A "carboxylate" or "carboxyl" encompasses both C-carboxy and O-carboxy groups, as defined herein.

A "carboxylic acid" group refers to a C-carboxy group in which R' is hydrogen.

A "thiocarboxy" or "thiocarboxylate" group refers to both —C(=S)—O—R' and C(=S)R' groups.

An "ester" refers to a C-carboxy group wherein R' is not hydrogen.

An ester bond refers to a —O—C(=O)— bond.

A thioester bond refers to a —O—C(=S)— bond or to a —S—C(=O) bond.

30 A "halo" group refers to fluorine, chlorine, bromine or iodine.

A "sulfinyl" group refers to an —S(=O)—R' group, where R' is as defined herein.

A "sulfonyl" group refers to an —S(=O)<sub>2</sub>—R' group, where R' is as defined herein.

A "sulfonate" group refers to an —S(=O)<sub>2</sub>—O—R' group, where R' is as defined herein.

40 A "sulfate" group refers to an —O—S(=O)<sub>2</sub>—O—R' group, where R' is as defined as herein.

A "sulfonamide" or "sulfonamido" group encompasses both S-sulfonamido and N-sulfonamido groups, as defined herein.

An "S-sulfonamido" group refers to a —S(=O)<sub>2</sub>—NR'R" group, with each of R' and R" as defined herein.

An "N-sulfonamido" group refers to an R'S(=O)<sub>2</sub>—NR" group, where each of R' and R" is as defined herein.

An "O-carbamyl" group refers to an —OC(=O)—NR'R" group, where each of R' and R" is as defined herein.

50 An "N-carbamyl" group refers to an R'OC(=O)—NR"— group, where each of R' and R" is as defined herein.

A "carbamyl" or "carbamate" group encompasses O-carbamyl and N-carbamyl groups.

A carbamate bond describes a —O—C(=O)—NR'— bond, where R' is as described herein.

An "O-thiocarbamyl" group refers to an —OC(=S)—NR'R" group, where each of R' and R" is as defined herein.

An "N-thiocarbamyl" group refers to an R'OC(=S)NR"— group, where each of R' and R" is as defined herein.

A "thiocarbamyl" or "thiocarbamate" group encompasses O-thiocarbamyl and N-thiocarbamyl groups.

A thiocarbamate bond describes a —O—C(=S)—NR'— bond, where R' is as described herein.

A "C-amido" group refers to a —C(=O)—NR'R" group, where each of R' and R" is as defined herein.

60 An "N-amido" group refers to an R'C(=O)—NR"— group, where each of R' and R" is as defined herein.

An "amide" group encompasses both C-amido and N-amido groups.

An amide bond describes a —NR'—C(=O)— bond, where R' is as defined herein.

An amine bond describes a bond between a nitrogen atom in an amine group (as defined herein) and an R' group in the amine group.

A thioamide bond describes a —NR'—C(=S)— bond, where R' is as defined herein.

A "urea" group refers to an —N(R')—C(=O)—NR"R" group, where each of R' and R" is as defined herein, and R" is defined as R' and R" are defined herein.

A "nitro" group refers to an —NO<sub>2</sub> group.

A "cyano" group refers to a group.

The term "phosphonyl" or "phosphonate" describes a —P(=O)(OR')(OR") group, with R' and R" as defined hereinabove.

The term "phosphate" describes an —O—P(=O)(OR')(OR") group, with each of R' and R" as defined hereinabove.

A "phosphoric acid" is a phosphate group in which each of R is hydrogen.

The term "phosphinyl" describes a —PR'R" group, with each of R' and R" as defined hereinabove.

The term "thiourea" describes a —N(R')—C(=S)—NR"— group, with each of R' and R" as defined hereinabove.

As described herein, multimeric protein structures described herein may exhibit improved stability and stronger and/or longer lasting  $\alpha$ -galactosidase activity at therapeutically important sites *in vivo*. Such multimeric protein structures are therefore highly beneficial for use in various medical applications in which  $\alpha$ -galactosidase activity is desirable, including therapeutic and research applications.

Hence, according to some embodiments, the multimeric protein structure described herein is for use as a medicament, for example, a medicament for treating Fabry disease.

According to another aspect of embodiments of the invention, there is provided a method of treating Fabry disease, the method comprising administering to a subject in need thereof a therapeutically effective amount of a multimeric protein structure described herein.

According to another aspect of embodiments of the invention, there is provided a pharmaceutical composition that comprises a multimeric protein structure as described herein and a pharmaceutically acceptable carrier.

As used herein a "pharmaceutical composition" refers to a preparation of one or more of the multimeric protein structures described herein, with other chemical components such as pharmaceutically acceptable and suitable carriers and excipients. The purpose of a pharmaceutical composition is to facilitate administration of a compound to an organism.

Hereinafter, the term "pharmaceutically acceptable carrier" refers to a carrier or a diluent that does not cause significant irritation to an organism and does not abrogate the biological activity and properties of the administered compound. Examples, without limitations, of carriers are: propylene glycol, saline, emulsions and mixtures of organic solvents with water, as well as solid (e.g., powdered) and gaseous carriers.

Herein the term "excipient" refers to an inert substance added to a pharmaceutical composition to further facilitate administration of a compound. Examples, without limitation, of excipients include calcium carbonate, calcium phosphate, various sugars and types of starch, cellulose derivatives, gelatin, vegetable oils and polyethylene glycols.

The pharmaceutical composition optionally comprises an additional ingredient which further stabilizes the  $\alpha$ -galactosidase of the multimeric protein structure. Optionally, the additional ingredient is galactose.

Alternatively, a galactose derivative (e.g., a galactose-containing glycoside) may be used instead of galactose. Optionally, a non-reducing galactose derivative is used.

Techniques for formulation and administration of drugs may be found in "Remington's Pharmaceutical Sciences"

10 Mack Publishing Co., Easton, PA, latest edition, which is incorporated herein by reference.

15 Pharmaceutical compositions of the present invention may be manufactured by processes well known in the art, e.g., by means of conventional mixing, dissolving, granulating, dragee-making, levigating, emulsifying, encapsulating, entrapping or lyophilizing processes.

20 Pharmaceutical compositions for use in accordance with the present invention thus may be formulated in conventional manner using one or more pharmaceutically acceptable carriers comprising excipients and auxiliaries, which facilitate processing of the multimeric protein structure into preparations which can be used pharmaceutically. Proper formulation is dependent upon the route of administration chosen.

25 For injection or infusion, the multimeric protein structures of embodiments of the invention may be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hank's solution, Ringer's solution, or physiological saline buffer with or without organic solvents such as propylene glycol, polyethylene glycol.

For transmucosal administration, penetrants are used in the formulation. Such penetrants are generally known in the art.

30 For oral administration, the multimeric protein structures of the invention can be formulated readily by combining the multimeric protein structures with pharmaceutically acceptable carriers well known in the art. Such carriers enable the multimeric protein structures described herein to be formulated as tablets, pills, dragees, capsules, liquids, gels, syrups, 35 slurries, suspensions, and the like, for oral ingestion by a patient. Pharmacological preparations for oral use can be made using a solid excipient, optionally grinding the resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries if desired, to obtain tablets or dragee cores. Suitable excipients are, in particular, fillers such as sugars, including lactose, sucrose, mannitol, or sorbitol; cellulose preparations such as, for example, maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethylcellulose, sodium carbomethylcellulose; and/or physiologically acceptable polymers such as polyvinylpyrrolidone (PVP). If desired, disintegrating agents may be added, such as cross-linked polyvinyl pyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate.

40 Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, titanium dioxide, lacquer solutions and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of doses of active multimeric protein structure.

45 Pharmaceutical compositions, which can be used orally, include push-fit capsules made of gelatin as well as soft, sealed capsules made of gelatin and a plasticizer, such as glycerol or sorbitol. The push-fit capsules may contain the

active ingredients in admixture with filler such as lactose, binders such as starches, lubricants such as talc or magnesium stearate and, optionally, stabilizers. In soft capsules, the multimeric protein structures may be dissolved or suspended in suitable liquids, such as fatty oils, liquid paraffin, or liquid polyethylene glycols. In addition, stabilizers may be added. All formulations for oral administration should be in dosages suitable for the chosen route of administration.

For buccal administration, the compositions may take the form of tablets or lozenges formulated in conventional manner.

For administration by inhalation, the multimeric protein structures for use according to embodiments of the present invention are conveniently delivered in the form of an aerosol spray presentation (which typically includes powdered, liquified and/or gaseous carriers) from a pressurized pack or a nebulizer, with the use of a suitable propellant, e.g., dichlorodifluoromethane, trichlorofluoromethane, dichloro-tetrafluoroethane or carbon dioxide. In the case of a pressurized aerosol, the dosage unit may be determined by providing a valve to deliver a metered amount. Capsules and cartridges of, e.g., gelatin for use in an inhaler or insufflator may be formulated containing a powder mix of the multimeric protein structures and a suitable powder base such as, but not limited to, lactose or starch.

The multimeric protein structures described herein may be formulated for parenteral administration, e.g., by bolus injection or continuous infusion. Formulations for injection or infusion may be presented in unit dosage form, e.g., in ampoules or in multidose containers with optionally, an added preservative. The compositions may be suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents.

Pharmaceutical compositions for parenteral administration include aqueous solutions of the multimeric protein structure preparation in water-soluble form. Additionally, suspensions of the multimeric protein structures may be prepared as appropriate oily injection suspensions and emulsions (e.g., water-in-oil, oil-in-water or water-in-oil in oil emulsions). Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or synthetic fatty acids esters such as ethyl oleate, triglycerides or liposomes. Aqueous injection suspensions may contain substances, which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol or dextran. Optionally, the suspension may also contain suitable stabilizers or agents, which increase the solubility of the multimeric protein structures to allow for the preparation of highly concentrated solutions.

Alternatively, the multimeric protein structures may be in powder form for constitution with a suitable vehicle, e.g., sterile, pyrogen-free water, before use.

The multimeric protein structure of embodiments of the present invention may also be formulated in rectal compositions such as suppositories or retention enemas, using, e.g., conventional suppository bases such as cocoa butter or other glycerides.

The pharmaceutical compositions herein described may also comprise suitable solid or gel phase carriers or excipients. Examples of such carriers or excipients include, but are not limited to, calcium carbonate, calcium phosphate, various sugars, starches, cellulose derivatives, gelatin and polymers such as polyethylene glycols.

Pharmaceutical compositions suitable for use in the context of the present invention include compositions wherein the active ingredients are contained in an amount effective to

achieve the intended purpose. More specifically, a therapeutically effective amount means an amount of multimeric protein structures effective to prevent, alleviate or ameliorate symptoms of disease or prolong the survival of the subject being treated.

For any multimeric protein structures used in the methods of the invention, the therapeutically effective amount or dose can be estimated initially from activity assays in animals. For example, a dose can be formulated in animal models to achieve a circulating concentration range that includes the IC<sub>50</sub> as determined by activity assays (e.g., the concentration of the test protein structures, which achieves a half-maximal increase in a biological activity of the multimeric protein structure). Such information can be used to more accurately determine useful doses in humans.

As is demonstrated in the Examples section that follows, a therapeutically effective amount for the multimeric protein structures of embodiments of the present invention may range between about 1 µg/kg body weight and about 500 mg/kg body weight.

Toxicity and therapeutic efficacy of the multimeric protein structures described herein can be determined by standard pharmaceutical procedures in experimental animals, e.g., by determining the EC<sub>50</sub>, the IC<sub>50</sub> and the LD<sub>50</sub> (lethal dose causing death in 50% of the tested animals) for a subject protein structure. The data obtained from these activity assays and animal studies can be used in formulating a range of dosage for use in human.

The dosage may vary depending upon the dosage form employed and the route of administration utilized. The exact formulation, route of administration and dosage can be chosen by the individual physician in view of the patient's condition. (See e.g., Fingl et al., 1975, in "The Pharmacological Basis of Therapeutics", Ch. 1 p. 1).

Dosage amount and interval may be adjusted individually to provide plasma levels of the active moiety which are sufficient to maintain the desired effects, termed the minimal effective concentration (MEC). The MEC will vary for each preparation, but can be estimated from in vitro data; e.g., the concentration necessary to achieve the desired level of activity in vitro. Dosages necessary to achieve the MEC will depend on individual characteristics and route of administration. HPLC assays or bioassays can be used to determine plasma concentrations.

Dosage intervals can also be determined using the MEC value. Preparations should be administered using a regimen, which maintains plasma levels above the MEC for 10-90% of the time, preferable between 30-90% and most preferably 50-90%.

Depending on the severity and responsiveness of the condition to be treated, dosing can also be a single administration of a slow release composition described hereinabove, with course of treatment lasting from several days to several weeks or until cure is effected or diminution of the disease state is achieved.

The amount of a composition to be administered will, of course, be dependent on the subject being treated, the severity of the affliction, the manner of administration, the judgment of the prescribing physician, etc.

Compositions of the present invention may, if desired, be presented in a pack or dispenser device, such as an FDA (the U.S. Food and Drug Administration) approved kit, which may contain one or more unit dosage forms containing the active ingredient. The pack may, for example, comprise metal or plastic foil, such as, but not limited to a blister pack or a pressurized container (for inhalation). The pack or dispenser device may be accompanied by instructions for

## 33

administration. The pack or dispenser may also be accompanied by a notice associated with the container in a form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceuticals, which notice is reflective of approval by the agency of the form of the compositions for human or veterinary administration. Such notice, for example, may be of labeling approved by the U.S. Food and Drug Administration for prescription drugs or of an approved product insert. Compositions comprising a multimeric protein structure of embodiments of the invention formulated in a compatible pharmaceutical carrier may also be prepared, placed in an appropriate container, and labeled for treatment of an indicated condition or diagnosis, as is detailed herein.

Thus, according to an embodiment of the present invention, depending on the selected multimeric protein structures, the pharmaceutical composition described herein is packaged in a packaging material and identified in print, in or on the packaging material, for use in the treatment of a condition in which the activity of the multimeric protein structure is beneficial, as described hereinabove.

As used herein the term "about" refers to  $\pm 10\%$

The terms "comprises", "comprising", "includes", "including", "having" and their conjugates mean "including but not limited to".

The term "consisting of" means "including and limited to".

The word "exemplary" is used herein to mean "serving as an example, instance or illustration". Any embodiment described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments.

The word "optionally" is used herein to mean "is provided in some embodiments and not provided in other embodiments". Any particular embodiment of the invention may include a plurality of "optional" features unless such features conflict.

As used herein, the singular form "a", "an" and "the" include plural references unless the context clearly dictates otherwise. For example, the term "a compound" or "at least one compound" may include a plurality of compounds, including mixtures thereof.

Throughout this application, various embodiments of this invention may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have specifically disclosed all the possible subranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed subranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases "ranging/ranges between" a first indicate number and a second indicate number and "ranging/ranges from" a first indicate number "to" a second indicate number are used herein interchangeably and are meant to include the first and second indicated numbers and all the fractional and integral numerals therebetween.

## 34

As used herein the term "method" refers to manners, means, techniques and procedures for accomplishing a given task including, but not limited to, those manners, means, techniques and procedures either known to, or readily developed from known manners, means, techniques and procedures by practitioners of the chemical, pharmacological, biological, biochemical and medical arts.

As used herein, the term "treating" includes abrogating, substantially inhibiting, slowing or reversing the progression of a condition, substantially ameliorating clinical or aesthetical symptoms of a condition or substantially preventing the appearance of clinical or aesthetical symptoms of a condition.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

Various embodiments and aspects of the present invention as delineated hereinabove and as claimed in the claims section below find experimental support in the following examples.

## EXAMPLES

Reference is now made to the following examples, which together with the above descriptions illustrate some embodiments of the invention in a non limiting fashion.

## Materials and Methods

## Materials:

bis-N-hydroxysuccinimide-poly(ethylene glycol) (bis-NHS-PEG) was obtained from Iris Biotech GmbH in PEG<sub>8</sub> and 2000 Dalton (PEG<sub>45</sub>) PEG forms, and from Pierce in PEG<sub>5</sub> form, and dissolved in dimethyl sulfoxide (DMSO) at a concentration of 25 mg/mL;

Citric acid was obtained from Sigma; Coomassie Blue G250 was obtained from Bio-Rad; Dimethyl sulfoxide was obtained from Sigma; D-(+)-galactose was obtained from Sigma; Human plasma (K3 EDTA) was obtained from Bioreclamation Inc.;

4-Methylumbelliferyl was obtained from Sigma; 4-Methylumbelliferyl- $\alpha$ -D-galactopyranoside was obtained from Sigma;

N-dodecanoyl-nitrobenzoxadiazole-ceramide trihexoside (Gb<sub>3</sub>-NBD) was obtained from Matreya; 2-(N-morpholino)ethanesulfonic acid was obtained from Merck;

Phosphate buffered saline was obtained from Sigma; p-Nitrophenyl- $\alpha$ -D-galactopyranoside was obtained from Sigma;

Primuline was obtained from Sigma; Primuline spray reagent was prepared by dissolving 12.5 mg primuline in 200 ml acetone:water (8:2 volume ratio);

Pyridine was obtained from Sigma; Sinapinic acid was obtained from Sigma; Sodium carbonate was obtained from Sigma; Sodium phosphate was obtained from Sigma;

35

Sodium taurocholate was obtained from Sigma; Trifluoroacetic acid was obtained from Sigma.

**Plant Recombinant Human  $\alpha$ -GAL-I:**

Plant recombinant human  $\alpha$ -GAL (prh- $\alpha$ -GAL) having SEQ ID NO: 1, referred to herein as plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I), was prepared as described in International Patent Application PCT/IL2008/000576 (published as WO 2008/132743).

Transgenic plant material was generated using *Nicotiana Benthamiana* plants infiltrated with genetic construct containing the expression cassette for  $\alpha$ -GAL-A, for expressing the human  $\alpha$ -GAL-A protein. This was performed in a growth chamber under controlled conditions. This was followed by harvest of plant material and extraction of soluble proteins from the plant cells. prh- $\alpha$ -GAL-A was then purified by a purification process involving standard methods for protein purification followed by a chemical modification step to manufacture the cross-linked protein. The current prh- $\alpha$ -GAL-A was extracted from plant material using homogenizers. The plant debris was removed by centrifugation and the protein was further purified using ammonium sulfate precipitation and acidification steps. The supernatant was filtered and loaded onto a hydrophobic column, followed by desalting and loading onto a cation exchange column. The pool of the cation exchange column was concentrated.

**Plant Recombinant Human  $\alpha$ -GAL-II:**

Plant recombinant human  $\alpha$ -GAL comprising a mixture of  $\alpha$ -GAL having SEQ ID NO: 2 and  $\alpha$ -GAL having SEQ ID NO: 3 (without the N-terminal amino acids EF present in SEQ ID NO: 1), referred to herein as prh- $\alpha$ -GAL-II, was prepared by a process similar to that described above for prh- $\alpha$ -GAL-I, using a different genetic construct.

cDNA encoding the human  $\alpha$ -galactosidase protein (EC 3.2.1-22 GenBank: X05790) was optimized and synthesized by GENEART AG (Regensburg, Germany). The codon usage without the leader peptide (endoplasmic reticulum target signal peptide) was adapted to the codon bias of *Nicotiana tabacum* genes. During the optimization process the following cis-acting sequence motifs were avoided: internal TATA-boxes, chi-sites and ribosomal entry sites, AT-rich or GC-rich sequence stretches, RNA instability elements ("killer motifs"), repeat sequences and RNA secondary structures, splice donor (cryptic) and acceptor sites, branch points. In addition, regions of very high (>80%) or very low (<30%) GC content has been avoided.

The nucleotide sequence of the native human  $\alpha$ -galactosidase leader peptide (endoplasmic reticulum target signal peptide) of full length human  $\alpha$ -galactosidase protein (GenBank: X05790) was replaced with a nucleotide sequence encoding the 33 amino acid endoplasmic reticulum targeting signal peptide (leader peptide) of the *Arabidopsis* ABPI protein. This signal peptide provides efficient targeting of  $\alpha$ -galactosidase to the secretory pathway and is cleaved from the polypeptide, by signal peptidase, once the protein has been translocated into the endoplasmic reticulum. A nucleotide sequence encoding the endoplasmic reticulum retention signal SEKDEL was added to the cDNA sequence at the 3' terminus, allowing retrieval of the expressed protein from the Golgi apparatus, effectively maintaining the protein in the endoplasmic reticulum.

