



Office de la Propriété
Intellectuelle
du Canada

Un organisme
d'Industrie Canada

Canadian
Intellectual Property
Office

An agency of
Industry Canada

CA 2374009 A1 2001/01/18

(21) **2 374 009**

(12) **DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION**

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2000/07/07

(87) Date publication PCT/PCT Publication Date: 2001/01/18

(85) Entrée phase nationale/National Entry: 2001/11/14

(86) N° demande PCT/PCT Application No.: DK 2000/000373

(87) N° publication PCT/PCT Publication No.: 2001/004273

(30) Priorité/Priority: 1999/07/09 (PA 1999 00999) DK

(51) Cl.Int.⁷/Int.Cl.⁷ C12N 9/34, C12P 19/14, C13K 1/06,
C12G 3/02

(71) Demandeur/Applicant:
NOVOZYMES A/S, DK

(72) Inventeurs/Inventors:
FRANDSEN, TORBEN PETER, DK;
HENDRIKSEN, HANNE VANG, DK;
VIND, JESPER, DK;
PEDERSEN, HENRIK, DK;
SVENDSEN, ALLAN, DK;
NIELSEN, BJARNE RONFELDT, DK

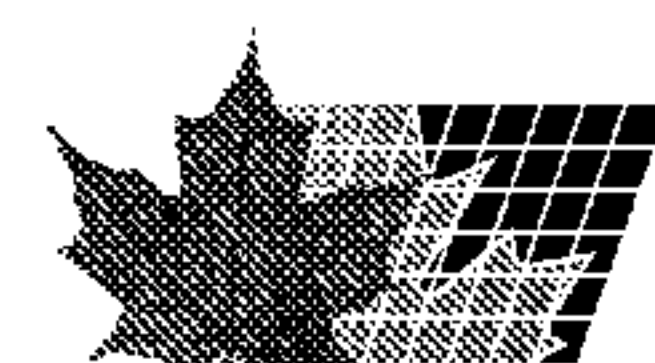
(74) Agent: DIMOCK STRATTON CLARIZIO LLP

(54) Titre : VARIANTE DE GLUCOAMYLASE

(54) Title: GLUCOAMYLASE VARIANT

(57) **Abrégé/Abstract:**

The invention relates to a variant of a parent fungal glucoamylase, which exhibits altered properties, in particular improved thermal stability and/or increased specific activity.



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
18 January 2001 (18.01.2001)

PCT

(10) International Publication Number
WO 01/04273 A2

(51) International Patent Classification⁷: C12N 9/00

(21) International Application Number: PCT/DK00/00373

(22) International Filing Date: 7 July 2000 (07.07.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PA 1999 00999 9 July 1999 (09.07.1999) DK

(71) Applicant: NOVO NORDISK A/S [DK/DK]; Novo Allé,
DK-2880 Bagsværd (DK).

(72) Inventors: NIELSEN, Bjarne, Rønfeldt; Liguster-
vænget 27, DK-2830 Virum (DK). SVENDSEN, Allan;
Bakkeleddet 28, DK-3460 Birkerød (DK). PEDERSEN,
Henrik; Præstevej 40, DK-5210 Odense SV (DK). VIND,
Jesper; Bagsværdvej 115, DK-2800 Lyngby (DK). HEN-
DRIKSEN, Hanne, Vang; Vejlemosevej 5A, DK-2840
Holte (DK). FRANDSEN, Torben, Peter; Alhambravej
22, 1.th, DK-1826 Frederiksberg C (DK).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ,
DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR,
HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR,
LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ,
NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM,
TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG,
CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— Without international search report and to be republished
upon receipt of that report.

For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.

(54) Title: GLUCOAMYLASE VARIANT

(57) Abstract: The invention relates to a variant of a parent fungal glucoamylase, which exhibits altered properties, in particular improved thermal stability and/or increased specific activity.



WO 01/04273 A2

Title: Glucoamylase variant**FIELD OF THE INVENTION**

The present invention relates to novel glucoamylase variants
5 (mutants) of parent AMG with altered properties, in particular
with improved thermal stability and/or increased specific
activity, which variants are, e.g., suitable for starch
conversion, in particular for producing glucose from starch,
and for ethanol production, sweetener production. More
10 specifically, the present invention relates to glucoamylase
variants and the use of such variant enzymes.