The protein of interest was expressed from a strong subgenomic viral promoter of the coat protein. The system relies on transient amplification (by agroinfection) of viral vectors delivered to a plant by *Agrobacterium*. In agroinfection, a plant functional promoter and the cDNA encoding a viral replicon are transferred as T-DNA from *Agrobacterium* into plant cells. The T-DNA is transcribed in planta by the plant promoter to generate biologically active viral RNA that initiates self replication.

36

For the transient expression a 3 vector recombination system based on the system previously developed as described [Gleba et al., *Vaccine* 2005, 23:2042-2048]. One of the vectors was inserted with  $\alpha$ -galactosidase cDNA and the two other vectors containing genes for construction of the whole viral replicon (RdRp and Integrase), thus generating the biologically active viral RNA that can initiate self replication.

*N. Benthamiana* plants were germinated and grown in commercial mix soil (Givat Ada, IL) supplemented with granular slow release fertilizer (Scott Marysville, OH) under a long day (16 hours light/8 hours dark) light regime at 24-25° C.

Agrobacteria were transformed with the pICH20866-alpha-GAL based replicon vector system using electroporation (2500 V, 5 milliseconds) [den Dulk-Ra and Hooykaas, *Methods Mol Biol* 1995, 55:63-72]. Plants were infiltrated with Agrobacteria containing the 3 ICON plasmids by vacuum infiltration with standard methods known in the art. Briefly, *N. benthamiana* plants, 5-6 week old, were infiltrated by immersing all aerial plant organs into a bacterial suspension and were placed in a vacuum chamber. A minus (~) 0.8 bar vacuum was applied for 1 minute, followed by a quick return to atmospheric pressure. Plants were returned to the greenhouse for additional 5-7 days under the same growth conditions.

Samples of *Nicotiana benthamiana* leaves were harvested 5 days post infiltration and extracted in Laemmli buffer for SDS-PAGE, or in activity assay buffer (20 mM citric acid, 30 mM sodium phosphate, 0.1% bovine serum albumin and 0.67% ethanol, pH 4.6.) for assay of catalytic activity of the plant expressed protein.

Human  $\alpha$ -galactosidase protein from plant extracts was purified by a two-step ammonium sulfate differential precipitation ("salting out": 1<sup>st</sup> step 0.57 M; 2<sup>nd</sup> step 2.27 M), followed by hydrophobic interaction chromatography (Phe-nyl 650 M resin) and cation exchange chromatography.

Two sequences (i.e., SEQ ID NO: 2 and SEQ ID NO: 3), which differ in the presence or absence of an N-terminal glycine, were obtained due to different leader sequence processing.

**4-Methylumbelliferyl- $\alpha$ -D-galactopyranoside Assay of  $\alpha$ -GAL Activity:**

$\alpha$ -GAL activity was measured using 4-methylumbelliferyl- $\alpha$ -D-galactopyranoside as a hydrolysis substrate. The assay was performed in citrate-phosphate buffer (20 mM citric acid, 30 mM sodium phosphate, pH 4.6). 10  $\mu$ L of sample containing the tested  $\alpha$ -GAL was incubated with 40  $\mu$ L assay buffer containing 5 mM 4-methylumbelliferyl- $\alpha$ -D-galactopyranoside. The reaction mixture was incubated at 37° C. for 60 minutes. 10  $\mu$ L of the reaction mixture were transferred into a black 96-well plate (Greiner), 90  $\mu$ L of stop solution (2 M sodium carbonate) was added, and fluorescence was measured at an excitation wavelength of 365 nm and an emission wavelength of 450 nm. Fluorescence was translated to product concentration, and further to activity, using a calibration curve of 4-methylumbelliferone, the reaction product.

**N-Dodecanoyl-Nitrobenzoxadiazole-Ceramide Trihexoside ( $G_b_3$ -NBD) Assay of  $\alpha$ -GAL Activity**

The fluorescently labeled substrate N-dodecanoyl-nitrobenzoxadiazole-ceramide trihexoside ( $G_b_3$ -NBD) is less lipophilic than  $G_b_3$ , facilitating its use in in-vitro enzymatic reactions.

10  $\mu$ L of 0.1  $\mu$ g/ $\mu$ L Gb<sub>3</sub>-NBD (in water with 10% ethanol), and 5  $\mu$ L of 0.2 mg/mL  $\alpha$ -GAL were added to 85  $\mu$ L of citrate-phosphate buffer at a pH of 4.6. The final  $\alpha$ -GAL concentration was 10  $\mu$ g/mL. The background or non-catalyzed reaction, without  $\alpha$ -GAL, was composed of 90  $\mu$ L of citrate-phosphate buffer at a pH of 4.6 with 10  $\mu$ L of 0.1  $\mu$ g/ $\mu$ L Gb<sub>3</sub>-NBD (in water with 10% ethanol). The reaction mixtures were incubated for 60 minutes at 37° C. Following the incubation, 50  $\mu$ L methanol was added to the reaction mixture, and the solutions were vortexed for 1 minute. 100  $\mu$ L chloroform was then added, and the solutions were further vortexed for 1 minute. Water and organic solvents were removed under vacuum using a Speed Vac system. The residues were dissolved in 80  $\mu$ L of chloroform:methanol (1:1). 30  $\mu$ L of each sample was loaded on HPTLC (high performance thin layer chromatography) Silica Gel 60 plates (Merck) using a Linomat V system (CAMAG). HPTLC plates were developed using a chloroform:methanol:H<sub>2</sub>O solution at a ratio of 100:42:6 as a solvent system. Plates were then allowed to dry and the substrate and product spots were visualized by irradiation under UV light at a wavelength of 365 nm.

#### p-Nitrophenyl- $\alpha$ -D-galactopyranoside (p-NP-G) Assay of $\alpha$ -GAL Activity:

p-Nitrophenyl- $\alpha$ -D-galactopyranoside was used as a hydrolysis substrate for  $\alpha$ -GAL activity assays. The assay buffer contained 20 mM citric acid, 30 mM sodium phosphate, 0.1% BSA (bovine serum albumin) and 0.67% ethanol at pH 4.6. The assay was performed in 96 well ELISA plates (Greiner). 50  $\mu$ L of sample were incubated with 150  $\mu$ L assay buffer and 30  $\mu$ L substrate was added to obtain a final concentration of 8 mM p-nitrophenyl- $\alpha$ -D-galactopyranoside. The reaction mixture was incubated at 37° C. for 90 minutes. After 90 minutes, 100  $\mu$ L of 1.98 M sodium carbonate was added to each well in order to terminate the reaction. The amount of reaction product was determined by measuring absorbance at 405 nm.

#### Measurement of $\alpha$ -GAL Stability In Vitro:

The stability of  $\alpha$ -GAL from various sources was determined by adding  $\alpha$ -GAL to one of the following conditions:

- 1) simulated lysosomal conditions: citrate-phosphate buffer (20 mM citric acid, 30 mM sodium phosphate), pH 4.6, 37° C.;
- 2) simulated physiological conditions: phosphate buffered saline (PBS), pH 7.4, 37° C.;
- 3) human plasma at 37° C.

The  $\alpha$ -GAL was added at a concentration of 1  $\mu$ g/mL, as determined by the activity of  $\alpha$ -GAL in the solution, and the solution was incubated at 37° C. Samples of each solution were withdrawn at predetermined time points and the  $\alpha$ -GAL activity was measured as described hereinabove. The value of the enzymatic activity immediately after addition of the tested  $\alpha$ -GAL to each environment was defined as 100%, and further activity results at the tested time points were calculated as a percentage of that initial activity.

#### Pharmacokinetics of $\alpha$ -GAL:

Individual Fabry ( $\alpha$ -Gal-A/-0) mice were placed in an illuminated plexiglass restraining device, and the enzyme was injected into the tail vein. Blood samples were obtained at the indicated times after injection by either tail bleed or retro-orbital eye bleed, using heparinized microhematocrit tubes. Plasma was diluted in 4-methylumbelliferyl- $\alpha$ -D-galactopyranoside activity buffer. A 4-methylumbelliferyl- $\alpha$ -D-galactopyranoside assay was performed as described above.

Terminal elimination half-life (T<sub>1/2</sub>) was calculated based on plasma activity results. The terminal half-life (elimina-

tion half-life) is the time required for the plasma concentration to decrease by 50% after pseudo-equilibrium of distribution has been reached. The terminal half-life was calculated from the terminal (log-linear) portion of the curve, by linear regression of time vs. log concentration [Toutain & Bousquet-Melou, *J Vet Pharmacol Ther* 2004, 27:427-39].

#### Bio-Distribution of $\alpha$ -GAL:

Fabry ( $\alpha$ -Gal-A/-0) mice were injected intravenously (in 10 the tail vein) with  $\alpha$ -GAL at a dose of 2 mg/Kg. Tissues (livers, kidneys, hearts, and spleens) were harvested 2 hours, 24 hours, 3 days, 7 days, 14 days or 28 days post-injection of the enzyme.  $\alpha$ -GAL levels in normal control mice and in 15 saline-administered (untreated) Fabry mice were compared with the levels in Fabry mice that received exogenous  $\alpha$ -GAL. To determine the  $\alpha$ -GAL activity in tissues, thawed tissue samples were placed in 2 mL polypropylene tubes containing lysis buffer (28 mM citric acid, 44 mM dibasic sodium phosphate, 0.5% sodium taurocholate, pH 4.4) as 20 described in Oshima et al. [*PNAS* 1997, 94:2540-2544]. The samples were homogenized by use of a Tissuelyzer (Retsch MM400) for 10 minutes. Debris was pelleted by centrifugation at 4° C., and the resulting supernatants were assayed for  $\alpha$ -GAL activity by a 4-methylumbelliferyl- $\alpha$ -D-galac- 25 tobyranoside assay, as described above. The same samples were also subjected to Western blot analysis.

#### In Vivo Gb<sub>3</sub> Assay:

The end point efficacy of injected  $\alpha$ -GAL was measured by assay of Gb<sub>3</sub> levels of the animal tissues, in order to 30 determine whether Gb<sub>3</sub> levels were decreased by  $\alpha$ -GAL activity.

To measure Gb<sub>3</sub> hydrolysis, neutral glycosphingolipids 35 were extracted from target organs (e.g., liver, kidney, heart and spleen). 100 mg tissue samples were homogenized in 1 mL of 2:1 (v/v) chloroform:methanol and centrifuged for 20 minutes at 13,500 rpm. 62  $\mu$ L of water was added to 1 mL homogenate to yield a solution of 20:10:2 chloroform:methanol:water. 10  $\mu$ L pyridine was added to the homogenate to give a final pyridine concentration of 1%. The sample 40 was agitated for 24 hours at 48° C. Solvents and water were removed under vacuum using a SpeedVac system. The sample was resuspended in 2.5 mL methanol and 250  $\mu$ L of 1 M KOH in methanol was then added. The sample was then shaken for 2 hours at 37° C. The saponification reaction was 45 stopped by the addition of 10  $\mu$ L of acetic acid. 2.5 mL chloroform was then added to the sample, followed by the addition of 2.5 mL cold water. The sample was vigorously shaken for 5 minutes and was allowed to rest for 5 minutes to allow phase separation. The upper phase, composed of methanol and water, was discarded, and the lower phase, composed of chloroform and methanol, was evaporated 50 under vacuum (SpeedVac), and the residue was resuspended in 300  $\mu$ L of 1:1 (v/v) chloroform:methanol for analysis of the glycosphingolipids by HPTLC.

Qualitative and semiquantitative analyses of tissue glycosphingolipids were performed by high performance thin layer chromatography (HPTLC) (CAMAG, Switzerland). HPTLC analysis was performed on HPTLC silica gel 60 glass coated plates (Merck). Samples were loaded on the 55 plates using a Linomat 5 system (CAMAG, Switzerland). Plates were developed using chloroform:methanol:water (60:35:4) as the solvent system. Neutral glycosphingolipids were detected with primuline spray reagent. Gb<sub>3</sub> was identified using porcine red blood cell Gb<sub>3</sub> (Matreya) as a standard, and quantified using a calibration curve of N-heptadecanoyl ceramide trihexoside (Matreya), a semi-synthetic standard. Plates were visualized and relevant spots were 60

39

quantified using a TLC Scanner III (CAMAG, Switzerland) supported by winCATS software (CAMAG, Switzerland). SDS-PAGE:

SDS-PAGE was carried out under reduced conditions using a Bio-Rad Criterion™ system and in-house casted 12% acrylamide gel. The gel was stained by Coomassie Blue G250 stain.

#### IEF (Isoelectric Focusing):

IEF was carried out using an Invitrogen Novex® mini-cell and precasted IEF gels having a pH range of 3-7 (Invitrogen). The gel was stained by Coomassie Blue G250. Mass Spectrometry (MALDI-TOF):

MALDI-TOF was performed using a Bruker Reflex IV MALDI-ToF Mass-spectrometer system (Bruker-Franzen Analytik GmbH, Germany) and a sinapinic acid/trifluoroacetic acid (TFA) (0.1% TFA/acetonitrile (2:1, v/v)) saturated matrix solution.

#### Example I

##### In Vitro Stability of Recombinant $\alpha$ -GAL

The in vitro stability of recombinant  $\alpha$ -GAL was measured in various conditions as described hereinabove in the Materials and Methods Section. Plant recombinant human  $\alpha$ -GAL-I, as well as Fabrazyme® and Replagal® commercial recombinant human  $\alpha$ -GAL, were tested.

As shown in FIG. 1, all of the tested types of  $\alpha$ -GAL exhibited a loss of activity under simulated lysosomal conditions.

In addition, as shown in FIG. 2, all of the tested types of  $\alpha$ -GAL exhibited a loss of activity under simulated physiological conditions. As further shown therein, the presence of 100 mg/mL galactose partially protected the activity of plant recombinant  $\alpha$ -GAL-I under such conditions.

Similarly, as shown in FIG. 3, all of the tested types of  $\alpha$ -GAL exhibited a loss of activity in human plasma at 37° C.

As shown in FIG. 4, the presence of 100 mg/mL galactose partially protected the activity of plant recombinant  $\alpha$ -GAL-I under simulated lysosomal conditions.

Size exclusion chromatography (SEC) experiments at lysosomal and neutral pH levels demonstrated changes in the protein structure (data not shown), while SDS-PAGE and Western blot analyses did not exhibit any degradation of the primary amino acid sequence (data not shown).

These results indicate that  $\alpha$ -GAL loses activity under lysosomal conditions and physiological conditions due to alteration of the  $\alpha$ -GAL protein structure, and that galactose partially prevents this loss of activity.

#### Example II

##### Cross-Linking of Plant Recombinant Human $\alpha$ -GAL-I with Bis-N-Hydroxysuccinimide-Poly(Ethylene Glycol) (Bis-NHS-PEG) Agents

Plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I) was cross-linked at 50:1, 100:1 and 200:1 molar ratios with bis-N-hydroxysuccinimide-poly(ethylene glycol) (bis-NHS-PEG) of various molecular weights, namely bis-NHS-PEG<sub>5</sub>, bis-NHS-PEG<sub>8</sub> or bis-NHS-PEG<sub>45</sub> (bis-NHS-PEG with 2,000 Dalton PEG), the structures of which are shown in FIG. 5.

The bis-NHS-PEG may attach to the protein at two sites on a protein (e.g., lysine residues), thereby forming cross-linking, or at one site on a protein. These two forms of attachment are depicted in FIG. 6.

40

100  $\mu$ g  $\alpha$ -GAL-I in 28.5  $\mu$ L of 2-(N-morpholino)ethanesulfonic acid (MES) buffer (25 mM, pH 6) was added to 13.5  $\mu$ L of phosphate buffer (100 mM, pH 8) containing 100 mg/ml galactose.

5  $\alpha$ -GAL-I was cross-linked with bis-NHS-PEG<sub>8</sub> at 1:50, 1:100, and 1:200 protein: reagent molar ratios, by adding bis-NHS-PEG<sub>5</sub> in 8  $\mu$ L DMSO to the  $\alpha$ -GAL-I solution (27.4  $\mu$ g  $\alpha$ -GAL-I solution for a 1:50 molar ratio, 54.8  $\mu$ g  $\alpha$ -GAL-I solution for a 1:100 molar ratio, and 109.7  $\mu$ g  $\alpha$ -GAL-I solution for a 1:200 molar ratio).

$\alpha$ -GAL-I was cross-linked with bis-NHS-PEG<sub>45</sub> at 1:50, 1:100, and 1:200 protein: reagent molar ratios, by adding bis-NHS-PEG<sub>45</sub> in 8  $\mu$ L DMSO to the  $\alpha$ -GAL-I solution (103  $\mu$ g  $\alpha$ -GAL-I solution for a 1:50 molar ratio, 206  $\mu$ g  $\alpha$ -GAL-I solution for a 1:100 molar ratio, and 412  $\mu$ g  $\alpha$ -GAL-I solution for a 1:200 molar ratio)  $\alpha$ -GAL-I was crosslinked with bis-NHS-PEG<sub>8</sub> at 1:50, 1:100, and 1:200 protein: reagent molar ratios, by adding bis-NHS-PEG<sub>8</sub> in

15 11.5  $\mu$ L DMSO to the  $\alpha$ -GAL-I solution (37  $\mu$ g  $\alpha$ -GAL-I for a 1:50 molar ratio, 73  $\mu$ g  $\alpha$ -GAL-I solution for a 1:100 molar ratio, and 146  $\mu$ g  $\alpha$ -GAL-I solution for a 1:200 molar ratio).

20 After adding the bis-NHS-PEG agent to the  $\alpha$ -GAL-I, the reactions were pipetted and agitated on an orbital shaker for 2 hours at room temperature.

In all reactions the excess of bis-NHS-PEG cross-linking reagent was removed by dialysis against saline (50 KDa cut off).

25 The yield of dimer increased with increasing protein concentration and DMSO concentration, reaching up to 30%.

30 The reaction products were analyzed by SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis), IEF (isoelectric focusing), Western blot, and MALDI-TOF mass spectrometry, as described hereinabove.

35 As shown in FIG. 7, the standard native prh- $\alpha$ -GAL-I was observed as a monomer (having a molecular weight of 48 KDa) following gel electrophoresis, whereas following reaction of prh- $\alpha$ -GAL-I with bis-NHS-PEG, prh- $\alpha$ -GAL-I appeared primarily in the form of a dimer (with some monomer present), indicating that the two monomers were covalently linked by cross-linking with bis-NHS-PEG.

40 As is further shown in FIG. 7, a higher proportion of monomeric prh- $\alpha$ -GAL-I was observed with the shorter cross-linkers, bis-NHS-PEG<sub>5</sub> and bis-NHS-PEG<sub>8</sub>, than with the longer cross-linker bis-NHS-PEG<sub>45</sub>. The bis-NHS-PEG<sub>45</sub> yielded a high proportion of cross-linked protein. These results indicate that the shorter cross-linkers are less effective at covalently linking monomers.

45 50 As is further shown in FIG. 7, for each of the tested cross-linkers, the molecular weight of the monomeric portion of prh- $\alpha$ -GAL-I increased following reaction with the cross-linker. The increase in molecular weight was greater when a higher ratio of cross-linker to protein was used (e.g., 200:1), and when the molecular weight of the cross-linker was greater (e.g., bis-NHS-PEG<sub>45</sub>). These results indicate that protein monomers which were not dimerized by cross-linking, were covalently attached to the bis-NHS-PEG cross-linker, i.e., the proteins were PEGylated.

55 60 The above results indicate that the use of higher molar excess of cross-linker to protein yields higher levels of  $\alpha$ -GAL modification, including both cross-linking to form a dimer and PEGylation of the proteins. However, a molar ratio of 100:1 provided a high level of cross-linking, especially in the reactions using the bis-NHS-PEG<sub>45</sub> reagent, such that a molar ratio of 200:1 provided only a marginal addition to the cross-linking efficiency.

As shown in FIG. 8, reacting prh- $\alpha$ -GAL-I with bis-NHS-PEG reduced the isoelectric point (pI) of prh- $\alpha$ -GAL-I, thereby confirming that the bis-NHS-PEG is covalently attached to the prh- $\alpha$ -GAL-I. Attachment of bis-NHS-PEG to prh- $\alpha$ -GAL-I converts basic amine groups in lysine residues to neutral amide groups, thereby reducing the pI. The reduction in pI was more pronounced when a greater molar excess (e.g., 200:1) of bis-NHS-PEG was used, confirming the above results obtained with SDS-PAGE.