BACKGROUND OF THE INVENTION

Glucoamylase (1,4- α -D-glucan glucohydrolase, EC
15 3.2.1.3) is an enzyme, which catalyzes the release of D-glucose
from the non-reducing ends of starch or related oligo- and
polysaccharide molecules. Glucoamylases are produced by several
filamentous fungi or yeasts, with those from *Aspergillus* being
commercially most important.

20 Commercially, the glucoamylase enzyme is used to convert
cornstarch, which is already partially hydrolyzed by an α -
amylase to glucose. The glucose is further converted by glucose
isomerase to a mixture composed almost equally of glucose and
fructose. This mixture, or the mixture further enriched with
25 fructose, is the commonly used high fructose corn syrup
commercialized throughout the world. This syrup is the world's
largest tonnage product produced by an enzymatic process. The
three enzymes involved in the conversion of starch to fructose
are among the most important industrial enzymes produced.

30 One of the main problems exist with regard to the
commercial use of glucoamylase in the production of high
fructose corn syrup is the relatively low thermal stability of
glucoamylase. Glucoamylase is not as thermally stable as α -
amylase or glucose isomerase and it is most active and stable
35 at lower pH's than either α -amylase or glucose isomerase.
Accordingly, it must be used in a separate vessel at a lower
temperature and pH.

Glucoamylase from *Aspergillus niger* has a catalytic (aa 1-440) and a starch binding domain (aa 509-616) separated by a long and highly O-glycosylated linker (Svensson et al. (1983), *Carlsberg Res. Commun.* **48**, 529-544, 1983 and (1986), *Eur. J. Biochem.* **154**, 497-502). The catalytic domain (aa 1-471) of glucoamylase from *A. awamori* var. X100 adopt an $(\alpha/\alpha)_6$ -fold in which six conserved $\alpha \rightarrow \alpha$ loop segments connect the outer and inner barrels (Aleshin et al. (1992), *J. Biol. Chem.* **267**, 19291-19298). Crystal structures of glucoamylase in complex with 1-deoxynojirimycin (Harris et al. (1993), *Biochemistry*, **32**, 1618-1626) and the pseudotetrasaccharide inhibitors acarbose and D-gluco-dihydroacarbose (Aleshin et al. (1996), *Biochemistry* **35**, 8319-8328) furthermore are compatible with glutamic acids 179 and 400 acting as general acid and base, respectively. The crucial role of these residues during catalysis have also been studied using protein engineering (Sierks et al. (1990), *Protein Engng.* **3**, 193-198; Frandsen et al. (1994), *Biochemistry*, **33**, 13808-13816). Glucoamylase-carbohydrate interactions at four glycosyl residue binding subsites, -1, +1, +2, and +3 are highlighted in glucoamylase-complex structures (Aleshin et al. (1996), *Biochemistry* **35**, 8319-8328) and residues important for binding and catalysis have been extensively investigated using site-directed mutants coupled with kinetic analysis (Sierks et al. (1989), *Protein Engng.* **2**, 621-625; Sierks et al. (1990), *Protein Engng.* **3**, 193-198; Berland et al. (1995), *Biochemistry*, **34**, 10153-10161; Frandsen et al. (1995), *Biochemistry*, **34**, 10162-10169).

Different substitutions in *A. niger* glucoamylase to enhance the thermal stability have been described: i) substitution of alpha-helical glycines: G137A and G139A (Chen et al. (1996), *Prot. Engng.* **9**, 499-505); ii) elimination of the fragile Asp-X peptide bonds, D257E and D293E/Q (Chen et al. (1995), *Prot. Engng.* **8**, 575-582); prevention of deamidation in N182 (Chen et al. (1994), *Biochem. J.* **301**, 275-281); iv) engineering of additional disulphide bond, A246C (Fierobe et al. (1996), *Biochemistry*, **35**, 8698-8704; and v)

introduction of Pro residues in position A435 and S436 (Li et al. (1997), *Protein Engng.* 10, 1199-1204. Furthermore Clark Ford presented a paper on Oct 17, 1997, ENZYME ENGINEERING 14, Beijing/China Oct 12-17, 97, Abstract number: Abstract book p. 5 0-61. The abstract suggests mutations in positions G137A, N20C/A27C, and S30P in (not disclosed) *Aspergillus awamori* glucoamylase to improve the thermal stability.

Additional information concerning glucoamylase can be found on an Internet homepage
10 (<http://www.public.iastate.edu/~pedro/glase/glase.html>)
"Glucoamylase WWW page" (Last changed 97/10/08) by Pedro M. Coutinho discloses informations concerning glucoamylases, including glucoamylases derivable from *Aspergillus* strains. Chemical and site-directed modifications in the *Aspergillus*
15 *niger* glucoamylase are listed.

BRIEF DISCLOSURE OF THE INVENTION

The object of the present invention is to provide glucoamylase variants suitable for used in, e.g., the
20 saccharification step in starch conversion processes.

A term "a thermostable glucoamylase variant" means in the context of the present invention a glucoamylase variant, which has a higher $T_{1/2}$ (half-time) in comparison to a corresponding parent glucoamylase. The determination of $T_{1/2}$ (Method I and
25 Method II) is described below in the "Materials & Methods" section.

The term "a glucoamylase variant with increased specific activity" means in the context of the present invention a glucoamylase variant with increased specific activity towards
30 the alpha-1,4 linkages in the saccharide in question. The specific activity is determined as k_{cat} or AGU/mg (measured as described below in the "Materials & Methods" section). An increased specific activity means that the k_{cat} or AGU/mg values are higher when compared to the k_{cat} or AGU/mg values,
35 respectively, of the corresponding parent glucoamylase.

The inventors of the present invention have provided a number of variants of a parent glucoamylase with improved

thermal stability and/or increased specific activity. The improved thermal stability is obtained by mutating, e.g., by substituting and/or deleting, inserting selected positions in a parent glucoamylase. This will be described in details below.

5

Nomenclature

In the present description and claims, the conventional one-letter and three-letter codes for amino acid residues are used.

10 For ease of reference, AMG variants of the invention are described by use of the following nomenclature:

Original amino acid(s):position(s):substituted amino acid(s)

According to this nomenclature, for instance the substitution of alanine for asparagine in position 30 is shown

15 as:

Ala30Asn or A30N

a deletion of alanine in the same position is shown as:

Ala30* or A30*

and insertion of an additional amino acid residue, such as

20 lysine, is shown as:

Ala30AlaLys or A30AK

A deletion of a consecutive stretch of amino acid residues, such as amino acid residues 30-33, is indicated as (30-33)* or Δ (A30-N33).

25 Where a specific AMG contains a "deletion" in comparison with other AMG and an insertion is made in such a position this is indicated as:

*36Asp or *36D

for insertion of an aspartic acid in position 36

30 Multiple mutations are separated by plus signs, i.e.:

Ala30Asp + Glu34Ser or A30N+E34S

representing mutations in positions 30 and 34 substituting alanine and glutamic acid for asparagine and serine, respectively. Multiple mutations may also be separated as

35 follows, i.e., meaning the same as the plus sign:

Ala30Asp/Glu34Ser or A30N/E34S

When one or more alternative amino acid residues may be inserted in a given position it is indicated as

A30N,E or A30N/E, or A30N or A30E

Furthermore, when a position suitable for modification is identified herein without any specific modification being suggested, it is to be understood that any amino acid residue may be substituted for the amino acid residue present in the position. Thus, for instance, when a modification of an alanine in position 30 is mentioned, but not specified, it is to be understood that the alanine may be deleted or substituted for any other amino acid, i.e., any one of:

R,N,D,A,C,Q,E,G,H,I,L,K,M,F,P,S,T,W,Y,V.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows the plasmid pCAMG91 containing the *Aspergillus niger* G1 glucoamylase gene.

DETAILED DISCLOSURE OF THE INVENTION

A goal of the work underlying the present invention was to improve the thermal stability and/or increase the specific activity of particular glucoamylases, which are obtainable from fungal organisms, in particular strain of the *Aspergillus* genus and which themselves had been selected on the basis of their suitable properties in, e.g., starch conversion or alcohol fermentation.

In this connection, the present inventors have surprisingly found that it is in fact possible to improve the thermal stability and/or increased specific activity of parent glucoamylases by modification of one or more amino acid residues of the amino acid sequence of the parent glucoamylase. The present invention is based on this finding.