As is further shown in FIG. 8, the pI is reduced more by bis-NHS-PEG<sub>5</sub> and bis-NHS-PEG<sub>8</sub> than by bis-NHS-PEG<sub>45</sub>.

This result indicates that bis-NHS-PEG<sub>5</sub> and bis-NHS-PEG<sub>8</sub> are more likely than bis-NHS-PEG<sub>45</sub> to result in PEGylation in which only one terminus of the cross-linker is attached to  $\alpha$ -GAL. A cross-linker attached to  $\alpha$ -GAL at only one terminus is more effective at reducing the pI because such a cross-linker comprises an acidic carboxylic ( $-\text{CO}_2\text{H}$ ) group at the non-attached terminus, in addition to converting a lysine amine group to an amide group at the attached terminus.

As shown in FIG. 9, reacting prh- $\alpha$ -GAL-I with bis-NHS-PEG<sub>45</sub> cross-linker increased the molecular weight of the prh- $\alpha$ -GAL-I dimer from 97 KDa to 113 KDa, as determined by MALDI-TOF mass spectrometry. The increase in molecular weight indicates an addition of approximately 8 molecules of bis-NHS-PEG<sub>45</sub> to the prh- $\alpha$ -GAL-I dimer.

As shown in FIG. 10, reacting prh- $\alpha$ -GAL-I with a bis-NHS-PEG<sub>8</sub> cross-linker increased the molecular weight of the prh- $\alpha$ -GAL-I dimer from 97 KDa to 104 KDa, as determined by MALDI-TOF mass spectrometry. The increase in molecular weight indicates an addition of approximately 10 molecules of bis-NHS-PEG<sub>8</sub> to the prh- $\alpha$ -GAL-I dimer.

### Example III

#### Activity of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-I

In order to determine whether the cross-linked plant recombinant  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I) described in Example II retained enzymatic activity, the cross-linked prh- $\alpha$ -GAL-I was assayed for its enzymatic activity using the 4-methyl-umbelliferyl- $\alpha$ -D-galactopyranoside assay described hereinabove.

As shown in Table 1 below, prh- $\alpha$ -GAL-I which was reacted with bis-NHS-PEG<sub>5</sub>, bis-NHS-PEG<sub>8</sub> or bis-NHS-PEG<sub>45</sub> at molar excesses of 50:1, 100:1 and 200:1 bis-NHS-PEG reagent in all cases exhibited a level of enzymatic activity similar to that of native prh- $\alpha$ -GAL-I. As shown therein, both moderate decreases and moderate increases in activity were observed in some cases, which may be a result of formulation effects. These results indicate that the cross-linking did not reduce the activity of prh- $\alpha$ -GAL-I.

TABLE 1

Activity results of cross-linked plant recombinant human $\alpha$ -GAL I			
Sample	Reagent	Molar excess	Activity mg/mL
standard	—	—	2
1	Bis-NHS-PEG <sub>5</sub>	50:1	2.25
2	Bis-NHS-PEG <sub>5</sub>	100:1	1.30
3	Bis-NHS-PEG <sub>5</sub>	200:1	1.24
4	Bis-NHS-PEG <sub>45</sub>	50:1	2.82

TABLE 1-continued

Activity results of cross-linked plant recombinant human $\alpha$ -GAL I			
Sample	Reagent	Molar excess	Activity mg/mL
5	Bis-NHS-PEG <sub>45</sub>	100:1	2.76
6	Bis-NHS-PEG <sub>45</sub>	200:1	3.48
7	Bis-NHS-PEG <sub>8</sub>	50:1	2.18
8	Bis-NHS-PEG <sub>8</sub>	100:1	2.43
9	Bis-NHS-PEG <sub>8</sub>	200:1	1.82

The activity of the bis-NHS-PEG<sub>45</sub> cross-linked prh- $\alpha$ -GAL-I was further verified using the N-dodecanoyl-NBD-ceramide trihexoside assay described hereinabove, which assays the activity of  $\alpha$ -GAL towards its natural substrate, ceramide trihexoside (Gb<sub>3</sub>). Replagal® mammalian recombinant human  $\alpha$ -GAL was assayed for comparison.

As shown in FIG. 11, following incubation of the cross-linked plant recombinant human  $\alpha$ -GAL-I with the fluorescent substrate, almost all substrate was converted to the product, N-dodecanoyl-nitrobenzoxadiazole-lactosyl ceramide, similarly to the reaction catalyzed by the mammalian recombinant  $\alpha$ -GAL (Replagal®). This result confirms that the cross-linking did not impair the enzymatic hydrolytic efficiency of the prh- $\alpha$ -GAL-I, using a close analog of the natural substrate.

### Example IV

#### In Vitro Stability of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-I

The in vitro stability of the cross-linked plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I), obtained as described in Example II, was measured in various conditions as described hereinabove in the Materials and Methods Section. The stability of Fabrazyme® and Replagal® commercial recombinant human  $\alpha$ -GALs was measured for comparison.

As shown in FIGS. 12A-12C, the stability of plant recombinant human  $\alpha$ -GAL-I under simulated lysosomal conditions was enhanced by cross-linking with bis-NHS-PEG<sub>5</sub> (FIG. 12A), bis-NHS-PEG<sub>8</sub> (FIG. 12B) and bis-NHS-PEG<sub>45</sub> (FIG. 12C). As further shown therein, the stability of the cross-linked prh- $\alpha$ -GAL-I over the course of one week compared favorably to the stability of the commercial recombinant human  $\alpha$ -GAL. After a small decrease in residual activity during the first 24 hours, the cross-linked prh- $\alpha$ -GAL-I maintained activity, even after 10 days. The initial decrease in activity, observed during the first 24 hours, may reflect the portion of plant recombinant human  $\alpha$ -GAL-I that did not undergo cross-linking.

As further shown in FIGS. 12A-12C, prh- $\alpha$ -GAL-I cross-linked by bis-NHS-PEG<sub>45</sub> exhibited the highest stability under simulated lysosomal conditions.

The stability of plant recombinant human  $\alpha$ -GAL-I in human plasma at 37° C. was also enhanced by cross-linking with bis-NHS-PEG<sub>45</sub> (data not shown).

These results indicate that cross-linking  $\alpha$ -GAL as described herein can increase the efficacy of  $\alpha$ -GAL in vivo by increasing the stability of  $\alpha$ -GAL in lysosomes, thereby allowing  $\alpha$ -GAL to act for a longer period of time in the lysosomes, and by increasing the stability of  $\alpha$ -GAL in the blood, thereby increasing the circulatory half-life of  $\alpha$ -GAL.

43

## Example V

In Vivo Pharmacokinetics and Bio-Distribution of Cross-Linked Plant Recombinant Human  $\alpha$ -GAL-I

The pharmacokinetics and bio-distribution of plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I) cross-linked with bis-NHS-PEG<sub>45</sub> or bis-NHS-PEG<sub>8</sub> as described in Example II was determined in Fabry mice injected with 2 mg/Kg of  $\alpha$ -GAL, as described hereinabove in the Materials and Methods Section. The pharmacokinetics and bio-distribution of non-cross-linked plant recombinant human  $\alpha$ -GAL-I and of Replagal® recombinant human  $\alpha$ -GAL was determined for comparison. Blood samples were collected for pharmacokinetic analysis 1, 3, 5, 10, 20, 30, 40, 60 and 120 minutes post-injection. For each type of  $\alpha$ -GAL, the treatment group consisted of six mice.

As shown in Table 2 below, cross-linking prh- $\alpha$ -GAL-I with bis-NHS-PEG<sub>8</sub> and with bis-NHS-PEG<sub>45</sub> increased the circulatory terminal half-life of plant recombinant human  $\alpha$ -GAL-I, with the latter exhibiting a more pronounced effect.

TABLE 2

Circulatory terminal half-lives of recombinant $\alpha$ -GAL	
$\alpha$ -GAL sample	t <sub>1/2</sub> (minutes)
Replagal® mammalian recombinant human $\alpha$ -GAL	8.1
Plant recombinant human $\alpha$ -GAL-I	4.8
Plant recombinant human $\alpha$ -GAL I cross-linked with bis-NHS-PEG <sub>8</sub>	6.2
Plant recombinant human $\alpha$ -GAL-I cross-linked with bis-NHS-PEG <sub>45</sub>	90

As shown in FIG. 13 and in Table 2, the terminal half-life of prh  $\alpha$ -GAL-I cross-linked by bis-NHS-PEG<sub>45</sub> was considerably greater than the terminal half-life of Replagal®  $\alpha$ -GAL.

As further shown in FIG. 13, the activity of plant recombinant human  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> at 20 minutes was about 40% of the activity at 1 minute. Furthermore, the cross-linked prh- $\alpha$ -GAL-I exhibited an active plasma presence even 4 hours post-injection.

These results indicate that the cross-linked prh- $\alpha$ -GAL-I remains active in vivo for a relative long time, which can allow the enzyme to reach additional tissues and organs.

As shown in FIGS. 14A and 14B, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> and bis-NHS-PEG<sub>45</sub> in the spleens of Fabry mice 2 hours post-injection were considerably higher than those of non-cross-linked plant recombinant  $\alpha$ -GAL-I as well those of Replagal® mammalian recombinant  $\alpha$ -GAL. As further shown therein, levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were higher than levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub>. The Western blot analyses (FIG. 14B) are consistent with the bio-distribution results obtained by assaying  $\alpha$ -GAL enzymatic activity (FIG. 14A).

As shown in FIGS. 15A and 15B, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> and bis-NHS-PEG<sub>45</sub> in the livers of Fabry mice 2 hours post-injection were considerably higher than those of non-cross-linked plant recombinant  $\alpha$ -GAL-I, but lower than levels of Replagal® mammalian recombinant  $\alpha$ -GAL in the liver. As further shown therein, levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were slightly higher than levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub>. The West-

44

ern blot analyses (FIG. 15B) are consistent with the bio-distribution results obtained by assaying  $\alpha$ -GAL enzymatic activity (FIG. 15A).

Lower levels of  $\alpha$ -GAL in the liver may be therapeutically advantageous, as about 95% of the recovered enzyme in enzyme replacement therapy is typically found in the liver, and hence high levels of recombinant  $\alpha$ -GAL in the liver indicate lower levels of exogenous  $\alpha$ -GAL in target organs, such as heart and kidneys.

As shown in FIG. 16, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> and bis-NHS-PEG<sub>45</sub> in the hearts of Fabry mice 2 hours post-injection were higher than those of non-cross-linked plant recombinant  $\alpha$ -GAL-I. As further shown therein, levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were higher than levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub>, as well as levels of Replagal® mammalian recombinant  $\alpha$ -GAL.

As shown in FIG. 17, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub> and bis-NHS-PEG<sub>45</sub> in the kidneys of Fabry mice 2 hours post-injection were higher than those of non-cross-linked plant recombinant  $\alpha$ -GAL-I. As further shown therein, levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were higher than levels of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>8</sub>, as well as levels of Replagal® mammalian recombinant  $\alpha$ -GAL.

Similarly, as shown in FIGS. 18-21, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were higher than the levels of non-cross-linked plant recombinant  $\alpha$ -GAL-I in the spleen (FIG. 18), liver (FIG. 19), heart (FIG. 20) and kidneys (FIG. 21) of Fabry mice, for up to 7 days post-injection. As further shown therein, the levels of plant recombinant  $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> were higher than the levels of Replagal® mammalian recombinant  $\alpha$ -GAL in the spleen, heart and kidneys.

These results indicate that  $\alpha$ -GAL cross-linked with bis-NHS-PEG, particularly bis-NHS-PEG<sub>45</sub>, exhibits enhanced uptake into organs, including the kidney and heart, which are major target organs in the treatment of Fabry disorder. These results are consistent with the increased circulatory half-life and enhanced stability of cross-linked  $\alpha$ -GAL.

## Example VI

Cross-Linking of Mammalian Recombinant Human  $\alpha$ -GAL with Bis-N-Hydroxysuccinimide-Poly(Ethylene Glycol) (Bis-NHS-PEG)

In order to confirm the advantageous effects of cross-linking described hereinabove, Replagal® mammalian recombinant human  $\alpha$ -GAL, which is produced from human fibrosarcoma line HT-1080, was cross-linked.

333  $\mu$ L of phosphate buffer (100 mM, pH 8) with 100 mg/ml D-(+)-galactose was added to 3.8 mg bis-NHS-PEG<sub>45</sub> in 151  $\mu$ L of DMSO solution (25 mg/ml) and 1.8 mg of Replagal® recombinant human  $\alpha$ -GAL in 130  $\mu$ L citrate buffer (25 mM, pH 6). Replagal®  $\alpha$ -GAL concentration was determined by an activity assay. The reaction mixture was agitated using an orbital shaker for 2 hours at room temperature. The excess of bis-NHS-PEG<sub>45</sub> cross-linking reagent was removed by dialysis against saline using a Vivaspin 6 concentrator with a cut-off of 50 KDa. The  $\alpha$ -GAL activity of the cross-linked Replagal®  $\alpha$ -GAL indicated that the  $\alpha$ -GAL concentration was 3 mg/mL.

The reaction products were analyzed by SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis),

45

IEF (isoelectric focusing), and MALDI-TOF mass spectrometry, as described hereinabove.

As shown in FIG. 22, the standard native Replagal® α-GAL was observed as a monomer following gel electrophoresis, whereas following reaction of Replagal® α-GAL with bis-NHS-PEG<sub>45</sub>, the α-GAL appeared in the form of a dimer, indicating that the two monomers were covalently linked by cross-linking with bis-NHS-PEG.

As shown in FIG. 23, reacting Replagal® α-GAL with bis-NHS-PEG<sub>45</sub> reduced the isoelectric point (pI) of the α-GAL, thereby confirming that the bis-NHS-PEG is covalently attached to the α-GAL.

As shown in FIG. 24, reacting Replagal® α-GAL with bis-NHS-PEG<sub>45</sub> cross-linker increased the molecular weight of the Replagal® α-GAL dimer from 103.0 KDa to 121.3 KDa, as determined by MALDI-TOF mass spectrometry. The increase in molecular weight indicates an addition of approximately 9-10 molecules of bis-NHS-PEG<sub>45</sub> to the α-GAL dimer, which is similar to results described hereinabove for prh-α-GAL-I.

#### Example VII

##### Activity of Cross-Linked Mammalian Recombinant Human α-GAL

In order to determine whether the cross-linking of mammalian recombinant α-GAL described in Example VI affected enzymatic activity, the cross-linked α-GAL was assayed for its enzymatic activity using a p-nitrophenyl-α-D-galactopyranoside (pNP-G) assay, according to the procedures described hereinabove.

As shown in FIG. 25 and in Table 3 below, mammalian recombinant human α-GAL which was cross-linked with bis-NHS-PEG<sub>45</sub> exhibited parameters of enzymatic activity which are very similar to those of native mammalian recombinant human α-GAL. These results indicate that the cross-linking did not significantly affect the activity or the catalytic machinery and mechanism of the mammalian recombinant human α-GAL.

TABLE 3

Activity results of cross-linked mammalian recombinant human α-GAL				
Sample	K <sub>M</sub> (μM)	V <sub>max</sub> (μM/minute)	k <sub>cat</sub> (second <sup>-1</sup> )	k <sub>cat</sub> /K <sub>M</sub> (second <sup>-1</sup> *μM <sup>-1</sup> )
Replagal ® α-GAL	3212 ± 98	4.20 ± 0.05	67.2 ± 1	0.0209 ± 0.001
Cross-linked	3419 ± 162	4.43 ± 0.07	70.9 ± 1	0.0210 ± 0.001
Replagal ® α-GAL				

#### Example VIII

##### In Vitro Stability of Cross-Linked Mammalian Recombinant Human α-GAL

The in vitro stability of the cross-linked Replagal® mammalian recombinant human α-GAL, obtained as described in Example VI, was measured in various conditions as described hereinabove in the Materials and Methods Section. The stability of non-cross-linked Replagal® α-GAL was measured for comparison, in order to assess the effect of cross-linking.

As shown in FIGS. 26A and 26B, the stability of mammalian recombinant human α-GAL under both simulated lysosomal conditions (FIG. 26A) and in human plasma (FIG. 26B) was considerably enhanced by cross-linking with bis-NHS-PEG<sub>45</sub>. The cross-linked mammalian recom-

46

biant human α-GAL exhibited higher stability under simulated lysosomal conditions than in plasma.

These results indicate that the cross-linking of α-GAL as described herein can stabilize recombinant α-GAL from multiple sources and expression platforms.

#### Example IX

##### In Vivo Pharmacokinetics and Bio-Distribution of Cross-Linked Mammalian Recombinant Human α-GAL

The pharmacokinetics and bio-distribution of the cross-linked mammalian recombinant human α-GAL described in Example VI was determined by measuring α-GAL activity in the spleen, liver, heart and kidneys of Fabry mice 2 hours, 7, 14, and 28 days post-injection, as well as Gb<sub>3</sub> levels in these organs, as described hereinabove in the Materials and Methods section. The bio-distribution of non-cross-linked Replagal® mammalian recombinant human α-GAL was determined for comparison.

As shown in FIGS. 27A-27D, the levels of cross-linked mammalian recombinant α-GAL in the spleens (FIG. 27A), liver (FIG. 27B), heart (FIG. 27C) and kidneys (FIG. 27D) of Fabry mice were considerably higher than those of non-cross-linked mammalian recombinant α-GAL.

As shown in FIGS. 28A-28D, cross-linked mammalian recombinant α-GAL decreased Gb<sub>3</sub> levels in the heart (FIG. 28A), kidney (FIG. 28B), liver (FIG. 28C) and spleen (FIG. 28D) of Fabry mice, over the course of 28 days post-injection. Cross-linked mammalian recombinant α-GAL decreased Gb<sub>3</sub> levels to a greater extent than did non-cross-linked recombinant α-GAL in the kidney (FIG. 28B) and spleen (FIG. 28D) of Fabry mice, and to about the same extent as non-cross-linked mammalian recombinant α-GAL in the heart (FIG. 28A) and liver (FIG. 28C).

These results indicate that cross-linking with bis-NHS-PEG results in considerably enhanced uptake of recombinant α-GAL from a variety of sources and expression

50

platforms into organs, including the kidney and heart, which are major target organs in the treatment of Fabry disorder. These results further indicate that cross-linking with bis-NHS-PEG results in a more substantial decrease of Gb<sub>3</sub> levels in organs.

#### Example X

##### Cross-Linking of Plant Recombinant Human α-GAL-II with Bis-N-Hydroxysuccinimide-Poly(Ethylene Glycol) (Bis-NHS-PEG)

Plant recombinant human α-GAL-II (prh-α-GAL-II), which lacks the amino acids EF present in the N-terminus of prh-α-GAL-I, was cross-linked with bis-NHS-PEG<sub>45</sub>, bis-NHS-PEG<sub>21</sub>, or bis-NHS-PEG<sub>68</sub> at a 200:1 molar ratio of bis-NHS-PEG to α-GAL, according to the protocol described in Example II.

The prh- $\alpha$ -GAL-II retained its biological activity following cross-linking with bis-NHS-PEG (data not shown).

The reaction products were analyzed by SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis) and MALDI-TOF mass spectrometry, as described herein above.

As shown in FIGS. 29A-29B, the standard native prh- $\alpha$ -GAL-II was observed as a monomer following gel electrophoresis, whereas following reaction of prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>45</sub> or bis-NHS-PEG<sub>21</sub> (FIG. 29A), or with bis-NHS-PEG<sub>68</sub> (FIG. 29B), prh- $\alpha$ -GAL-II appeared primarily in the form of a dimer (with some monomer present), indicating that the two monomers were covalently linked by cross-linking with a bis-NHS-PEG cross-linking agent.

As is further shown in FIGS. 29A-29B, for each of the tested cross-linkers, the molecular weight of the monomeric portion of prh- $\alpha$ -GAL-II increased following reaction with the cross-linker. The increase in molecular weight was greater for bis-NHS-PEG<sub>45</sub> than for bis-NHS-PEG<sub>21</sub> (FIG. 29A), and was greatest for bis-NHS-PEG<sub>68</sub> (compare FIG. 29A with FIG. 29B). These results indicate that the monomers which were not dimerized by cross-linking, were covalently attached to the bis-NHS-PEG cross-linker, i.e., the proteins were PEGylated.