Accordingly, in a first aspect the present invention relates to a variant of a parent glucoamylase comprising one or more mutations in the positions described further below.

Parent Glucoamylases

Parent glucoamylase contemplated according to the present invention include wild-type glucoamylases, fungal glucoamylases, in particular fungal glucoamylases obtainable from an *Aspergillus* strain, such as an *Aspergillus niger* or
5 *Aspergillus awamori* glucoamylases and variants or mutants thereof, homologous glucoamylases, and further glucoamylases being structurally and/or functionally similar to SEQ ID NO:2. Specifically contemplated are the *Aspergillus niger* glucoamylases G1 and G2 disclosed in Boel et al. (1984),
10 "Glucoamylases G1 and G2 from *Aspergillus niger* are synthesized from two different but closely related mRNAs", EMBO J. 3 (5), p. 1097-1102. The G2 glucoamylase is disclosed in SEQ ID NO: 2. In another embodiment the AMG backbone is derived from *Talaromyces*, in particular *T. emersonii* disclosed
15 in WO 99/28448 (See SEQ ID NO: 7 of WO 99/28448).

Commercial Parent Glucoamylases

Contemplated commercially available parent glucoamylases include AMG from Novo Nordisk, and also glucoamylase from the
20 companies Genencor, Inc. USA, and Gist-Brocades, Delft, The Netherlands.

Glucoamylase variants of the invention

In the first aspect, the invention relates to a variant of
25 a parent glucoamylase, comprising an alteration at one or more of the following positions: 59, 66, 72, 119, 189, 223, 227, 313, 340, 342, 352, 379, 386, 393, 395, 402, 408, 416, 425, 427, 444, 486, 490, 494,
wherein (a) the alteration is independently
30 (i) an insertion of an amino acid downstream of the amino acid which occupies the position,
(ii) a deletion of the amino acid which occupies the position, or
(iii) a substitution of the amino acid which occupies the
35 position with a different amino acid,
(b) the variant has glucoamylase activity and (c) each position corresponds to a position of the amino acid sequence of the

parent glucoamylase having the amino acid sequence of SEQ ID NO: 2.

Further, the invention relates to a variant of a parent glucoamylase which parent glucoamylase has an amino acid
 5 sequence which has a degree of identity to the amino acid sequence of SEQ ID NO: 2 of at least about 65%, preferably at least about 70%, more preferably at least about 80%, even more preferably at least about 90%, most preferably at least about 95%, and even most preferably at least about 97%.

10 The invention also relates to a variant of a parent glucoamylase, comprising one or more of the following: V59A, L66V/R, T72I, S119P, I189T, Y223F, F227Y, N313G, S340G, E342A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,T,W,Y,V, preferably E342T, K352R, S356G, T379A, S386K,N,R,P, A393R, S395R, Y402F, E408R,
 15 T416A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,E,W,Y,V preferably T416H, A425T, N427S/M, S444G, S486G, T490A, T494P/A, wherein (a) the variant has glucoamylase activity and (b) each position corresponds to a position of the amino acid sequence of the parent glucoamylase having the amino acid sequence of SEQ ID
 20 NO: 2.

Specific combinations of mutations include:

L66R+Y402F+N427S+S486G+A1V; N427M+S44G+V470M+T2K+S30P;
 T416H+Y402F+312Q+S119P; A425T+E408R+E386K+A495T;
 T379A+T2E+S386K+A393R; S386N+E408R; L66V+T2R+S394P+Y402F+RL;
 25 S386R+T2R+A393R;I189T+Y223F+F227Y+S119P+Y402F;
 S386P+S340G+D357S+T360V; V59A+S119P; V59A+N313G; V59A+A393R;
 V59A+Y402F; V59A+E408R; V59A+S119P+N313G; V59A+N313G+A393R;
 V59A+A393R+Y402F; V59A+Y402F+E408R; V59A+S119P+N313G+A393R;
 V59A+N313G+A393R+Y402F; V59A+A393R+Y402F+E408R;
 30 V59A+S119P+N313G+A393R+Y402F; V59A+N313G+A393R+Y402F+E408R;
 V59A+S119P+L66R; V59A+S119P+S340G; V59A+S119P+S395R;
 V59A+S119P+L66R+S340G; V59A+S119P+S340G+S395R;
 V59A+S119P+S395R+L66R; V59A+S119P+S395R+L66R+S340G;
 V59A+N313G+L66R; V59A+N313G+S340G; V59A+N313G+S395R;
 35 V59A+N313G+L66R+S340G;V59A+N313G+S340G+S395R;
 V59A+N313G+S395R+L66R; V59A+N313G+S395R+L66R+S340G;
 V59A+A393R+L66R; V59A+A393R+S340G; V59A+A393R+S395R;