As shown in FIGS. 30A-30C, reacting prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>21</sub> cross-linker increased the molecular weight of the prh- $\alpha$ -GAL-II dimer from 95 KDa (FIG. 30A) to 109 KDa (FIG. 30B), while reacting prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>45</sub> cross-linker increased the molecular weight of the prh- $\alpha$ -GAL-II dimer to 114 KDa (FIG. 30C), as determined by MALDI-TOF mass spectrometry. The increase in molecular weight indicates an addition of approximately 13 molecules of bis-NHS-PEG<sub>21</sub>, or approximately 9 molecules of bis-NHS-PEG<sub>45</sub>, to the prh- $\alpha$ -GAL-II dimer.

#### Example XI

##### In Vitro Stability of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-II

The in vitro stability of the cross-linked plant recombinant human  $\alpha$ -GAL-II (prh- $\alpha$ -GAL-II) obtained as described in Example X was measured under various conditions as described hereinabove in the Materials and Methods Section. The stability of Replagal® commercial recombinant human  $\alpha$ -GAL was measured for comparison.

As shown in FIGS. 31A-31D, the stability of plant recombinant human  $\alpha$ -GAL-II was enhanced by cross-linking with either bis-NHS-PEG<sub>68</sub> (FIGS. 31B and 31D), bis-NHS-PEG<sub>45</sub> (FIGS. 31A-31D) or bis-NHS-PEG<sub>21</sub> (FIGS. 31A and 31C), under both simulated lysosomal conditions (FIGS. 31A and 31B) and in human plasma (FIGS. 31C and 31D). The different cross-linkers enhanced the stability of prh- $\alpha$ -GAL-II to comparable extents. As further shown therein, the stability of the cross-linked prh- $\alpha$ -GAL-II was greater than the stability of the Replagal® recombinant human  $\alpha$ -GAL. The cross-linked prh- $\alpha$ -GAL-II exhibited higher stability under simulated lysosomal conditions as well as under plasma conditions.

As further shown in FIGS. 31A-31D, non-cross-linked prh- $\alpha$ -GAL-II is considerably more stable than non-cross-linked prh- $\alpha$ -GAL-I (see FIGS. 1 and 3 for comparison), under both simulated lysosomal conditions (FIGS. 1 and 31A-31B) and in human plasma (FIGS. 3 and 31C-31D), although prh- $\alpha$ -GAL-II still exhibits some instability.

These results indicate that the cross-linking of  $\alpha$ -GAL as described herein can stabilize different types of  $\alpha$ -GALs.

#### Example XII

##### In Vivo Pharmacokinetics and Bio-Distribution of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-II

10 The pharmacokinetics and bio-distribution of the PEG<sub>45</sub>-cross-linked and PEG<sub>21</sub>-cross-linked plant recombinant human  $\alpha$ -GAL-II (prh- $\alpha$ -GAL-II), described in Example X, was determined by measuring  $\alpha$ -GAL activity in plasma and organs as described hereinabove in the Materials and Methods section. The pharmacokinetics and bio-distribution of 15 non-cross-linked Replagal® mammalian recombinant human  $\alpha$ -GAL were determined for comparison.

Blood samples were collected for pharmacokinetic analyses at 1, 5, 10, 30, 60, 120, 240, 480 and 1440 minutes after 20 injection of Fabry mice with 1 mg/Kg of  $\alpha$ -GAL.

Bio-distribution of  $\alpha$ -GAL was determined by harvesting the liver, kidneys, heart and spleen of Fabry mice 2 hours, 7 days, 14 days and 28 days post-injection with 2 mg/Kg 25  $\alpha$ -GAL.

As shown in FIGS. 32A and 32B and in Table 4, cross-linking of prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>45</sub> considerably increased the circulatory terminal half-life of prh- $\alpha$ -GAL-II, yielding a circulatory half-life considerably greater than that of mammalian recombinant  $\alpha$ -GAL or of non-cross-linked prh- $\alpha$ -GAL-II.

TABLE 4

Circulatory terminal half-life of recombinant $\alpha$ -GAL	
Test item	t <sub>1/2</sub> (min)
Replagal® $\alpha$ -GAL	13.3
plant recombinant alpha-GAL-II	4.8
plant recombinant alpha-GAL-II cross-linked with bis-NHS-PEG <sub>45</sub>	581.6

45 As shown in FIGS. 33A-33L, cross-linking of prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>45</sub> increased the uptake of prh- $\alpha$ -GAL-II in heart (FIG. 33A), kidney (FIG. 33B), liver (FIG. 33C) and spleen (FIG. 33D) of Fabry mice, although to a lesser degree in the liver.

50 As shown in FIGS. 33E-33L, cross-linking of prh- $\alpha$ -GAL-II with bis-NHS-PEG<sub>21</sub> also increased the uptake of prh- $\alpha$ -GAL-II in heart (FIGS. 33E and 33I), kidney (FIGS. 33F and 33J), liver (FIGS. 33G and 33K) and spleen (FIGS. 55 33H and 33L) of Fabry mice, although such an increase was not always evident after only 2 hours.

55 As further shown therein, the levels of cross-linked prh- $\alpha$ -GAL-II were greater than the levels of mammalian recombinant  $\alpha$ -GAL in the heart (FIGS. 33A, 33E and 33I), kidney (FIGS. 33B, 33F and 33J), and spleen (FIGS. 33D, 33H and 33L) of Fabry mice, and lower than the levels of mammalian recombinant  $\alpha$ -GAL in the liver (FIGS. 33C, 33G and 33K).

60 These results indicate that cross-linked prh- $\alpha$ -GAL-II exhibits considerably enhanced activity of  $\alpha$ -GAL in the plasma and in various organs, particularly in organs other than the liver.

Effect of pH on Activity of Plant Recombinant Human  $\alpha$ -GAL

The pH of the environment has a significant effect on the stability and kinetics of lysosomal enzymes such  $\alpha$ -GAL. The pH may affect binding of substrate to the enzyme. The pH can also affect the protonation or deprotonation of catalytic groups, such as carboxyl or amino groups, which are part of the enzyme's active site, and thus affect the kinetic behavior of the enzyme. The stability of the tertiary or quaternary structure of enzymes is also pH-dependent, and affects the velocity of the enzymatic reaction, especially at extremely acidic or alkaline pH values.

The activity of PEG<sub>45</sub>-cross-linked and non-cross-linked plant recombinant human  $\alpha$ -GAL-II was determined at various pH values using a pNP-G substrate, in order to examine the pH-dependence of  $\alpha$ -GAL activity, and the effect of cross-linking thereon. The measurements were performed in solutions of 20 mM citrate and 30 mM sodium phosphate.

The kinetic parameters characterizing  $\alpha$ -GAL activity at various pH values are summarized in Table 5 below, and in FIGS. 34A-34C.

As shown in FIGS. 34A-34C, cross-linking of the  $\alpha$ -GAL-II increased the  $V_{max}$  (FIG. 34A) and  $k_{cat}$  (FIG. 34C) parameters, and did not have a significant effect on the  $K_M$  parameter (FIG. 34B).

TABLE 5

pH	Sample	$K_M$ ( $\mu$ M)	$V_{max}$ ( $\mu$ M/minute)	$k_{cat}$ (second <sup>-1</sup> )	$k_{cat}/K_M$ (second <sup>-1</sup> * $\mu$ M <sup>-1</sup> )
2.8	prh- $\alpha$ -GAL-II	15216	0.57	9.04	0.0006
	prh- $\alpha$ -GAL-II-CL45	13618	0.90	14.37	0.0011
3.2	prh- $\alpha$ -GAL-II	11476	0.55	8.85	0.0008
	prh- $\alpha$ -GAL-II-CL45	8489	1.34	21.44	0.0025
3.6	prh- $\alpha$ -GAL-II	11147	1.76	28.16	0.0025
	prh- $\alpha$ -GAL-II-CL45	4699	2.23	35.68	0.0076
4.04	prh- $\alpha$ -GAL-II	5709	1.98	31.68	0.0055
	prh- $\alpha$ -GAL-II-CL45	3207	2.74	43.76	0.0136
4.4	prh- $\alpha$ -GAL-II	4596	2.40	38.40	0.0084
	prh- $\alpha$ -GAL-II-CL45	3122	3.22	51.57	0.0165
4.8	prh- $\alpha$ -GAL-II	4531	2.32	37.12	0.0082
	prh- $\alpha$ -GAL-II-CL45	3345	2.95	47.23	0.0141
5.29	prh- $\alpha$ -GAL-II	6793	2.06	32.99	0.0049
	prh- $\alpha$ -GAL-II-CL45	3973	2.78	44.48	0.0112
5.66	prh- $\alpha$ -GAL-II	10396	1.75	28.05	0.0027
	prh- $\alpha$ -GAL-II-CL45	4883	2.70	43.20	0.0088
6.09	prh- $\alpha$ -GAL-II	11357	1.44	23.04	0.0020
	prh- $\alpha$ -GAL-II-CL45	8336	1.54	24.59	0.0030
6.4	prh- $\alpha$ -GAL-II	21046	1.32	21.12	0.0010
	prh- $\alpha$ -GAL-II-CL45	16844	1.46	23.36	0.0014
6.76	prh- $\alpha$ -GAL-II	25188	1.12	17.92	0.0007
	prh- $\alpha$ -GAL-II-CL45	18313	1.14	18.24	0.0010
7.36	prh- $\alpha$ -GAL-II	—	—	—	—
	prh- $\alpha$ -GAL-II-CL45	32692	0.52	8.37	0.0003

The enhancement of the  $V_{max}$  and  $k_{cat}$  parameters indicates an increase in catalytic activity. This increase is particularly significant at pH values of at least about 7, where the catalytic activity of non-cross-linked  $\alpha$ -GAL-II is negligible.

$K_M$  is a kinetic parameter associated with enzyme/substrate affinity. The absence of a significant effect of cross-linking on  $K_M$  values indicates that the cross-linking has no significant effect on  $\alpha$ -GAL affinity to the pNP-G substrate.

Effect of PEGylation on Stability of  $\alpha$ -GAL

5 The effect of PEGylation per se on  $\alpha$ -GAL stability was ascertained, in order to determine whether the stabilizing effect of PEG cross-linkers is due to the properties of PEG or due to the cross-linking.

10 Plant recombinant human  $\alpha$ -GAL-I was reacted with N-hydroxysuccinimide (NHS)-activated methoxy-capped PEGs with different molecular weights (2, 5, and 10 KDa). Such PEG reagents have a single NHS group, and consequently PEGylate the protein without forming cross-linking. The reaction products were analyzed by SDS-PAGE.

15 As shown in FIG. 35, the methoxy-capped PEGylating agents PEGylated the  $\alpha$ -GAL (visible as an increase in molecular weight of the  $\alpha$ -GAL), but did not substantially generate  $\alpha$ -GAL dimers, indicating that the  $\alpha$ -GAL was not cross-linked.

20 As shown in FIGS. 36A and 36B, PEGylating plant recombinant human  $\alpha$ -GAL-I without forming cross-linking did not substantially increase the stability of the plant recombinant  $\alpha$ -GAL, under either simulated lysosomal conditions (FIG. 36A) or in human plasma (FIG. 36B).

25 These results indicate that the stabilizing effect of the cross-linking described hereinabove is not a result of PEGylation per se.

Effect of PEG Chain Length on Activity of Cross-Linked  $\alpha$ -GAL

In order to assess the effect of the chain length of PEG 65 cross-linkers on  $\alpha$ -GAL activity, plant recombinant human  $\alpha$ -GAL-I was cross-linked with bis-NHS-PEG<sub>2</sub>, bis-NHS-PEG<sub>4</sub>, bis-NHS-PEG<sub>68</sub> and bis-NHS-PEG<sub>150</sub> agents, using

51

essentially the same procedures as described in Example II (PEG<sub>68</sub> and PEG<sub>150</sub> are approximate chain lengths). The α-GAL-I was cross-linked at 50:1, 100:1 and 200:1 bis-NHS-PEG:α-GAL molar ratios. The reaction products were analyzed by SDS-PAGE, as described hereinabove. α-GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> as described in Example II was also analyzed for comparison.

As shown in FIG. 37, SDS-PAGE analysis showed that all of the bis-NHS-PEG agents cross-linked the α-GAL so as to result in a covalently cross-linked dimer, and that cross-linking was more efficient when a 200:1 molar ratio was used.

The enzymatic activity of the cross-linked α-GAL-I was then determined as described in Example III. The results are summarized in Table 6 below.

TABLE 6

Activity results of cross-linked plant recombinant human α-GAL-I			
Reagent	Molar ratio (reagent:α-GAL-I)	Expected α-GAL activity [mg/mL]	Measured α-GAL activity [mg/mL]
bis-NHS-PEG <sub>2</sub>	50:1	2	1.159
	100:1	2	1.001
	200:1	2	0.970
bis-NHS-PEG <sub>4</sub>	50:1	2	1.399
	100:1	2	1.333
	200:1	2	1.048
bis-NHS-PEG <sub>68</sub>	50:1	2	1.822
	100:1	2	2.252
	200:1	2	2.425
bis-NHS-PEG <sub>150</sub>	50:1	2	1.804
	100:1	2	2.031
	200:1	2	1.825

As shown in Table 6, cross-linking with PEG<sub>2</sub> and PEG<sub>4</sub> moderately reduced α-GAL activity (by approximately 30-50%), whereas cross-linking with longer PEG chains did not significantly affect α-GAL activity.

These results indicate that cross-linking with PEG chains longer than PEG<sub>4</sub> is advantageous in terms of preserving activity of the cross-linked α-GAL.

## Example XVI

## Cross-Linking of α-GAL Using Bis-COOH-PEG Agents

As an alternative to the above-described cross-linking of α-GAL using pre-prepared (e.g., commercially available) bis-NHS-PEG agents, α-GAL was cross-linked with bis-COOH-PEG agents by activating the carboxyl (i.e., COOH) groups in situ shortly before the cross-linking reaction was effected.

Bis-COOH-PEG<sub>12</sub>, bis-COOH-PEG<sub>28</sub> and bis-COOH-PEG<sub>45</sub> were each activated by being reacted with 1.1 molar equivalents per carboxyl group (i.e., 2.2 molar equivalents per bis-COOH-PEG) of both NHS (N-hydroxysuccinimide) and EDC (1-ethyl-3-(3-dimethylaminopropyl) carbodiimide). The reaction mixture was then shaken in DMSO for 30 minutes at room temperature. The activated bis-COOH-PEG, which is essentially bis-NHS-PEG, was then reacted

52

with plant recombinant human α-GAL-I at molar ratios of 50:1, 100:1 and 200:1, as described in Example II. The reaction products were analyzed by SDS-PAGE, as described hereinabove. α-GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> as described in Example II was also analyzed for comparison.

As shown in FIG. 38, SDS-PAGE analysis showed that all of the bis-COOH-PEG agents cross-linked the α-GAL to some extent, but that cross-linking was more efficient when a 200:1 molar ratio was used.

The enzymatic activity of the cross-linked α-GAL-I was then determined as described in Example III. The results are summarized in Table 7 below.

TABLE 7

Activity results of cross-linked plant recombinant human α-GAL-I			
Reagent	Molar ratio (reagent:α-GAL-I)	Expected α-GAL activity [mg/mL]	Measured α-GAL activity [mg/mL]
Bis-HOOC-PEG <sub>12</sub>	50:1	1.5	1.236
	100:1	1.5	1.304
	200:1	1.5	1.404
Bis-HOOC-PEG <sub>28</sub>	50:1	1.5	1.326
	100:1	1.5	1.371
	200:1	1.5	1.460
Bis-HOOC-PEG <sub>45</sub>	50:1	1.5	1.349
	100:1	1.5	1.541
	200:1	1.5	1.628

As shown in Table 7, cross-linking with each of the tested bis-COOH-PEG agents resulted in α-GAL with about the expected activity.

These results indicate that cross-linking bis-COOH-PEG agents does not reduce α-GAL activity in comparison to cross-linking with bis-NHS-PEG agents.

These results further confirm the above-described findings that cross-linking with PEG chains longer than PEG<sub>4</sub> does not significantly reduce the activity of the cross-linked  $\alpha$ -GAL.

#### Example XVII

##### Effect of Length and Type of Cross-Linking Agent on In Vitro Stability of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-I

In order to further characterize the effect of chain length on cross-linked  $\alpha$ -GAL stability, and to compare the stability of  $\alpha$ -GAL cross-linked with bis-COOH-PEG agents (e.g., as described in Example XVI) with that of  $\alpha$ -GAL cross-linked with bis-NHS-PEG agents, the in vitro stability of plant recombinant human  $\alpha$ -GAL-I (prh- $\alpha$ -GAL-I) cross-linked with bis-NHS-PEG<sub>2</sub>, bis-NHS-PEG<sub>4</sub>, bis-COOH-PEG<sub>12</sub>, bis-COOH<sub>28</sub>, and bis-COOH-PEG<sub>45</sub>, obtained as described in Examples XV and XVI, was measured in various conditions as described hereinabove in the Materials and Methods Section, and compared with the stability of prh- $\alpha$ -GAL-I cross-linked with bis-NHS-PEG<sub>45</sub> as described in Example II. The stability of Replagal® commercial recombinant human  $\alpha$ -GAL and non-crosslinked prh-GAL-I was measured for comparison.

As shown in FIG. 39, the stability of plant recombinant human  $\alpha$ -GAL-I under simulated lysosomal conditions was enhanced by cross-linking with each of the bis-NHS-PEG and bis-COOH-PEG agents.

As further shown therein, the stability of the cross-linked prh- $\alpha$ -GAL-I was correlated with the length of the cross-linking PEG chain, with bis-NHS-PEG<sub>45</sub> and bis-COOH-PEG<sub>45</sub> providing the most stability, and bis-NHS-PEG<sub>2</sub> providing the least stability. However, cross-linking with bis-COOH-PEG<sub>45</sub> provided only marginally more stability than did cross-linking with bis-COOH-PEG<sub>45</sub>, suggesting that above a certain length, the stability is not affected by PEG chain length.

As further shown in FIG. 39, cross-linking with bis-NHS-PEG<sub>45</sub> provided slightly more stability than did cross-linking with bis-COOH-PEG<sub>45</sub>. This may be a result of incomplete activation of the bis-COOH-PEG agent. However the difference in stability was slight.

In addition, cross-linking with each of the bis-NHS-PEG and bis-COOH-PEG agents enhanced the stability of the plant recombinant human  $\alpha$ -GAL-I in human plasma at 37° C. (data not shown).

These results provide further evidence that cross-linking  $\alpha$ -GAL as described herein can increase the efficacy of  $\alpha$ -GAL in vivo by increasing the stability of  $\alpha$ -GAL in lysosomes and in the blood, and that PEG chains of about 28-45 units in length are more effective at stabilizing  $\alpha$ -GAL by cross-linking than are shorter PEG chains.

#### Example XVIII

##### Kinetic Parameters of Cross-Linked Plant Recombinant Human $\alpha$ -GAL-II

The kinetic parameters of cross-linked plant recombinant human  $\alpha$ -GAL-II, obtained as described in Example X, as well as of non-cross-linked plant recombinant human  $\alpha$ -GAL-II, were determined using a pNP-G substrate and Michaelis-Menten analysis, in order to examine the effect of cross-linking thereon. The measurements were performed in a solution of 20 mM citrate, 30 mM sodium phosphate, 0.1% bovine serum albumin and 0.67% ethanol, at a pH of 4.6.

The kinetic parameters were calculated using protein content values based on an activity assay.

As shown in Table 8 below, cross-linking of  $\alpha$ -GAL-II resulted in improved kinetic properties, as compared with non-cross-linked  $\alpha$ -GAL-II. The Michaelis constant ( $K_M$ ) was reduced, indicating higher affinity of the enzyme to the substrate. Furthermore, the  $k_{cat}/K_M$ , which signifies the overall catalytic efficiency of the enzyme with this substrate under the described conditions, was enhanced for the cross-linked species.