V59A+A393R+L66R+S340G; V59A+A393R+S340G+S395R;
V59A+A393R+S395R+L66R+S340G; V59A+Y402F+L66R;
V59A+Y402F+S340G; V59A+Y402F+S395R; V59A+Y402F+L66R+S395R;
V59A+Y402F+L66R+S340G;
5 V59A+Y402F+L66R+S395R+S340G; V59A+E408R+L66R;
V59A+E408R+S395R; V59A+E408R+S340G; V59A+E408R+S395R+S340G;
V59A+E408R+L66R+S340G; V59A+E408R+L66R+S395R;
V59A+E408R+L66R+S395R+S340G; V59A+S119P+N313G+L66R;
V59A+S119P+N313G+L66R+S340G; V59A+S119P+N313G+L66R+S395R;
10 V59A+S119P+N313G+L66R+S395R+S340G; V59A+N313G+A393R+ L66R;
V59A+N313G+A393R+ L66R+S395R; V59A+N313G+A393R+ L66R+S340G;
V59A+N313G+A393R+ L66R+S340G+S395R; V59A+A393R+Y402F;
V59A+Y402F+E408R; V59A+S119P+N313G+A393R;
V59A+N313G+A393R+Y402F; V59A+A393R+Y402F+E408R;
15 V59A+S119P+N313G+A393R+Y402F;
V59A+N313G+A393R+Y402F+E408R;
S119P+N313G; N313G+A393R; A393R+Y402F; Y402F+E408R;
S119P+N313G+A393R; N313G+A393R+Y402F; A393R+Y402F+E408R;
V59A+S119P+N313G+A393R+Y402F; N313G+A393R+Y402F+E408R;
20 S119P+L66R; V59A+S119P+S340G; S119P+S395R; S119P+L66R+S340G;
S119P+S340G+S395R; S119P+S395R+L66R; S119P+S395R+L66R+S340G;
N313G+L66R; N313G+S340G; N313G+S395R; N313G+L66R+S340G;
N313G+S340G+S395R; N313G+S395R+L66R; N313G+S395R+L66R+S340G;
A393R+L66R; A393R+S340G; A393R+S395R; A393R+L66R+S340G;
25 A393R+S340G+S395R; A393R+S395R+L66R+S340G; Y402F+L66R;
Y402F+S340G; Y402F+S395R; Y402F+L66R+S395R; Y402F+L66R+S340G;
Y402F+L66R+S395R+S340G; E408R+L66R; E408R+S395R; E408R+S340G;
E408R+S395R+S340G; E408R+L66R+S340G; E408R+L66R+S395R;
E408R+L66R+S395R+S340G; S119P+N313G+L66R;
30 S119P+N313G+L66R+S340G; S119P+N313G+L66R+S395R;
S119P+N313G+L66R+S395R+S340G; N313G+A393R+L66R;
N313G+A393R+L66R+S395R; N313G+A393R+ L66R+S340G; N313G+A393R+
L66R+S340G+S395R; A393R+Y402F; Y402F+E408R;
V59A+S119P+N313G+A393R; N313G+A393R+Y402F; A393R+Y402F+E408R;
35 S119P+N313G+A393R+Y402F; N313G+A393R+Y402F+E408R.
V59A+S119P+S340G; S119P+S395R; S119P+S340G; S119P+S340G+S395R;
S119P+S395R; S119P+S395R+S340G; N313G+S340G; N313P+S395R;