TABLE 8

Michaelis-Menten parameters of non-cross-linked plant recombinant human $\alpha$ -GAL-II (prh- $\alpha$ -GAL-II) and plant recombinant human $\alpha$ -GAL-II cross-linked with bis-NHS-PEG <sub>21</sub> (prh- $\alpha$ -GAL-II-CL21), bis-NHS-PEG <sub>45</sub> (prh- $\alpha$ -GAL-II-CL45) or bis-NHS-PEG <sub>68</sub> (prh- $\alpha$ -GAL-II-CL68)				
Sample	$K_M$ ( $\mu$ M)	$V_{max}$ ( $\mu$ M/min)	$k_{cat}$ (sec <sup>-1</sup> )	$k_{cat}/K_M$ (sec <sup>-1</sup> $\mu$ M <sup>-1</sup> )
prh- $\alpha$ -GAL-II	4801	4.59	73.49	0.015
prh- $\alpha$ -GAL-II-CL21	2661	4.85	77.55	0.029
prh- $\alpha$ -GAL-II-CL45	2583	4.87	77.87	0.030
prh- $\alpha$ -GAL-II-CL68	2556	4.12	65.97	0.026

#### Example XIX

##### Reproducibility of Cross-Linking of Plant Recombinant Human $\alpha$ -GAL-II

The batch-to-batch reproducibility of cross-linking was assessed after preparing 5 batches of plant recombinant human  $\alpha$ -GAL-II (prh- $\alpha$ -GAL-II) cross-linked with bis-NHS-PEG<sub>45</sub> at a 200:1 ratio, using procedures similar to those described in Example II.

In batches 1, 2, 4 and 5, 1 mg of prh- $\alpha$ -GAL-II was reacted with 3.98 mg bis-NHS-PEG.

In batch 3, 20.5 mg of prh- $\alpha$ -GAL-II was reacted with 80.7 mg bis-NHS-PEG.

The enzymatic activity of the cross-linked prh- $\alpha$ -GAL-II was determined as described in Example III. The results are summarized in Table 9 below.

TABLE 9

Activity results of cross-linked plant recombinant human $\alpha$ -GAL-II from different batches		
Batch no.	Expected $\alpha$ -GAL activity [mg/mL]	Measured $\alpha$ -GAL activity [mg/mL]
1	1.25	1.38
2	1.25	1.23
3	1.43	1.4
4	1.25	0.85
5	1.25	1.11

As shown in Table 9, the measured activity was close to the expected activity in all 5 batches. In 4 of the 5 batches, the measured activity differed from the expected activity by about 10% or less.

These results indicate that the obtained activity of the cross-linked prh- $\alpha$ -GAL-II is relatively predictable and reproducible.

The stability of the cross-linked prh- $\alpha$ -GAL-II under lysosomal conditions and in human plasma was determined as described hereinabove.

## 55

As shown in FIGS. 40A and 40B, the stability of the cross-linked prh- $\alpha$ -GAL-II exhibited good reproducibility under both simulated lysosomal conditions and in human plasma.

The cross-linking was also analyzed by SDS-PAGE analysis, IEF (isoelectric focusing) analysis, and MALDI-TOF mass spectrometry, as described hereinabove. Non-cross-linked prh- $\alpha$ -GAL-II was analyzed for comparison.

As shown in FIG. 41, the cross-linked prh- $\alpha$ -GAL-II from the different batches exhibited the same degree of covalent dimerization under SDS-PAGE analysis.

As shown in FIG. 42, the cross-linked prh- $\alpha$ -GAL-II from the different batches exhibited the same isoelectric points under IEF analysis.

As shown in FIGS. 43A-43F, the cross-linked prh- $\alpha$ -GAL-II from batches 1-5 (FIGS. 43B-43F, respectively) all exhibited an increase of approximately 20-21 KDa in the dimer form, as compared to the non-cross-linked prh- $\alpha$ -GAL-II (FIG. 43A). Such an increase corresponds to about 10 PEG molecules per  $\alpha$ -GAL dimer. As further shown in FIGS. 43B-43F, the cross-linked prh- $\alpha$ -GAL-II from the different batches exhibited similar proportions of monomer vs. dimer.

These results further indicate that good reproducibility in cross-linking of  $\alpha$ -GAL.

The kinetic parameters of the cross-linked prh- $\alpha$ -GAL-II were determined using a pNP-G substrate and Michaelis-Menten analysis, in order to examine the reproducibility of enzymatic activity. The measurements were performed in a solution of 20 mM citrate, 30 mM sodium phosphate, 0.1% bovine serum albumin and 0.67% ethanol, at a pH of 4.6. The kinetic parameters were calculated using protein content values based on optical density at 280 nm.

As shown in FIG. 44, the cross-linked prh- $\alpha$ -GAL-II from the different batches exhibited similar profiles of catalytic velocity vs. substrate concentration.

## 56

As shown in Table 10 below, the cross-linked prh- $\alpha$ -GAL-II from the different batches exhibited good reproducibility of the  $V_{max}$  and  $k_{cat}$  parameters. The  $K_m$  parameter varied more between batches, although this may be an artifact of the protein quantification.

The above results indicate good reproducibility in the enzymatic properties of cross-linked  $\alpha$ -GAL.

TABLE 10

Michaelis-Menten parameters of plant recombinant human  $\alpha$ -GAL II cross-linked with bis-NHS-PEG<sub>45</sub> in different batches

Batch no.	$K_m$ ( $\mu$ M)	$V_{max}$ ( $\mu$ M/min)	$k_{cat}$ (sec <sup>-1</sup> )	$k_{cat}/K_m$ (sec <sup>-1</sup> $\mu$ M <sup>-1</sup> )
1	4939	3.87	61.92	0.0125
2	2215	3.30	52.86	0.0239
3	4470	3.95	63.12	0.0141
4	3285	3.72	59.53	0.018
5	2243	3.91	62.60	0.028

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention. To the extent that section headings are used, they should not be construed as necessarily limiting.

## SEQUENCE LISTING

```

<160> NUMBER OF SEQ ID NOS: 15

<210> SEQ ID NO 1
<211> LENGTH: 405
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Plant recombinant human alpha-GAL (prh-alpha-GAL)

<400> SEQUENCE: 1

Glu Phe Leu Asp Asn Gly Leu Ala Arg Thr Pro Thr Met Gly Trp Leu
1           5          10          15

His Trp Glu Arg Phe Met Cys Asn Leu Asp Cys Gln Glu Pro Asp
20          25          30

Ser Cys Ile Ser Glu Lys Leu Phe Met Glu Met Ala Glu Leu Met Val
35          40          45

Ser Glu Gly Trp Lys Asp Ala Gly Tyr Glu Tyr Leu Cys Ile Asp Asp
50          55          60

Cys Trp Met Ala Pro Gln Arg Asp Ser Glu Gly Arg Leu Gln Ala Asp
65          70          75          80

Pro Gln Arg Phe Pro His Gly Ile Arg Gln Leu Ala Asn Tyr Val His
85          90          95

Ser Lys Gly Leu Lys Leu Gly Ile Tyr Ala Asp Val Gly Asn Lys Thr

```

## US 12,385,026 B2

**57**

-continued

**58**

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

<210> SEQ ID NO 2  
<211> LENGTH: 404  
<212> TYPE: PRT  
<213> ORGANISM: Artificial sequence  
<220> FEATURE:  
<223> OTHER INFORMATION: Plant recombinant human alpha-GAL (prh-alpha-GAL)

&lt;400&gt; SEQUENCE: 2

Leu Asp Asn Gly Leu Ala Arg Thr Pro Thr Met Gly Trp Leu His Trp		
1	5	10
15		
Glu Arg Phe Met Cys Asn Leu Asp Cys Gln Glu Glu Pro Asp Ser Cys		
20	25	30
30		
Ile Ser Glu Lys Leu Phe Met Glu Met Ala Glu Leu Met Val Ser Glu		
35	40	45

## US 12,385,026 B2

**59****60**

-continued

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

<210> SEQ ID NO 3  
<211> LENGTH: 405  
<212> TYPE: PRT  
<213> ORGANISM: Artificial sequence  
<220> FEATURE:  
<223> OTHER INFORMATION: Plant recombinant human alpha-GAL (prh-alpha-GAL)  
<400> SEQUENCE: 3

## US 12,385,026 B2

**61****62**

-continued

---

Gly Leu Asp Asn Gly Leu Ala Arg Thr Pro Thr Met Gly Trp Leu His  
1               5               10               15

Trp Glu Arg Phe Met Cys Asn Leu Asp Cys Gln Glu Glu Pro Asp Ser  
20              25              30

Cys Ile Ser Glu Lys Leu Phe Met Glu Met Ala Glu Leu Met Val Ser  
35              40              45

Glu Gly Trp Lys Asp Ala Gly Tyr Glu Tyr Leu Cys Ile Asp Asp Cys  
50              55              60

Trp Met Ala Pro Gln Arg Asp Ser Glu Gly Arg Leu Gln Ala Asp Pro  
65              70              75              80

Gln Arg Phe Pro His Gly Ile Arg Gln Leu Ala Asn Tyr Val His Ser  
85              90              95

Lys Gly Leu Lys Leu Gly Ile Tyr Ala Asp Val Gly Asn Lys Thr Cys  
100             105             110

Ala Gly Phe Pro Gly Ser Phe Gly Tyr Tyr Asp Ile Asp Ala Gln Thr  
115             120             125

Phe Ala Asp Trp Gly Val Asp Leu Leu Lys Phe Asp Gly Cys Tyr Cys  
130             135             140

Asp Ser Leu Glu Asn Leu Ala Asp Gly Tyr Lys His Met Ser Leu Ala  
145             150             155             160

Leu Asn Arg Thr Gly Arg Ser Ile Val Tyr Ser Cys Glu Trp Pro Leu  
165             170             175

Tyr Met Trp Pro Phe Gln Lys Pro Asn Tyr Thr Glu Ile Arg Gln Tyr  
180             185             190

Cys Asn His Trp Arg Asn Phe Ala Asp Ile Asp Asp Ser Trp Lys Ser  
195             200             205

Ile Lys Ser Ile Leu Asp Trp Thr Ser Phe Asn Gln Glu Arg Ile Val  
210             215             220

Asp Val Ala Gly Pro Gly Trp Asn Asp Pro Asp Met Leu Val Ile  
225             230             235             240

Gly Asn Phe Gly Leu Ser Trp Asn Gln Gln Val Thr Gln Met Ala Leu  
245             250             255

Trp Ala Ile Met Ala Ala Pro Leu Phe Met Ser Asn Asp Leu Arg His  
260             265             270

Ile Ser Pro Gln Ala Lys Ala Leu Leu Gln Asp Lys Asp Val Ile Ala  
275             280             285

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

Asp Asn Phe Glu Val Trp Glu Arg Pro Leu Ser Gly Leu Ala Trp Ala  
305             310             315             320

Val Ala Met Ile Asn Arg Gln Glu Ile Gly Gly Pro Arg Ser Tyr Thr  
325             330             335

Ile Ala Val Ala Ser Leu Gly Lys Gly Val Ala Cys Asn Pro Ala Cys  
340             345             350

Phe Ile Thr Gln Leu Leu Pro Val Lys Arg Lys Leu Gly Phe Tyr Glu  
355             360             365

Trp Thr Ser Arg Leu Arg Ser His Ile Asn Pro Thr Gly Thr Val Leu  
370             375             380

Leu Gln Leu Glu Asn Thr Met Gln Met Ser Leu Lys Asp Leu Leu Ser  
385             390             395             400

Glu Lys Asp Glu Leu  
405

-continued

&lt;210&gt; SEQ ID NO 4

&lt;211&gt; LENGTH: 753

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Cucumis melo

&lt;400&gt; SEQUENCE: 4

Met	Thr	Val	Gly	Ala	Gly	Ile	Thr	Ile	Ser	Asp	Ala	Asn	Leu	Thr	Val
1						5								10	15

Leu	Gly	Asn	Arg	Val	Leu	Ser	Asp	Val	His	Asn	Asn	Ile	Thr	Leu	Thr
						20			25			30			

Ala	Ala	Pro	Gly	Gly	Gly	Val	Met	Asn	Gly	Ala	Phe	Ile	Gly	Val	Gln
						35		40			45				

Ser	Asp	Gln	Ile	Gly	Ser	Arg	Arg	Val	Phe	Pro	Ile	Gly	Lys	Leu	Ile
						50		55			60				

Gly	Leu	Arg	Phe	Leu	Cys	Ala	Phe	Arg	Phe	Lys	Leu	Trp	Trp	Met	Thr
					65		70		75		80				

Gln	Arg	Met	Gly	Cys	Ser	Gly	Gln	Glu	Val	Pro	Phe	Glu	Thr	Gln	Phe
					85		90		95						

Leu	Val	Val	Glu	Thr	Arg	Asp	Gly	Ser	Asn	Ile	Ala	Gly	Asn	Gly	Glu
					100		105		110						

Glu	Gly	Asp	Ala	Val	Tyr	Thr	Val	Phe	Leu	Pro	Ile	Leu	Glu	Gly	Asp
					115		120		125						

Phe	Arg	Ala	Val	Leu	Gln	Gly	Asn	Asp	Asn	Asn	Glu	Ile	Glu	Ile	Cys
					130		135		140						

Leu	Glu	Ser	Gly	Asp	Pro	Ser	Val	Asp	Gly	Phe	Glu	Gly	Ser	His	Leu
					145		150		155		160				

Val	Phe	Val	Gly	Ala	Gly	Ser	Asp	Pro	Phe	Glu	Thr	Ile	Thr	Tyr	Ala
					165		170		175						

Val	Lys	Ser	Val	Glu	Lys	His	Leu	Gln	Thr	Phe	Ala	His	Arg	Glu	Arg
					180		185		190						

Lys	Lys	Met	Pro	Asp	Ile	Leu	Asn	Trp	Phe	Gly	Trp	Cys	Thr	Trp	Asp
					195		200		205						

Ala	Phe	Tyr	Thr	Asp	Val	Thr	Ser	Asp	Gly	Val	Lys	Lys	Gly	Leu	Glu
					210		215		220						

Ser	Phe	Glu	Asn	Gly	Gly	Ile	Pro	Pro	Lys	Phe	Val	Ile	Ile	Asp	Asp
					225		230		235		240				

Gly	Trp	Gln	Ser	Val	Ala	Lys	Asp	Ala	Thr	Ser	Ala	Asp	Cys	Lys	Ala
					245		250		255						

Asp	Asn	Thr	Ala	Asn	Phe	Ala	Asn	Arg	Leu	Thr	His	Ile	Lys	Glu	Asn
					260		265		270						

Tyr	Lys	Phe	Gln	Lys	Asp	Gly	Lys	Glu	Gly	Glu	Arg	Ile	Glu	Asn	Pro
					275		280		285						

Ala	Leu	Gly	Leu	Gln	His	Ile	Val	Ser	Tyr	Met	Lys	Glu	Lys	His	Ala
					290		295		300						

Thr	Lys	Tyr	Val	Tyr	Val	Trp	His	Ala	Ile	Thr	Gly	Tyr	Trp	Gly	Gly
					305		310		315		320				

Val	Ser	Ala	Gly	Val	Lys	Glu	Met	Glu	Gln	Tyr	Glu	Ser	Lys	Ile	Ala
					325		330		335						

Tyr	Pro	Val	Ala	Ser	Pro	Gly	Val	Glu	Ser	Asn	Glu	Pro	Cys	Asp	Ala
					340		345		350						

Leu	Asn	Ser	Ile	Thr	Lys	Thr	Gly	Leu	Gly	Leu	Val	Asn	Pro	Glu	Lys
					355		360		365						

Val	Phe	Asn	Phe	Tyr	Asn	Glu	Gln	His	Ser	Tyr	Leu	Ala	Ser	Ala	Gly
					370		375		380						

## US 12,385,026 B2

**65****66**

-continued

Val	Asp	Gly	Val	Lys	Val	Asp	Val	Gln	Asn	Ile	Leu	Glu	Thr	Leu	Gly
385					390				395				400		
Ala	Gly	His	Gly	Gly	Arg	Val	Lys	Leu	Ala	Arg	Lys	Tyr	His	Gln	Ala
					405			410				415			
Leu	Glu	Ala	Ser	Ile	Ser	Arg	Asn	Phe	Gln	Asp	Asn	Gly	Ile	Ile	Ser
					420			425				430			
Cys	Met	Ser	His	Asn	Thr	Asp	Gly	Leu	Tyr	Ser	Ser	Lys	Arg	Asn	Ala
					435			440				445			
Val	Ile	Arg	Ala	Ser	Asp	Asp	Phe	Trp	Pro	Arg	Asp	Pro	Ala	Ser	His
					450			455				460			
Thr	Ile	His	Ile	Ala	Ser	Val	Ala	Tyr	Asn	Ser	Leu	Phe	Leu	Gly	Glu
					465			470			475				480
Phe	Met	Pro	Asp	Trp	Asp	Met	Phe	His	Ser	Leu	His	Pro	Met	Ala	
					485			490				495			
Glu	Tyr	His	Gly	Ala	Ala	Arg	Ala	Val	Gly	Gly	Cys	Ala	Ile	Tyr	Val
					500			505			510				
Ser	Asp	Lys	Pro	Gly	Gln	His	Asp	Phe	Asn	Leu	Leu	Lys	Lys	Leu	Val
					515			520				525			
Leu	Pro	Asp	Gly	Ser	Ile	Leu	Arg	Ala	Lys	Leu	Pro	Gly	Arg	Pro	Thr
					530			535				540			
Lys	Asp	Cys	Leu	Phe	Thr	Asp	Pro	Ala	Arg	Asp	Gly	Lys	Ser	Leu	Leu
					545			550			555				560
Lys	Ile	Trp	Asn	Leu	Asn	Asp	Leu	Ser	Gly	Val	Val	Gly	Val	Phe	Asn
					565			570				575			
Cys	Gln	Gly	Ala	Gly	Trp	Cys	Lys	Val	Gly	Lys	Lys	Asn	Leu	Ile	His
					580			585				590			
Asp	Glu	Asn	Pro	Asp	Thr	Ile	Thr	Gly	Val	Ile	Arg	Ala	Lys	Asp	Val
					595			600				605			
Ser	Tyr	Leu	Trp	Lys	Ile	Ala	Gly	Glu	Ser	Trp	Thr	Gly	Asp	Ala	Val
					610			615			620				
Ile	Phe	Ser	His	Leu	Ala	Gly	Glu	Val	Val	Tyr	Leu	Pro	Gln	Asp	Ala
					625			630			635				640
Ser	Met	Pro	Ile	Thr	Leu	Lys	Pro	Arg	Glu	Phe	Asp	Val	Phe	Thr	Val
					645			650			655				
Val	Pro	Val	Lys	Glu	Leu	Val	Asn	Asp	Ile	Lys	Phe	Ala	Pro	Ile	Gly
					660			665				670			
Leu	Ile	Lys	Met	Phe	Asn	Ser	Gly	Gly	Ala	Val	Lys	Glu	Met	Asn	His
					675			680				685			
Gln	Pro	Gly	Ser	Ser	Asn	Val	Ser	Leu	Lys	Val	Arg	Gly	Ser	Gly	Pro
					690			695			700				
Phe	Gly	Ala	Tyr	Ser	Ser	Lys	Pro	Lys	Arg	Val	Ala	Val	Asp	Ser	
					705			710			715				720
Glu	Glu	Val	Glu	Phe	Met	Tyr	Asp	Glu	Gly	Gly	Leu	Ile	Thr	Ile	Asp
					725			730			735				
Leu	Lys	Val	Pro	Glu	Lys	Glu	Leu	Tyr	Leu	Trp	Asp	Ile	Arg	Ile	Glu
					740			745				750			

Leu

<210> SEQ ID NO 5  
<211> LENGTH: 772  
<212> TYPE: PRT  
<213> ORGANISM: Cucumis melo

&lt;400&gt; SEQUENCE: 5

## US 12,385,026 B2

**67****68**

-continued

---

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

## US 12,385,026 B2

**69****70**

-continued

420	425	430
Asp Ser Leu Tyr Ser Ala Lys Gln Thr Ala Val Val Arg Ala Ser Asp		
435	440	445
Asp Tyr Tyr Pro Arg Asp Pro Ala Ser His Thr Ile His Ile Ser Ser		
450	455	460
Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu Phe Met Gln Pro Asp Trp		
465	470	475
Asp Met Phe His Ser Leu His Pro Thr Ala Glu Tyr His Gly Ala Ala		
485	490	495
Arg Ala Ile Gly Gly Cys Ala Ile Tyr Val Ser Asp Lys Pro Gly Asn		
500	505	510
His Asn Phe Asp Leu Leu Lys Lys Leu Val Leu Pro Asp Gly Ser Val		
515	520	525
Leu Arg Ala Gln Leu Pro Gly Arg Pro Thr Arg Asp Ser Leu Phe Asn		
530	535	540
Asp Pro Ala Arg Asp Gly Thr Ser Leu Leu Lys Ile Trp Asn Met Asn		
545	550	555
Lys Cys Ser Gly Val Val Gly Val Phe Asn Cys Gln Gly Ala Gly Trp		
565	570	575
Cys Arg Ile Thr Lys Lys Thr Arg Ile His Asp Glu Ser Pro Gly Thr		
580	585	590
Leu Thr Thr Ser Val Arg Ala Ala Asp Val Asp Ala Ile Ser Gln Val		
595	600	605
Ala Gly Ala Asp Trp Lys Gly Asp Thr Ile Val Tyr Ala Tyr Arg Ser		
610	615	620
Gly Asp Leu Ile Arg Leu Pro Lys Gly Ala Ser Val Pro Val Thr Leu		
625	630	635
Lys Val Leu Glu Tyr Asp Leu Leu His Ile Ser Pro Leu Lys Asp Ile		
645	650	655
Ala Ser Asn Ile Ser Phe Ala Pro Ile Gly Leu Leu Asp Met Phe Asn		
660	665	670
Thr Gly Gly Ala Val Glu Gln Val Asn Val Gln Val Val Glu Pro Ile		
675	680	685
Pro Glu Phe Asp Gly Glu Val Ala Ser Glu Leu Thr Cys Ser Leu Pro		
690	695	700
Asn Asp Arg Pro Pro Thr Ala Thr Ile Thr Met Lys Ala Arg Gly Cys		
705	710	715
Arg Arg Phe Gly Leu Tyr Ser Ser Gln Arg Pro Leu Lys Cys Ser Val		
725	730	735
Asp Lys Val Asp Val Asp Phe Val Tyr Asp Glu Val Thr Gly Leu Val		
740	745	750
Thr Phe Glu Ile Pro Ile Pro Thr Glu Glu Met Tyr Arg Trp Asn Ile		
755	760	765
Glu Ile Gln Val		
770		

&lt;210&gt; SEQ ID NO 6

&lt;211&gt; LENGTH: 767

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Tetragonia tetragonoides

&lt;400&gt; SEQUENCE: 6

Met Thr Ile Thr Pro Ser Ile Ser Val Ser Asn Gly Asn Leu Val Val		
1	5	10
		15

-continued

---

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

## US 12,385,026 B2

73

74

-continued

435	440	445
Arg Ala Ser Asp Asp Phe Tyr Pro Arg Asp Pro Ala Ser His Thr Ile		
450	455	460
His Ile Ser Ser Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu Phe Met		
465	470	475
Gln Pro Asp Trp Asp Met Phe His Ser Leu His Pro Ala Ala Asp Tyr		
485	490	495
His Ala Ala Ala Arg Ala Val Gly Gly Cys Pro Ile Tyr Val Ser Asp		
500	505	510
Lys Pro Gly Phe His Asn Phe Glu Leu Leu Lys Lys Leu Val Leu Pro		
515	520	525
Asp Gly Ser Val Leu Arg Ala Arg Leu Pro Gly Arg Pro Thr Arg Asp		
530	535	540
Cys Leu Phe Asn Asp Pro Ala Arg Asp Gly Thr Ser Leu Leu Lys Ile		
545	550	555
Trp Asn Lys Asn Asn Cys Ser Gly Val Val Gly Val Phe Asn Cys Gln		
565	570	575
Gly Ala Gly Trp Cys Lys Ile Glu Lys Lys Ile Arg Ile His Asp Thr		
580	585	590
Ser Pro Gly Thr Leu Thr Gly Ser Val Arg Ala Thr Asp Val Asp Ser		
595	600	605
Ile Ala Glu Val Ala Gly Gln Gly Trp Asn Gly Asp Val Val Val Tyr		
610	615	620
Leu Tyr Arg Ala Gly Glu Leu Val Cys Leu Pro Lys Gly Ala Ser Leu		
625	630	635
Pro Val Thr Leu Lys Val Arg Glu Tyr Glu Leu Phe His Phe Cys Pro		
645	650	655
Ile Lys Glu Ile Thr Ser Asn Ile Ser Phe Ala Pro Ile Gly Leu Leu		
660	665	670
Asp Met Phe Asn Gly Ser Gly Ala Val Asp Gln Phe Asp Val Gln Leu		
675	680	685
Thr Ser Glu Asn Arg Thr Glu Leu Ser Asp Gly Glu Lys Arg Ser Pro		
690	695	700
Ser Ala Ser Ile Gln Leu Lys Val Arg Gly Cys Gly Arg Phe Gly Ala		
705	710	715
Tyr Ser Ser Gln Cys Pro Leu Lys Cys Thr Val Gly Gly Ala Asp Ser		
725	730	735
Gly Phe Asn Tyr Asp Glu Glu Thr Cys Leu Leu Thr Leu Thr Leu Pro		
740	745	750
Val Pro Gln Glu Glu Met Tyr Arg Trp Pro Val Glu Ile Gln Val		
755	760	765

&lt;210&gt; SEQ\_ID NO 7

&lt;211&gt; LENGTH: 772

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Cucumis sativus

&lt;400&gt; SEQUENCE: 7

Met Thr Val Thr Pro Lys Ile Thr Val Asn Asp Gly Asn Leu Val Val			
1	5	10	15

His Gly Lys Thr Ile Leu Thr Gly Val Pro Asp Asn Ile Val Leu Thr		
20	25	30

Pro Gly Ser Gly Leu Gly Leu Val Ala Gly Ala Phe Ile Gly Ala Thr		
35	40	45

-continued

---

Ala Ser Asn Ser Lys Ser Leu His Val Phe Pro Val Gly Val Leu Glu  
 50 55 60

Gly Thr Arg Phe Leu Cys Cys Phe Arg Phe Lys Leu Trp Trp Met Thr  
 65 70 75 80

Gln Arg Met Gly Thr Ser Gly Arg Asp Ile Pro Phe Glu Thr Gln Phe  
 85 90 95

Leu Leu Met Glu Ser Gln Gly Asn Asp Gly Glu Asp Pro Asp Asn Ser  
 100 105 110

Ser Thr Ile Tyr Thr Val Phe Leu Pro Leu Leu Glu Gly Gln Phe Arg  
 115 120 125

Ala Ala Leu Gln Gly Asn Glu Lys Asn Glu Met Glu Ile Cys Leu Glu  
 130 135 140

Ser Gly Asp Asn Thr Val Glu Thr Asn Gln Gly Leu Ser Leu Val Tyr  
 145 150 155 160

Met His Ala Gly Thr Asn Pro Phe Glu Val Ile Thr Gln Ala Val Lys  
 165 170 175

Ala Val Glu Lys His Thr Gln Thr Phe Leu His Arg Glu Lys Lys Lys  
 180 185 190

Leu Pro Ser Phe Leu Asp Trp Phe Gly Trp Cys Thr Trp Asp Ala Phe  
 195 200 205

Tyr Thr Asp Val Thr Ala Glu Gly Val Val Glu Gly Leu Gln Ser Leu  
 210 215 220

Ser Asp Gly Gly Ala Pro Pro Lys Phe Leu Ile Ile Asp Asp Gly Trp  
 225 230 235 240

Gln Gln Ile Glu Ala Lys Pro Lys Asp Ala Asp Cys Val Val Gln Glu  
 245 250 255

Gly Ala Gln Phe Ala Ser Arg Leu Ser Gly Ile Lys Glu Asn His Lys  
 260 265 270

Phe Gln Lys Asn Gly Asn Asn Tyr Asp Gln Val Pro Gly Leu Lys Val  
 275 280 285

Val Val Asp Asp Ala Lys Lys Gln His Lys Val Lys Phe Val Tyr Ala  
 290 295 300

Trp His Ala Leu Ala Gly Tyr Trp Gly Gly Val Lys Pro Ala Ser Pro  
 305 310 315 320

Gly Met Glu His Tyr Asp Ser Ala Leu Ala Tyr Pro Val Gln Ser Pro  
 325 330 335

Gly Met Leu Gly Asn Gln Pro Asp Ile Val Val Asp Ser Leu Ala Val  
 340 345 350

His Gly Ile Gly Leu Val His Pro Lys Lys Val Phe Asn Phe Tyr Asn  
 355 360 365

Glu Leu His Ser Tyr Leu Ala Ser Cys Gly Ile Asp Gly Val Lys Val  
 370 375 380

Asp Val Gln Asn Ile Ile Glu Thr Leu Gly Ala Gly His Gly Gly Arg  
 385 390 395 400

Val Thr Leu Thr Arg Ser Tyr His Gln Ala Leu Glu Ala Ser Ile Ala  
 405 410 415

Arg Asn Phe Ser Asp Asn Gly Cys Ile Ala Cys Met Cys His Asn Thr  
 420 425 430

Asp Ser Leu Tyr Ser Ala Lys Gln Thr Ala Val Val Arg Ala Ser Asp  
 435 440 445

Asp Tyr Tyr Pro Arg Asp Pro Ala Ser His Thr Ile His Ile Ser Ser  
 450 455 460

Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu Phe Met Gln Pro Asp Trp

## US 12,385,026 B2

77

-continued

78

---

465	470	475	480
Asp Met Phe His Ser Leu His Pro Thr Ala Glu Tyr His Gly Ala Ala			
485	490	495	
Arg Ala Ile Gly Gly Cys Ala Ile Tyr Val Ser Asp Lys Pro Gly Asn			
500	505	510	
His Asn Phe Asp Leu Leu Lys Lys Leu Val Leu Pro Asp Gly Ser Val			
515	520	525	
Leu Arg Ala Gln Leu Pro Gly Arg Pro Thr Arg Asp Ser Leu Phe Asn			
530	535	540	
Asp Pro Ala Arg Asp Gly Thr Ser Leu Leu Lys Ile Trp Asn Met Asn			
545	550	555	560
Lys Cys Ser Gly Val Val Gly Val Phe Asn Cys Gln Gly Ala Gly Trp			
565	570	575	
Cys Arg Ile Thr Lys Lys Thr Arg Ile His Asp Glu Ser Pro Gly Thr			
580	585	590	
Leu Thr Thr Ser Val Arg Ala Ala Asp Val Asp Ala Ile Ser Gln Val			
595	600	605	
Ala Gly Ala Asp Trp Lys Gly Asp Thr Ile Val Tyr Ala Tyr Arg Ser			
610	615	620	
Gly Asp Leu Thr Arg Leu Pro Lys Gly Ala Ser Val Pro Val Thr Leu			
625	630	635	640
Lys Val Leu Glu Tyr Asp Leu Phe His Ile Ser Pro Leu Lys Asp Ile			
645	650	655	
Thr Ser Asn Ile Ser Phe Ala Pro Ile Gly Leu Val Asp Met Phe Asn			
660	665	670	
Ile Gly Gly Ala Val Glu Gln Val Asp Ile Gln Val Val Glu Pro Ile			
675	680	685	
Pro Glu Phe Asp Gly Glu Val Ala Ser Glu Leu Thr Cys Ser Leu Pro			
690	695	700	
Asp Asp Arg Pro Pro Thr Ala Thr Ile Thr Met Lys Ala Arg Gly Cys			
705	710	715	720
Gly Arg Phe Gly Leu Tyr Ser Ser Gln Arg Pro Leu Lys Cys Ser Val			
725	730	735	
Asp Lys Val Gly Thr Asp Phe Val Tyr Asp Asp Val Thr Gly Leu Val			
740	745	750	
Thr Phe Glu Ile Pro Ile Pro Thr Glu Glu Met Tyr Arg Trp Asn Ile			
755	760	765	
Glu Ile Glu Val			
770			

&lt;210&gt; SEQ ID NO 8

&lt;211&gt; LENGTH: 211

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Zea mays

&lt;400&gt; SEQUENCE: 8

Pro Phe Glu Val Ile Thr Ser Ser Val Lys Ala Val Glu Arg His Leu
1 5 10 15

Gln Thr Phe Ser His Arg Glu Lys Lys Met Pro Asp Ile Leu Asn
20 25 30

Trp Phe Gly Trp Cys Thr Trp Asp Ala Phe Tyr Thr Asn Val Thr Ala
35 40 45

Gln Gly Val Lys Gln Gly Leu Gln Ser Leu Glu Lys Gly Gly Val Ser
50 55 60

## US 12,385,026 B2

79

80

-continued

Pro Arg Phe Val Ile Ile Asp Asp Gly Trp Gln Ser Val Ala Met Asp  
65 70 75 80

Pro Val Gly Ile Ala Cys Leu Ser Asp Asn Ser Ala Asn Phe Ala Asn  
85 90 95

Arg Leu Thr His Ile Arg Glu Asn His Lys Phe Gln Lys Asn Gly Arg  
100 105 110

Glu Gly His Arg Glu Asp Asp Pro Ala Lys Gly Leu Ala His Val Val  
115 120 125

Asn Glu Ile Lys Gly Lys His Gln Leu Lys Tyr Val Tyr Val Trp His  
130 135 140

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

Glu His Tyr Gly Ser Lys Met Gln Arg Pro Val Pro Ser Pro Gly Val  
165 170 175

Pro Lys Asn Glu Arg Cys Glu Ala Leu Asp Ser Met Thr Ala Asn Gly  
180 185 190

Leu Gly Leu Val Asn Leu Asp Arg Ala Phe Ser Phe Tyr Asp Glu Leu  
195 200 205

His Ser Tyr  
210

<210> SEQ\_ID NO 9  
<211> LENGTH: 747  
<212> TYPE: PRT  
<213> ORGANISM: Zea mays

<400> SEQUENCE: 9

Met Thr Val Ala Ser Ser Val Arg Leu Ala Gly Gly Asn Leu Thr Val  
1 5 10 15

Cys Gly Arg Thr Val Leu Ser Gly Val Pro Asp Ala Val Val Ala Thr  
20 25 30

Ser Ala Ala Thr Glu Gly Ala Val Asp Gly Ile Phe Leu Gly Ala Asp  
35 40 45

Phe Ala Glu Pro Ala Ala Arg His Val Val Ser Leu Gly Asp Leu Arg  
50 55 60

Asp Val Arg Phe Met Ala Cys Phe Arg Phe Lys Leu Trp Trp Met Ala  
65 70 75 80

Gln Arg Met Gly Glu Lys Gly Ser Asp Val Pro Arg Glu Thr Gln Phe  
85 90 95

Leu Leu Val Glu Ser Arg Gly Val Gly Asp Glu Asp Ala Ala Tyr Val  
100 105 110

Val Phe Leu Pro Leu Val Glu Gly Ala Phe Arg Ala Ser Ile Gln Gly  
115 120 125

Gly Ala Gly Asp Ala Leu Glu Leu Cys Val Glu Ser Gly Asp Asp Asp  
130 135 140

Thr Arg Ala Ala Ser Phe Glu Arg Ser Leu Phe Val Gly Ala Ala Glu  
145 150 155 160

Ser Asp Pro Phe Ala Ala Ile Ser Gly Ala Val Ala Ala Lys Ser  
165 170 175

Ala Leu Arg Thr Phe Arg Val Arg Ala Glu Lys Lys Leu Pro Gly Ile  
180 185 190

Val Asp Tyr Phe Gly Trp Cys Thr Trp Asp Ala Phe Tyr Gln Asp Val  
195 200 205

Thr Gln Glu Gly Val Glu Ala Gly Leu Arg Ser Leu Ile Ala Gly Gly  
210 215 220

-continued

---

Ala Pro Pro Lys Phe Val Ile Ile Asp Asp Gly Trp Gln Ser Val Ala  
 225                    230                    235                    240  
 Thr Asp Thr Asn Glu Ser Ala Gly Glu Asp Lys Pro Pro Leu Leu Ser  
 245                    250                    255  
 Arg Leu Thr Gly Ile Lys Glu Asn Ser Lys Phe Gln Asn Ala Asp Asp  
 260                    265                    270  
 Pro Ala Ala Gly Ile Lys Thr Val Val Arg Leu Ala Lys Glu Glu Tyr  
 275                    280                    285  
 Arg Leu Lys Tyr Val Tyr Val Trp His Ala Ile Thr Gly Tyr Trp Gly  
 290                    295                    300  
 Gly Val Arg Pro Gly Glu Glu His Tyr Arg Ser Ser Met Gln Phe Pro  
 305                    310                    315                    320  
 Lys Val Ser Pro Gly Val Met Glu Asn Glu Pro Gly Met Lys Thr Asp  
 325                    330                    335  
 Val Leu Thr Val Gln Gly Leu Gly Leu Val His Pro Arg Ala Val Tyr  
 340                    345                    350  
 Arg Phe Tyr Asp Glu Leu His Ala Tyr Leu Ala Ala Gly Val Asp  
 355                    360                    365  
 Gly Val Lys Val Asp Val Gln Cys Ile Leu Glu Thr Leu Gly Ala Gly  
 370                    375                    380  
 His Gly Gly Arg Val Gln Leu Thr Arg Gln Tyr His Gln Ala Leu Asp  
 385                    390                    395                    400  
 Ala Ser Val Ala Lys Asn Phe Pro Glu Asn Gly Ile Ile Ala Cys Met  
 405                    410                    415  
 Ser His Asn Thr Asp Ala Leu Tyr Cys Ser Lys Gln Thr Ala Val Val  
 420                    425                    430  
 Arg Ala Ser Asp Asp Phe Cys Pro Arg Asp Pro Ala Ser His Thr Ile  
 435                    440                    445  
 His Ile Ala Ser Val Ala Tyr Asn Ser Val Phe Leu Gly Glu Phe Met  
 450                    455                    460  
 Leu Pro Asp Trp Asp Met Phe His Ser Leu His Gln Ala Gly Asp Tyr  
 465                    470                    475                    480  
 His Gly Ser Ala Arg Ala Ile Ser Gly Gly Pro Val Tyr Val Ser Asp  
 485                    490                    495  
 Ala Pro Gly Lys His Asn Phe Glu Leu Leu Lys Lys Ile Val Leu Pro  
 500                    505                    510  
 Asp Gly Ser Ile Leu Arg Ala Arg Leu Pro Gly Arg Pro Thr Lys Asp  
 515                    520                    525  
 Cys Leu Phe Thr Asp Pro Ala Arg Asp Gly Val Ser Leu Leu Lys Ile  
 530                    535                    540  
 Trp Asn Met Asn Lys Phe Thr Gly Val Leu Gly Val Tyr Asn Cys Gln  
 545                    550                    555                    560  
 Gly Ala Ala Trp Asn Ser Val Glu Lys Lys Asn Thr Phe His Gln Thr  
 565                    570                    575  
 Gly Thr Glu Ala Leu Thr Cys Gly Val Lys Gly Gly Asp Val His Leu  
 580                    585                    590  
 Ile Ser Glu Ala Ala Thr Asp Thr Glu Trp Asp Gly Asp Cys Ala Met  
 595                    600                    605  
 Tyr Arg His Ala Asp Gly Asp Leu Val Val Leu Pro His Asp Ala Ala  
 610                    615                    620  
 Leu Pro Val Ser Leu Lys Val Leu Glu His Asp Ile Leu Thr Val Ser  
 625                    630                    635                    640

-continued

---

Pro Ile Lys Glu Leu Ala Pro Gly Phe Arg Phe Ala Pro Ile Gly Leu  
645 650 655

Val Asp Met Phe Asn Ser Gly Gly Ala Val Glu Gly Leu Thr Tyr His  
660 665 670

Leu Leu Gly Gly Asp Gly Ser Thr Leu Gly Ser Glu Ala Val Ala Leu  
675 680 685

Ala Cys Met Glu Val Lys Gly Cys Gly Arg Phe Gly Ala Tyr Ser Ser  
690 695 700

Val Arg Pro Arg Lys Ser Thr Leu Gly Ser Ala Gln Ile Glu Leu Lys  
705 710 715 720