N313G+S340G; N313G+S395R; N313G+S395R+S340G; A393R+S340G;
A393R+S395R+S340G; Y402F+S395R; Y402F+S340G;
Y402F+S395R+S340G; E408R+S340G; E408R+S395R;
E408R+S395R+S340G; S119P+N313G; S119P+N313G+S340G;
5 S119P+N313G+S395R; S119P+N313G+S395R+S340G; N313G+A393R;
N313G+A393R+S395R; N313G+A393R+S340G; N313G+A393R+
S340G+S395R; .
N313G+A393R; V59A+N313G+A393R+Y402F; V59A+S340G; L66R+S340G;
S340G+S395R; S395R+L66R; S395R+L66R+S340G; N313G+L66R;
10 N313G+L66R+S340G; N313G+L66R+S395R; N313G+L66R+S395R+S340G;
V59A+N313G+A393R; N313G+A393R+Y402F;
S119P+A393R; A393R+Y402F; V59A+S119P+A393R+Y402F;
A393R+Y402F+E408R; S119P+S395R+L66R+S340G; L66R+S340G;
S340G+S395R; S395R+L66R; S395R+L66R+S340G; S119P+L66R;
15 S119P+L66R+S340G; S119P+L66R+S395R; S119P+L66R+S395R+S340G;
A393R+ L66R; A393R+L66R+S395R; A393R+ L66R+S340G; A393R+
L66R+S340G+S395R; V59A+S119P+A393R; A393R+Y402F;
S119P+A393R+Y402F; A393R+Y402F+E408R;
S119P+N313G; N313G+Y402F; Y402F+E408R; V59A+S119P+N313G+Y402F;
20 N313G+Y402F+E408R; L66R+S340G; S340G+S395R; S395R+L66R+S340G;
N313G+L66R; N313G+L66R+S395R; N313G+L66R+S340G;
N313G+L66R+S340G+S395R;
V59A+S119P+N313G; N313G+Y402F; Y402F+E408R; S119P+N313G+Y402F;
N313G+Y402F+E408R.
25 S119P+S340G; S119P+L66R; S119P+L66R+S340G; N313G+S340G;
N313G+L66R; N313G+L66R+S340G; A393R+S340G; A393R+L66R+S340G;
Y402F+L66R; Y402F+L66R+S340G; Y402F+L66R+S340G; E408R+S340G;
E408R+L66R; E408R+L66R+S340G;
S119P+N313G+L66R; S119P+N313G+L66R+S340G; N313G+A393R+L66R;
30 N313G+A393R+ L66R+S340G;
N313G+A393R; A393R+E408R; V59A+S119P+N313G+A393R;
N313G+A393R+E408R;
L66R+S395R; L66R+S340G; L66R+S395R+S340G; N313G+A393R;
A393R+E408R; S119P+N313G+A393R; N313G+A393R+E408R.
35 A393R+Y402F; N313G+A393R+Y402F; S395R+S340G; L66R+S340G;
L66R+S395R; L66R+S395R+S340G; A393R+Y402F; N313G+A393R+Y402F.
S119P+L66R; V59A+S119P; S119P+S395R; S119P+L66R; S119P+S395R;

10

S119P+S395R+L66R; N313G+L66R; N313G+S395R; N313G+S395R+L66R;
 A393R+L66R; A393R+S395R; A393R+S395R+L66R; Y402F+L66R;
 Y402F+L66R+S395R; E408R+S395R; E408R+L66R; E408R+L66R+S395R;
 S119P+N313G+L66R; S119P+N313G+L66R+S395R; N313G+A393R+L66R;
 5 N313G+A393R+L66R+S395R;
 N9A+S56A+V59A+S119P+A246T+N313G+E342T+A393R+S394R+Y402F+E408R;
 S56A+V59A+S119P+A246T+N313G+E342T+A393R+S394R+Y402F+E408R;
 V59A+S119P+A246T+N313G+E342T+A393R+S394R+Y402F+E408R;
 S119P+A246T+N313G+E342T+A393R+S394R+Y402F+E408R;
 10 A246T+N313G+E342T+A393R+S394R+Y402F+E408R;
 N313G+E342T+A393R+S394R+Y402F+E408R;
 E342T+A393R+S394R+Y402F+E408R;
 A393R+S394R+Y402F+E408R; S394R+Y402F+E408R; Y402F+E408R;
 V59A+L66R+T72I+S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M
 15 ;
 L66R+T72I+S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M;
 T72I+S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M;
 S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M;
 N313G+S340G+S356G+A393R+Y402F+E408R+N427M;
 20 S340G+S356G+A393R+Y402F+E408R+N427M;
 S356G+A393R+Y402F+E408R+N427M; A393R+Y402F+E408R+N427M;
 Y402F+E408R+N427M; E408R+N427M;
 I189T+Y223F+F227Y+S119P+Y402F; Y223F+F227Y+S119P+Y402F;
 F227Y+S119P+Y402F; S119P+Y402F; I189T+Y223F+F227Y+Y402F;
 25 I189T+Y223F+F227Y; I189T+Y223F; I189T+F227Y; I189T+F227Y+S119P;
 I189T+F227Y+Y402F; Y223F+F227Y+Y402F; Y223F+F227Y+S119P.