Tyr Asp Ser Ser Ser Gly Leu Leu Ile Leu Gln Leu Asp Ala Met Pro  
725 730 735

Lys Glu Arg Val His Lys Ile Val Ile Glu Leu  
740 745

<210> SEQ ID NO 10

<211> LENGTH: 753

<212> TYPE: PRT

<213> ORGANISM: Oryza sativa

<400> SEQUENCE: 10

Met Thr Val Gly Ala Gly Val Ala Val Gln Asp Gly Gly Leu Val Ala  
1 5 10 15

Leu Gly Ala Thr Val Leu Thr Glu Val Arg Asp Asn Val Leu Leu Thr  
20 25 30

Pro Ala Ala Gly Ala Gly Met Thr Ser Gly Thr Phe Val Gly Val Arg  
35 40 45

Ser Ala Thr Ala Gly Ser Arg Ser Val Phe Pro Val Gly Lys Leu Arg  
50 55 60

Gly Leu Arg Phe Ile Cys Thr Phe Arg Phe Lys Met Trp Trp Met Thr  
65 70 75 80

Gln Arg Met Gly Thr Ser Gly Arg Asp Ile Pro Phe Glu Thr Gln Phe  
85 90 95

Leu Leu Val Glu Ala Ala Asp Ala Asp Gly Ser His Leu Ala Gly Asp  
100 105 110

Gly Ala Ala Ala Val Tyr Thr Val Phe Leu Pro Ile Leu Glu Gly Pro  
115 120 125

Phe Arg Ala Val Leu Gln Gly Asn Ser Asp Asp Glu Leu Glu Ile Cys  
130 135 140

Leu Glu Ser Gly Asp Pro Ala Val Glu Ser Phe Glu Gly Thr His Leu  
145 150 155 160

Val Phe Val Gly Ala Gly Ser Asp Pro Phe Glu Val Ile Thr Asn Ser  
165 170 175

Val Lys Ala Val Glu Arg His Leu Gln Thr Phe Thr His Arg Glu Lys  
180 185 190

Lys Lys Met Pro Asp Met Leu Asn Trp Phe Gly Trp Cys Thr Trp Asp  
195 200 205

Ala Phe Tyr Thr Asp Val Thr Ser Glu Gly Val Met Glu Gly Leu Gln  
210 215 220

Ser Leu Gly Lys Gly Gly Thr Gly Pro Lys Phe Val Ile Ile Asp Asp  
225 230 235 240

Gly Trp Gln Ser Val Ser Met Asp Pro Ala Gly Ile Ala Ser Leu Ala  
245 250 255

Asp Asn Ser Ala Asn Phe Ala Asn Arg Leu Thr His Ile Lys Glu Asn  
260 265 270

-continued

His Lys Phe Gln Leu Asn Gly Arg Lys Gly His Arg Glu Glu Asn Pro  
 275                    280                    285  
 Ala Asn Gly Leu Ala His Ile Val Asn Glu Ile Lys Gly Lys His Gln  
 290                    295                    300  
 Leu Lys Tyr Val Tyr Val Trp His Ala Ile Thr Gly Tyr Trp Gly Gly  
 305                    310                    315                    320  
 Val Arg Pro Gly Ala Asp Gly Met Glu His Tyr Glu Ser Lys Met Gln  
 325                    330                    335  
 Tyr Pro Val Ser Ser Pro Gly Val Gln Lys Asn Glu Pro Cys Asp Ala  
 340                    345                    350  
 Leu Asn Ser Ile Thr Thr Asn Gly Leu Gly Leu Val Asn Pro Asp Arg  
 355                    360                    365  
 Val Phe Ser Phe Tyr Asn Glu Leu His Ala Tyr Leu Ala Ser Ala Gly  
 370                    375                    380  
 Ile Asp Gly Val Lys Val Asp Val Gln Asn Ile Leu Glu Thr Leu Gly  
 385                    390                    395                    400  
 Ala Gly His Gly Gly Arg Val Leu Ala Arg Lys Tyr His Gln Ala  
 405                    410                    415  
 Leu Glu Ala Ser Ile Ala Arg Asn Phe Arg Asp Asn Gly Ile Ile Cys  
 420                    425                    430  
 Cys Met Ser His Asn Thr Asp Asn Leu Tyr Ser Ser Lys Arg Ser Ala  
 435                    440                    445  
 Val Val Arg Ala Ser Asp Asp Phe Trp Pro Arg Asp Pro Ala Ser His  
 450                    455                    460  
 Thr Ile His Ile Ala Ser Val Ala Tyr Asn Thr Val Phe Leu Gly Glu  
 465                    470                    475                    480  
 Phe Met Gln Pro Asp Trp Asp Met Phe His Ser Val His Pro Met Ala  
 485                    490                    495  
 Glu Tyr His Ala Ala Ala Arg Ala Val Gly Gly Cys Ala Ile Tyr Val  
 500                    505                    510  
 Ser Asp Lys Pro Gly Asn His Asp Phe Asn Leu Leu Lys Lys Leu Val  
 515                    520                    525  
 Leu Pro Asp Gly Ser Ile Leu Arg Ala Lys Leu Pro Gly Arg Pro Thr  
 530                    535                    540  
 Arg Asp Cys Leu Phe Ser Asp Pro Ala Arg Asp Gly Lys Ser Ile Leu  
 545                    550                    555                    560  
 Lys Ile Trp Asn Leu Asn Glu His Ser Gly Val Ile Gly Ala Phe Asn  
 565                    570                    575  
 Cys Gln Gly Ala Gly Trp Cys Arg Val Gly Lys Lys Asn Leu Val His  
 580                    585                    590  
 Asp Glu Gln Pro Ala Thr Val Thr Gly Val Ile Arg Ala Gln Asp Val  
 595                    600                    605  
 His His Leu Ala Thr Val Ala Ala Asp Gly Trp Asn Gly Asp Val Ile  
 610                    615                    620  
 Val Tyr Ser His Ile Gly Gly Glu Val Thr Cys Leu Pro Lys Asn Ala  
 625                    630                    635                    640  
 Ser Leu Pro Val Thr Leu Lys Thr Arg Glu Tyr Glu Val Phe Thr Val  
 645                    650                    655  
 Val Pro Leu Lys Lys Leu Asp Asn Gly Val Ser Phe Ala Ala Val Gly  
 660                    665                    670  
 Leu Ile Gly Met Phe Asn Ser Gly Gly Ala Val Thr Ala Val Arg Tyr  
 675                    680                    685

## US 12,385,026 B2

**87**

-continued

Val Glu Asp Ala Gly Val Glu Val Arg Val Arg Gly Ser Gly Thr Val  
690 695 700

Gly Ala Tyr Ser Ser Ala Lys Pro Ala Arg Val Val Val Asp Ser Glu  
705 710 715 720

Ala Ala Glu Phe Ser Tyr Asp Asp Gly Cys Gly Leu Val Thr Phe Glu  
725 730 735

Leu Ala Val Pro Glu Gln Glu Leu Tyr Ser Trp Thr Ile Ser Ile Glu  
740 745 750

Tyr

&lt;210&gt; SEQ ID NO 11

&lt;211&gt; LENGTH: 777

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Pisum sativum

&lt;400&gt; SEQUENCE: 11

Met Thr Val Thr Pro Lys Ile Ser Val Asn Asp Gly Asn Leu Val Val  
1 5 10 15

His Gly Lys Thr Ile Leu Lys Gly Val Pro Glu Asn Val Val Leu Thr  
20 25 30

Pro Gly Ser Gly Asn Gly Leu Leu Thr Gly Gly Ala Phe Ile Gly Ala  
35 40 45

Thr Ala Ser Asn Ser Lys Ser Leu His Val Phe Pro Ile Gly Ile Leu  
50 55 60

Glu Gly Leu Arg Phe Val Cys Cys Phe Arg Phe Lys Leu Trp Trp Met  
65 70 75 80

Thr Gln Arg Met Gly Thr Cys Gly Arg Asp Ile Pro Leu Glu Thr Gln  
85 90 95

Phe Met Leu Ile Glu Ser Lys Asp Ser Glu Gly Glu Gly Asn Ser  
100 105 110

Pro Val Ile Tyr Thr Val Leu Leu Pro Leu Leu Glu Gly Pro Phe Arg  
115 120 125

Ser Val Leu Gln Gly Asn Glu Lys Ser Glu Ile Glu Ile Cys Phe Glu  
130 135 140

Ser Gly Asp His Ala Val Glu Thr Asn Gln Gly Leu His Met Val Tyr  
145 150 155 160

Met His Ala Gly Thr Asn Pro Phe Glu Val Ile Asn Gln Ala Val Lys  
165 170 175

Ala Val Glu Lys His Met Gln Thr Phe His His Arg Glu Lys Lys Arg  
180 185 190

Leu Pro Ser Phe Leu Asp Met Phe Gly Trp Cys Thr Trp Asp Ala Phe  
195 200 205

Tyr Thr Asp Val Thr Ala Glu Gly Val Glu Gln Gly Leu Lys Ser Leu  
210 215 220

Ser Glu Gly Gly Thr Pro Pro Arg Phe Leu Ile Ile Asp Asp Gly Trp  
225 230 235 240

Gln Gln Ile Glu Ser Lys Ala Lys Asp Pro Gly Cys Val Val Gln Glu  
245 250 255

Gly Ala Gln Phe Ala Thr Met Leu Thr Gly Ile Lys Glu Asn Ala Lys  
260 265 270

Phe Gln Lys Asn Lys Asn Glu Glu His Ser Glu Pro Thr Ser Gly Leu  
275 280 285

Lys His Leu Val Asp Gly Val Lys Lys His His Asn Val Lys Asn Val  
290 295 300

**88**

## US 12,385,026 B2

**89****90**

-continued

---

Tyr Val Trp His Ala Leu Ala Gly Tyr Trp Gly Gly Val Lys Pro Ala  
305                   310                   315                   320

Ala Thr Gly Met Glu His Tyr Asp Thr Ala Leu Ala Tyr Pro Val Gln  
325                   330                   335

Ser Pro Gly Val Leu Gly Asn Gln Pro Asp Ile Val Met Asp Ser Leu  
340                   345                   350

Ser Val His Gly Leu Gly Leu Val His Pro Lys Lys Val Phe Asn Phe  
355                   360                   365

Tyr Asn Glu Leu His Ala Tyr Leu Ala Ser Cys Gly Val Asp Gly Val  
370                   375                   380

Lys Val Asp Val Gln Asn Ile Ile Glu Thr Leu Gly Ala Gly His Gly  
385                   390                   395                   400

Gly Arg Val Ser Leu Thr Arg Ser Tyr His His Ala Leu Glu Ala Ser  
405                   410                   415

Ile Ala Arg Asn Phe Ser Asp Asn Gly Cys Ile Ala Cys Met Cys His  
420                   425                   430

Asn Thr Asp Gly Leu Tyr Ser Ala Lys Gln Thr Ala Val Val Arg Ala  
435                   440                   445

Ser Asp Asp Phe Tyr Pro Arg Asp Pro Ala Ser His Thr Ile His Ile  
450                   455                   460

Ser Ser Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu Phe Met Gln Pro  
465                   470                   475                   480

Asp Trp Asp Met Phe His Ser Leu His Pro Ala Ala Glu Tyr His Ala  
485                   490                   495

Ala Ala Arg Ala Ile Gly Gly Cys Pro Ile Tyr Val Ser Asp Lys Pro  
500                   505                   510

Gly Asn His Asn Phe Asp Leu Leu Lys Lys Leu Val Leu Ser Asp Gly  
515                   520                   525

Ser Val Leu Arg Ala Gln Leu Pro Gly Arg Pro Thr Arg Asp Ser Leu  
530                   535                   540

Phe Val Asp Pro Ala Arg Asp Arg Thr Ser Leu Leu Lys Ile Trp Asn  
545                   550                   555                   560

Met Asn Lys Cys Thr Gly Val Val Gly Val Phe Asn Cys Gln Gly Ala  
565                   570                   575

Gly Trp Cys Lys Val Glu Lys Lys Thr Arg Ile His Asp Ile Ser Pro  
580                   585                   590

Gly Thr Leu Thr Ser Ser Val Cys Ala Ser Asp Val Asp Leu Ile Thr  
595                   600                   605

Gln Val Ala Gly Ala Glu Trp His Gly Glu Thr Ile Val Tyr Ala Tyr  
610                   615                   620

Arg Ser Gly Glu Val Ile Arg Leu Pro Lys Gly Val Ser Ile Pro Val  
625                   630                   635                   640

Thr Leu Lys Val Leu Glu Phe Glu Leu Phe His Phe Cys Pro Ile Gln  
645                   650                   655

Glu Ile Ser Ser Ser Ile Ser Phe Ala Thr Ile Gly Leu Met Asp Met  
660                   665                   670

Phe Asn Thr Gly Gly Ala Val Glu Glu Val Glu Ile His Arg Glu Thr  
675                   680                   685

Asp Asn Lys Gln Glu Leu Phe Glu Gly Glu Ala Val Ser Ser Glu Leu  
690                   695                   700

Ile Thr Ser Leu Gly Pro Asn Arg Thr Thr Ala Thr Ile Thr Leu  
705                   710                   715                   720

Lys Val Arg Gly Ser Gly Lys Phe Gly Val Tyr Ser Ser Gln Arg Pro

## US 12,385,026 B2

**91****92**

-continued

725	730	735
-----	-----	-----

Ile Lys Cys Met Val Asp Gly Thr Glu Thr Asp Phe Asn Tyr Asp Ser	740	745
---	-----	-----

Glu Thr Gly Leu Thr Thr Phe Ile Ile Pro Val Pro Gln Glu Glu Leu	755	760
---	-----	-----

Tyr Lys Trp Leu Ile Glu Ile Gln Val	770	775
-------------------------------------	-----	-----

&lt;210&gt; SEQ ID NO 12

&lt;211&gt; LENGTH: 753

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Cucumis sativus

&lt;400&gt; SEQUENCE: 12

Met Thr Val Gly Ala Gly Ile Thr Ile Ser Asp Ala Asn Leu Thr Val	1	5
---	---	---

10

15

Leu Gly Asn Arg Val Leu Ser Asp Val His Asn Asn Ile Thr Leu Thr	20	25
---	----	----

30

Ala Ala Pro Gly Gly Val Met Asn Gly Ala Phe Ile Gly Val Gln	35	40
---	----	----

45

Ser Asp Gln Ile Gly Ser Arg Arg Val Phe Pro Ile Gly Lys Leu Ile	50	55
---	----	----

60

Gly Leu Arg Phe Leu Cys Ala Phe Arg Phe Lys Leu Trp Trp Met Thr	65	70
---	----	----

75

80

Gln Arg Met Gly Cys Ser Gly Gln Glu Ile Pro Phe Glu Thr Gln Phe	85	90
---	----	----

95

Leu Val Val Glu Thr Arg Asp Gly Ser Asn Ile Ala Gly Asn Gly Glu	100	105
---	-----	-----

110

Glu Gly Asp Ala Val Tyr Thr Val Phe Leu Pro Ile Leu Glu Gly Asp	115	120
---	-----	-----

125

Phe Arg Ala Val Leu Gln Gly Asn Asp Asn Asn Glu Leu Glu Ile Cys	130	135
---	-----	-----

140

Leu Glu Ser Gly Asp Pro Ser Val Asp Gly Phe Glu Gly Ser His Leu	145	150
---	-----	-----

155

160

Val Phe Val Gly Ala Gly Ser Asp Pro Phe Glu Thr Ile Thr Tyr Ala	165	170
---	-----	-----

175

Val Lys Ser Val Glu Lys His Leu Gln Thr Phe Ala His Arg Glu Arg	180	185
---	-----	-----

190

Lys Lys Met Pro Asp Ile Leu Asn Trp Phe Gly Trp Cys Thr Trp Asp	195	200
---	-----	-----

205

Ala Phe Tyr Thr Asp Val Thr Ser Asp Gly Val Lys Lys Gly Leu Glu	210	215
---	-----	-----

220

Ser Phe Glu Asn Gly Gly Ile Pro Pro Lys Phe Val Ile Ile Asp Asp	225	230
---	-----	-----

240

Gly Trp Gln Ser Val Ala Lys Asp Ala Ala Ser Thr Asp Cys Lys Ala	245	250
---	-----	-----

255

Asp Asn Thr Ala Asn Phe Ala Asn Arg Leu Thr His Ile Lys Glu Asn	260	265
---	-----	-----

270

Tyr Lys Phe Gln Lys Asp Gly Lys Glu Gly Glu Arg Ile Glu Asn Pro	275	280
---	-----	-----

285

Ala Leu Gly Leu Gln His Ile Val Ser Tyr Met Lys Glu Lys His Ala	290	295
---	-----	-----

300

Thr Lys Tyr Val Tyr Val Trp His Ala Ile Thr Gly Tyr Trp Gly Gly	305	310
---	-----	-----

315

320

-continued

---

Val Ser Ser Gly Val Lys Glu Met Glu Gln Tyr Glu Ser Lys Ile Ala  
325 330 335

Tyr Pro Val Ala Ser Pro Gly Val Glu Ser Asn Glu Pro Cys Asp Ala  
340 345 350

Leu Asn Ser Ile Ser Lys Thr Gly Leu Gly Leu Val Asn Pro Glu Lys  
355 360 365

Val Phe Asn Phe Tyr Asn Glu Gln His Ser Tyr Leu Ala Ser Ala Gly  
370 375 380

Val Asp Gly Val Lys Val Asp Val Gln Asn Ile Leu Glu Thr Leu Gly  
385 390 395 400

Ala Gly His Gly Gly Arg Val Lys Leu Ala Arg Lys Tyr His Gln Ala  
405 410 415

Leu Glu Ala Ser Ile Ser Arg Asn Phe Gln Asp Asn Gly Ile Ile Ser  
420 425 430

Cys Met Ser His Asn Thr Asp Gly Leu Tyr Ser Ser Lys Arg Asn Ala  
435 440 445

Val Ile Arg Ala Ser Asp Asp Phe Trp Pro Arg Asp Pro Ala Ser His  
450 455 460

Thr Ile His Ile Ala Ser Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu  
465 470 475 480

Phe Met Gln Pro Asp Trp Asp Met Phe His Ser Leu His Pro Met Ala  
485 490 495

Glu Tyr His Gly Ala Ala Arg Ala Val Gly Gly Cys Ala Ile Tyr Val  
500 505 510

Ser Asp Lys Pro Gly Gln His Asp Phe Asn Leu Leu Lys Lys Leu Val  
515 520 525

Leu His Asp Gly Ser Ile Leu Arg Ala Lys Leu Pro Gly Arg Pro Thr  
530 535 540

Lys Asp Cys Leu Phe Ala Asp Pro Ala Arg Asp Gly Lys Ser Leu Leu  
545 550 555 560

Lys Ile Trp Asn Met Asn Asp Leu Ser Gly Val Val Gly Val Phe Asn  
565 570 575

Cys Gln Gly Ala Gly Trp Cys Lys Val Gly Lys Lys Asn Leu Ile His  
580 585 590

Asp Glu Asn Pro Asp Thr Ile Thr Gly Val Ile Arg Ala Lys Asp Val  
595 600 605

Ser Tyr Leu Trp Lys Ile Ala Gly Glu Ser Trp Thr Gly Asp Ala Val  
610 615 620

Ile Phe Ser His Leu Ala Gly Glu Val Val Tyr Leu Pro Gln Asp Ala  
625 630 635 640

Ser Met Pro Ile Thr Leu Lys Ser Arg Glu Phe Asp Val Phe Thr Val  
645 650 655

Val Pro Val Lys Glu Leu Ala Asn Asp Ile Lys Phe Ala Pro Ile Gly  
660 665 670

Leu Met Lys Met Phe Asn Ser Gly Gly Ala Val Lys Glu Met Asn His  
675 680 685

Gln Pro Gly Ser Ser Asn Val Ser Leu Lys Val Arg Gly Ser Gly Pro  
690 695 700

Phe Gly Ala Tyr Ser Ser Lys Pro Lys Arg Val Ala Val Asp Ser  
705 710 715 720

Glu Glu Val Glu Phe Ile Tyr Asp Glu Gly Gly Leu Ile Thr Ile Asp  
725 730 735

Leu Lys Val Pro Glu Lys Glu Leu Tyr Leu Trp Asp Ile Arg Ile Glu

## US 12,385,026 B2

**95****96**

-continued

740

745

750

Leu

&lt;210&gt; SEQ ID NO 13

&lt;211&gt; LENGTH: 772

&lt;212&gt; TYPE: PRT

&lt;213&gt; ORGANISM: Cucumis melo

&lt;400&gt; SEQUENCE: 13

Met	Thr	Val	Thr	Pro	Lys	Ile	Ser	Val	Asn	Asp	Gly	Asn	Leu	Val	Val
1															
													10		15