The invention also relates to a variant of a parent
 glucoamylase which parent glucoamylase is encoded by a nucleic
 acid sequence which hybridizes under medium, more preferably
 30 high stringency conditions, with the nucleic acid sequence of
 SEQ ID NO: 1 or its complementary strand.

Improved thermal stability

In still another aspect, the invention relates to a variant
 35 of a parent glucoamylase with improved thermal stability, in
 particular in the range from 40-80°C, preferably 63-75°C, in

particular at pH 4-5, using maltodextrin as the substrate, said variant comprising one or more mutations in the following positions in the amino acid sequence shown in SEQ ID NO: 2: 59, 66, 72, 119, 189, 223, 227, 313, 340, 342, 352, 379, 386, 393, 5 395, 402, 408, 416, 425, 427, 444, 486, 490, 494, or in a corresponding position in a homologous glucoamylase which displays at least 60% homology with the amino acid sequences shown in SEQ ID NO: 2.

Specific substitutions contemplated to give improved thermal stability including: V59A, L66V/R, T72I, S119P, I189T, Y223F, F227Y, N313G, S340G, E342A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,T,W,Y,V, preferably E342T, K352R, S356G, T379A, S386K,N,R,P, A393R, S395R, Y402F, E408R, T416A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,E,W,Y,V, preferably T416H, 15 A425T, N427S/M, S444G, S486G, T490A, T494P/A.

Specific combinations of mutations include:

E408R+A425T+S465P+T494A,
A425T+E408R+S386K+A495T,
T379A+T2E+S386K+A393R,
20 S386N+E408R,
L66V+T2R+S394P+Y402F+RL(N-terminal extension),
S386R+T2R+A393R.
N427S+S486G+A1V+L66R+Y402F,
N427M+S44G+V470M+T2K+S30P,
25 T490A+V59A++A393R+PLASD(N-terminal extension)

All of the variant listed in the section "Glucoamylase variants of the invention" are contemplated to have improved thermostability. Examples 2 and 4 show this for selected variants of the invention.

30

Increased Specific Activity

In still another aspect, the invention relates to a variant of a parent glucoamylase with improved specific activity, said variant comprising one or more mutations in the following positions in the amino acid sequence shown in SEQ ID NO: 2: 59, 66, 72, 119, 189, 223, 227, 313, 340, 342, 352, 379, 386, 393, 395, 402, 408, 416, 425, 427, 444, 486, 490,

494, preferably 189, 223, 227 or in a corresponding position in a homologous glucoamylase which displays at least 60% homology with the amino acid sequences shown in SEQ ID NO: 2.

Specific mutations contemplated to give increased specific activity include: V59A, L66V/R, T72I, S119P, I189T, Y223F, F227Y, N313G, S340G, , K352R, S356G, T379A, S386K,N,R,P, A393R, S395R, Y402F, E408R, T416A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,E,W,Y,V preferably T416H, A425T, N427S/M, S444G S486G, T490A, T494P/A, preferably I189T, Y223F, F227Y.

Specific combinations of mutations include:

I189T+Y223F+F227Y+S119P+Y402F;
Y223F+F227Y+S119P+Y402F; F227Y+S119P+Y402F; S119P+Y402F;
I189T+Y223F+F227Y+Y402F; I189T+Y223F+F227Y; I189T+Y223F;
I189T+F227Y; I189T+F227Y+S119P; I189T+F227Y+Y402F;
Y223F+F227Y+Y402F; Y223F+F227Y+S119P.