His	Gly	Lys	Thr	Ile	Leu	Thr	Gly	Val	Pro	Asp	Asn	Ile	Val	Leu	Thr
													20		30

Pro	Gly	Ser	Gly	Leu	Gly	Leu	Val	Ala	Gly	Ala	Phe	Ile	Gly	Ala	Thr
													35		45

Ala	Ser	Asn	Ser	Lys	Ser	Leu	His	Val	Phe	Pro	Val	Gly	Val	Leu	Glu
													50		60

Gly	Thr	Arg	Phe	Leu	Cys	Cys	Phe	Arg	Phe	Lys	Leu	Trp	Trp	Met	Thr
													65		80

Gln	Arg	Met	Gly	Thr	Ser	Gly	Arg	Asp	Ile	Pro	Phe	Glu	Thr	Gln	Phe
													85		95

Leu	Leu	Met	Glu	Ser	Lys	Gly	Asn	Asp	Gly	Glu	Asp	Pro	Asp	Asn	Ser
													100		110

Ser	Thr	Ile	Tyr	Thr	Val	Phe	Leu	Pro	Leu	Leu	Glu	Gly	Gln	Phe	Arg
													115		125

Ala	Ala	Leu	Gln	Gly	Asn	Glu	Lys	Asn	Glu	Met	Glu	Ile	Cys	Leu	Glu
													130		140

Ser	Gly	Asp	Asn	Thr	Val	Glu	Thr	Asn	Gln	Gly	Leu	Ser	Leu	Val	Tyr
													145		160

Met	His	Ala	Gly	Thr	Asn	Pro	Phe	Glu	Val	Ile	Thr	Gln	Ala	Val	Lys
													165		175

Ala	Val	Glu	Lys	His	Thr	Gln	Thr	Phe	Leu	His	Arg	Glu	Lys	Lys	Lys
													180		190

Leu	Pro	Ser	Phe	Leu	Asp	Trp	Phe	Gly	Trp	Cys	Thr	Trp	Asp	Ala	Phe
													195		205

Tyr	Thr	Asp	Ala	Thr	Ala	Glu	Val	Val	Glu	Gly	Leu	Lys	Ser	Leu	
													210		220

Ser	Glu	Gly	Gly	Ala	Pro	Pro	Lys	Phe	Leu	Ile	Ile	Asp	Asp	Gly	Trp
													225		240

Gln	Gln	Ile	Glu	Ala	Lys	Pro	Lys	Asp	Ala	Asp	Cys	Val	Val	Gln	Glu
													245		255

Gly	Ala	Gln	Phe	Ala	Ser	Arg	Leu	Ser	Gly	Ile	Lys	Glu	Asn	His	Lys
													260		270

Phe	Gln	Lys	Asn	Gly	Asn	Asn	Tyr	Asp	Gln	Val	Pro	Gly	Leu	Lys	Val
													275		285

Val	Val	Asp	Asp	Ala	Lys	Lys	Gln	His	Lys	Val	Lys	Phe	Val	Tyr	Ala
													290		300

Trp	His	Ala	Leu	Ala	Gly	Tyr	Trp	Gly	Gly	Val	Lys	Pro	Ala	Ser	Pro
													305		320

Gly	Met	Glu	His	Tyr	Asp	Ser	Ala	Leu	Ala	Tyr	Pro	Val	Gln	Ser	Pro
													325		335

Gly	Met	Leu	Gly	Asn	Gln	Pro	Asp	Ile	Val	Val	Asp	Ser	Leu	Ala	Val
													340		350

His Gly Ile Gly Leu Val His Pro Lys Lys Val Phe Asn Phe Tyr Asn

## US 12,385,026 B2

**97****98**

-continued

355                    360                    365

Glu Leu His Ser Tyr Leu Ala Ser Cys Gly Ile Asp Gly Val Lys Val  
 370                    375                    380

Asp Val Gln Asn Ile Ile Glu Thr Leu Gly Ala Gly His Gly Gly Arg  
 385                    390                    395                    400

Val Thr Leu Thr Arg Ser Tyr His Gln Ala Leu Glu Ala Ser Ile Ala  
 405                    410                    415

Arg Asn Phe Ser Asp Asn Gly Cys Ile Ala Cys Met Cys His Asn Thr  
 420                    425                    430

Asp Ser Leu Tyr Ser Ala Lys Gln Thr Ala Val Val Arg Ala Ser Asp  
 435                    440                    445

Asp Tyr Tyr Pro Arg Asp Pro Thr Ser His Thr Ile His Ile Ser Ser  
 450                    455                    460

Val Ala Tyr Asn Ser Leu Phe Leu Gly Glu Phe Met Gln Pro Asp Trp  
 465                    470                    475                    480

Asp Met Phe His Ser Leu His Pro Thr Ala Glu Tyr His Gly Ala Ala  
 485                    490                    495

Arg Ala Ile Gly Gly Cys Ala Ile Tyr Val Ser Asp Lys Pro Gly Asn  
 500                    505                    510

His Asn Phe Asp Leu Leu Lys Lys Leu Val Leu Pro Asp Gly Ser Val  
 515                    520                    525

Leu Arg Ala Gln Leu Pro Gly Arg Pro Thr Arg Asp Ser Leu Phe Asn  
 530                    535                    540

Asp Pro Ala Arg Asp Gly Ile Ser Leu Leu Lys Ile Trp Asn Met Asn  
 545                    550                    555                    560

Lys Cys Ser Gly Val Val Gly Val Phe Asn Cys Gln Gly Ala Gly Trp  
 565                    570                    575

Cys Arg Ile Thr Lys Lys Thr Arg Ile His Asp Glu Ser Pro Gly Thr  
 580                    585                    590

Leu Thr Thr Ser Val Arg Ala Ala Asp Val Asp Ala Ile Ser Gln Val  
 595                    600                    605

Ala Gly Ala Asp Trp Lys Gly Asp Thr Ile Val Tyr Ala Tyr Arg Ser  
 610                    615                    620

Gly Asp Leu Ile Arg Leu Pro Lys Gly Ala Ser Val Pro Val Thr Leu  
 625                    630                    635                    640

Lys Val Leu Glu Tyr Asp Leu Leu His Ile Ser Pro Leu Lys Asp Ile  
 645                    650                    655

Ala Ser Asn Ile Ser Phe Ala Pro Ile Gly Leu Leu Asp Met Phe Asn  
 660                    665                    670

Thr Gly Gly Ala Val Glu Gln Val Asn Val Gln Val Val Glu Pro Ile  
 675                    680                    685

Pro Glu Phe Asp Gly Glu Val Ala Ser Glu Leu Thr Cys Ser Leu Pro  
 690                    695                    700

Asn Asp Arg Pro Pro Thr Ala Thr Ile Thr Met Lys Ala Arg Gly Cys  
 705                    710                    715                    720

Arg Arg Phe Gly Leu Tyr Ser Ser Gln Arg Pro Leu Lys Cys Ser Val  
 725                    730                    735

Asp Lys Val Asp Val Asp Phe Val Tyr Asp Glu Val Thr Gly Leu Val  
 740                    745                    750

Thr Phe Glu Ile Pro Ile Pro Thr Glu Glu Met Tyr Arg Trp Asp Ile  
 755                    760                    765

Glu Ile Gln Val  
 770

-continued

<210> SEQ\_ID NO 14  
<211> LENGTH: 378  
<212> TYPE: PRT  
<213> ORGANISM: Coffea arabica

&lt;400&gt; SEQUENCE: 14

Met Val Lys Ser Pro Gly Thr Glu Asp Tyr Thr Arg Arg Ser Leu Leu  
1               5               10               15

Ala Asn Gly Leu Gly Leu Thr Pro Pro Met Gly Trp Asn Ser Trp Asn  
20              25              30

His Phe Arg Cys Asn Leu Asp Glu Lys Leu Ile Arg Glu Thr Ala Asp  
35              40              45

Ala Met Val Ser Lys Gly Leu Ala Ala Leu Gly Tyr Lys Tyr Ile Asn  
50              55              60

Leu Asp Asp Cys Trp Ala Glu Leu Asn Arg Asp Ser Gln Gly Asn Leu  
65              70              75              80

Val Pro Lys Gly Ser Thr Phe Pro Ser Gly Ile Lys Ala Leu Ala Asp  
85              90              95

Tyr Val His Ser Lys Gly Leu Lys Leu Gly Ile Tyr Ser Asp Ala Gly  
100             105             110

Thr Gln Thr Cys Ser Lys Thr Met Pro Gly Ser Leu Gly His Glu Glu  
115             120             125

Gln Asp Ala Lys Thr Phe Ala Ser Trp Gly Val Asp Tyr Leu Lys Tyr  
130             135             140

Asp Asn Cys Asn Asn Asn Ile Ser Pro Lys Glu Arg Tyr Pro Ile  
145             150             155             160

Met Ser Lys Ala Leu Leu Asn Ser Gly Arg Ser Ile Phe Phe Ser Leu  
165             170             175

Cys Glu Trp Gly Glu Glu Asp Pro Ala Thr Trp Ala Lys Glu Val Gly  
180             185             190

Asn Ser Trp Arg Thr Thr Gly Asp Ile Asp Asp Ser Trp Ser Ser Met  
195             200             205

Thr Ser Arg Ala Asp Met Asn Asp Lys Trp Ala Ser Tyr Ala Gly Pro  
210             215             220

Gly Gly Trp Asn Asp Pro Asp Met Leu Glu Val Gly Asn Gly Gly Met  
225             230             235             240

Thr Thr Thr Glu Tyr Arg Ser His Phe Ser Ile Trp Ala Leu Ala Lys  
245             250             255

Ala Pro Leu Leu Ile Gly Cys Asp Ile Arg Ser Met Asp Gly Ala Thr  
260             265             270

Phe Gln Leu Leu Ser Asn Ala Glu Val Ile Ala Val Asn Gln Asp Lys  
275             280             285

Leu Gly Val Gln Gly Asn Lys Val Lys Thr Tyr Gly Asp Leu Glu Val  
290             295             300

Trp Ala Gly Pro Leu Ser Gly Lys Arg Val Ala Val Ala Leu Trp Asn  
305             310             315             320

Arg Gly Ser Ser Thr Ala Thr Ile Thr Ala Tyr Trp Ser Asp Val Gly  
325             330             335

Leu Pro Ser Thr Ala Val Val Asn Ala Arg Asp Leu Trp Ala His Ser  
340             345             350

Thr Glu Lys Ser Val Lys Gly Gln Ile Ser Ala Ala Val Asp Ala His  
355             360             365

Asp Ser Lys Met Tyr Val Leu Thr Pro Gln

## US 12,385,026 B2

**101****102**

-continued

370

375

<210> SEQ\_ID NO 15  
<211> LENGTH: 398  
<212> TYPE: PRT  
<213> ORGANISM: Artificial Sequence  
<220> FEATURE:  
<223> OTHER INFORMATION: recombinant human alpha-galactosidase A  
<400> SEQUENCE: 15

Leu Asp Asn Gly Leu Ala Arg Thr Pro Thr Met Gly Trp Leu His Trp  
1               5               10               15

Glu Arg Phe Met Cys Asn Leu Asp Cys Gln Glu Glu Pro Asp Ser Cys  
20              25              30

Ile Ser Glu Lys Leu Phe Met Glu Met Ala Glu Leu Met Val Ser Glu  
35              40              45

Gly Trp Lys Asp Ala Gly Tyr Glu Tyr Leu Cys Ile Asp Asp Cys Trp  
50              55              60

Met Ala Pro Gln Arg Asp Ser Glu Gly Arg Leu Gln Ala Asp Pro Gln  
65              70              75              80

Arg Phe Pro His Gly Ile Arg Gln Leu Ala Asn Tyr Val His Ser Lys  
85              90              95

Gly Leu Lys Leu Gly Ile Tyr Ala Asp Val Gly Asn Lys Thr Cys Ala  
100            105            110

Gly Phe Pro Gly Ser Phe Gly Tyr Tyr Asp Ile Asp Ala Gln Thr Phe  
115            120            125

Ala Asp Trp Gly Val Asp Leu Leu Lys Phe Asp Gly Cys Tyr Cys Asp  
130            135            140

Ser Leu Glu Asn Leu Ala Asp Gly Tyr Lys His Met Ser Leu Ala Leu  
145            150            155            160

Asn Arg Thr Gly Arg Ser Ile Val Tyr Ser Cys Glu Trp Pro Leu Tyr  
165            170            175

Met Trp Pro Phe Gln Lys Pro Asn Tyr Thr Glu Ile Arg Gln Tyr Cys  
180            185            190

Asn His Trp Arg Asn Phe Ala Asp Ile Asp Asp Ser Trp Lys Ser Ile  
195            200            205

Lys Ser Ile Leu Asp Trp Thr Ser Phe Asn Gln Glu Arg Ile Val Asp  
210            215            220

Val Ala Gly Pro Gly Gly Trp Asn Asp Pro Asp Met Leu Val Ile Gly  
225            230            235            240

Asn Phe Gly Leu Ser Trp Asn Gln Gln Val Thr Gln Met Ala Leu Trp  
245            250            255

Ala Ile Met Ala Ala Pro Leu Phe Met Ser Asn Asp Leu Arg His Ile  
260            265            270

Ser Pro Gln Ala Lys Ala Leu Leu Gln Asp Lys Asp Val Ile Ala Ile  
275            280            285

Asn Gln Asp Pro Leu Gly Lys Gln Gly Tyr Gln Leu Arg Gln Gly Asp  
290            295            300

Asn Phe Glu Val Trp Glu Arg Pro Leu Ser Gly Leu Ala Trp Ala Val  
305            310            315            320

Ala Met Ile Asn Arg Gln Glu Ile Gly Gly Pro Arg Ser Tyr Thr Ile  
325            330            335

Ala Val Ala Ser Leu Gly Lys Gly Val Ala Cys Asn Pro Ala Cys Phe  
340            345            350

Ile Thr Gln Leu Leu Pro Val Lys Arg Lys Leu Gly Phe Tyr Glu Trp

-continued

355	360	365
Thr Ser Arg Leu Arg Ser His Ile Asn Pro Thr Gly Thr Val Leu Leu		
370	375	380

385	390	395
Gln Leu Glu Asn Thr Met Gln Met Ser Leu Lys Asp Leu Leu		

10  
What is claimed is:

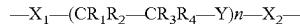
1. A stabilized form of  $\alpha$ -galactosidase comprising two  $\alpha$ -galactosidase monomers covalently linked to one another via a linking moiety, wherein each of said two  $\alpha$ -galactosidase monomers has the amino acid sequence of SEQ ID NO: 15 3.

2. The stabilized form of  $\alpha$ -galactosidase of claim 1, wherein the linking moiety is a non-peptidic moiety.

3. The stabilized form of  $\alpha$ -galactosidase of claim 2, 20 wherein the linking moiety comprises poly (alkylene glycol) and at least two functional groups, wherein each functional group forms a covalent bond with one of the native  $\alpha$ -galactosidase monomers.

4. The stabilized form of  $\alpha$ -galactosidase of claim 3, 25 wherein the poly (alkylene glycol) comprises ethylene glycol or propylene glycol units linked together.

5. The stabilized form of  $\alpha$ -galactosidase of claim 3, wherein the linking moiety has the following general formula:

30  
wherein:

each of  $X_1$  and  $X_2$  is a functional group that forms a covalent bond with at least one  $\alpha$ -galactosidase monomer;

C is a carbon atom;

Y is an oxygen atom, a sulfur atom or NR<sub>5</sub>, wherein

NR<sub>5</sub> is a nitrogen atom attached to R<sub>5</sub>;

n is an integer from 5 to 150; and

each of R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub> and R<sub>5</sub> is independently selected 40 from the group consisting of hydrogen, alkyl, cycloalkyl, alkenyl, alkynyl, alkoxy, hydroxy, oxo, thiol and thioalkoxy.

6. The stabilized form of  $\alpha$ -galactosidase of claim 5, wherein at least one of said functional groups forms an 45 amide bond with an  $\alpha$ -galactosidase monomer.

7. The stabilized form of  $\alpha$ -galactosidase of claim 5, wherein said linking moiety is at least 20 atoms long.

8. The stabilized form of  $\alpha$ -galactosidase of claim 5, 50 wherein n is at least 25.

9. The stabilized form of  $\alpha$ -galactosidase of claim 5, wherein n is an integer from 40 to 70.

10. The stabilized form of  $\alpha$ -galactosidase of claim 5, 55 wherein each of R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub> and R<sub>5</sub> is independently selected from the group consisting of hydrogen and OXO.

11. The stabilized form of  $\alpha$ -galactosidase of claim 1, 60 featuring a characteristic selected from the group consisting of:

(a) an  $\alpha$ -galactosidase activity upon subjecting the stabilized form of  $\alpha$ -galactosidase to human plasma conditions for one hour which is at least 10% higher than an activity of naturally occurring  $\alpha$ -galactosidase upon subjecting said naturally occurring  $\alpha$ -galactosidase to said human plasma conditions for one hour;

(b) an  $\alpha$ -galactosidase activity which decreases upon subjecting the stabilized form of  $\alpha$ -galactosidase to human plasma conditions for one hour by a percentage

which is at least 10% less than the percentage by which an activity of naturally occurring  $\alpha$ -galactosidase decreases upon subjecting said naturally occurring  $\alpha$ -galactosidase to said human plasma conditions for one hour;

(c) an  $\alpha$ -galactosidase activity which remains in a range of 50% to 150% of the initial activity upon subjecting the stabilized form of  $\alpha$ -galactosidase to human plasma conditions for one hour;

(d) an  $\alpha$ -galactosidase activity upon subjecting the stabilized form of  $\alpha$ -galactosidase to lysosomal conditions for one week, which is at least 10% higher than an activity of naturally occurring  $\alpha$ -galactosidase upon subjecting said naturally occurring  $\alpha$ -galactosidase to said lysosomal conditions for one week;

(e) an  $\alpha$ -galactosidase activity which decreases upon subjecting the stabilized form of  $\alpha$ -galactosidase to lysosomal conditions for one day by a percentage which is at least 10% less than the percentage by which an activity of naturally occurring  $\alpha$ -galactosidase decreases upon subjecting said naturally occurring  $\alpha$ -galactosidase to said lysosomal conditions for one day;

(f) an  $\alpha$ -galactosidase activity which remains in a range of 50% to 150% of the initial activity upon subjecting the stabilized form of  $\alpha$ -galactosidase to lysosomal conditions for one day;

(g) an  $\alpha$ -galactosidase activity immediately upon subjecting the stabilized form of  $\alpha$ -galactosidase to lysosomal conditions, which is at least 10% higher than an activity of naturally occurring  $\alpha$ -galactosidase immediately upon subjecting said naturally occurring  $\alpha$ -galactosidase to said lysosomal conditions;

(h) an  $\alpha$ -galactosidase activity immediately upon subjecting the stabilized form of  $\alpha$ -galactosidase to an aqueous solution having a pH of 7 and a temperature of 37° C., which is at least 10% higher than an activity of naturally occurring  $\alpha$ -galactosidase immediately upon subjecting said naturally occurring  $\alpha$ -galactosidase to said aqueous solution having a pH of 7 and a temperature of 37° C.; and

(i) a circulating half-life in human plasma which is higher than a circulating half-life of naturally occurring  $\alpha$ -galactosidase.

12. A pharmaceutical composition comprising the stabilized form of  $\alpha$ -galactosidase of claim 11 and a pharmaceutically acceptable carrier.

13. A method of treating Fabry disease in a subject in need thereof, said method comprising administering to said subject the stabilized form of  $\alpha$ -galactosidase of claim 1, such that said Fabry disease in said subject is treated.

14. The method of claim 13, wherein said administering is by an intravenous infusion.

15. A process of preparing the stabilized form of  $\alpha$ -galactosidase of claim 1, said process comprising reacting  $\alpha$ -galactosidase comprising two  $\alpha$ -galactosidase monomers

**105**

with a cross-linking agent, wherein said cross-linking agent comprises a linking moiety and at least two reactive groups.

**16.** The process of claim **15**, wherein said reactive groups comprise a leaving group.

\* \* \* \* \*

5

**106**