All of the variant listed in the section "Glucoamylase variants of the invention" are contemplated to have increased specific activity. Example 3 shows this for a selected variant of the invention.

Homology (identity)

The homology referred to above of the parent glucoamylase is determined as the degree of identity between two protein sequences indicating a derivation of the first sequence from the second. The homology may suitably be determined by means of computer programs known in the art such as GAP provided in the GCG program package (Program Manual for the Wisconsin Package, Version 8, August 1994, Genetics Computer Group, 575 Science Drive, Madison, Wisconsin, USA 53711) (Needleman, S.B. and Wunsch, C.D., (1970), Journal of Molecular Biology, 48, p. 443-453). Using GAP with the following settings for polypeptide sequence comparison: GAP creation penalty of 3.0 and GAP extension penalty of 0.1, the mature part of a polypeptide encoded by an analogous DNA sequence of the invention exhibits a degree of identity preferably of at least 80%, at least 90%, more preferably at least 95%, more

preferably at least 97%, and most preferably at least 99% with the mature part of the amino acid sequence shown in SEQ ID NO: 2.

In an embodiment the parent glucoamylase is the
5 *Aspergillus niger* G1 glucoamylase (Boel et al. (1984), EMBO J. 3 (5), p. 1097-1102 (SEQ ID NO: 13). The parent glucoamylase may be a truncated glucoamylase, e.g., the *A. niger* G2 glucoamylase (SEQ ID NO: 2).

Preferably, the parent glucoamylase comprises the amino
10 acid sequences of SEQ ID NO: 2; or allelic variants thereof; or a fragment thereof that has glucoamylase activity.

A fragment of SEQ ID NO: 2 is a polypeptide which has one or more amino acids deleted from the amino and/or carboxyl terminus of this amino acid sequence. For instance, the AMG G2
15 (SEQ ID NO: 2) is a fragment of the *Aspergillus niger* G1 glucoamylase (Boel et al. (1984), EMBO J. 3 (5), p. 1097-1102) having glucoamylase activity. An allelic variant denotes any of two or more alternative forms of a gene occupying the same chromosomal locus. Allelic variation arises naturally through
20 mutation, and may result in polymorphism within populations. Gene mutations can be silent (no change in the encoded polypeptide) or may encode polypeptides having altered amino acid sequences. An allelic variant of a polypeptide is a polypeptide encoded by an allelic variant of a gene.

25 The amino acid sequences of homologous parent glucoamylases may differ from the amino acid sequence of SEQ ID NO: 2 by an insertion or deletion of one or more amino acid residues and/or the substitution of one or more amino acid residues by different amino acid residues. Preferably, amino
30 acid changes are of a minor nature, that is conservative amino acid substitutions that do not significantly affect the folding and/or activity of the protein; small deletions, typically of one to about 30 amino acids; small amino- or carboxyl-terminal extensions, such as an amino-terminal
35 methionine residue; a small linker peptide of up to about 20-25 residues; or a small extension that facilitates purification by changing net charge or another function, such

as a poly-histidine tract, an antigenic epitope or a binding domain.

In another embodiment, the isolated parent glucoamylase is encoded by a nucleic acid sequence which hybridises under very low stringency conditions, preferably low stringency conditions, more preferably medium stringency conditions, more preferably medium-high stringency conditions, even more preferably high stringency conditions, and most preferably very high stringency conditions with a nucleic acid probe which hybridises under the same conditions with (i) the nucleic acid sequence of SEQ ID NO: 1, (ii) the cDNA sequence of SEQ ID NO:1, (iii) a sub-sequence of (i) or (ii), or (iv) a complementary strand of (i), (ii), or (iii) (J. Sambrook, E.F. Fritsch, and T. Maniatus, 1989, *Molecular Cloning, A Laboratory Manual*, 2d edition, Cold Spring Harbor, New York).

The sub-sequence of SEQ ID NO: 1 may be at least 100 nucleotides or preferably at least 200 nucleotides. Moreover, the sub-sequence may encode a polypeptide fragment, which has glucoamylase activity. The parent polypeptides may also be allelic variants or fragments of the polypeptides that have glucoamylase activity.

The nucleic acid sequence of SEQ ID NO: 1 or a subsequence thereof, as well as the amino acid sequence of SEQ ID NO: 2, or a fragment thereof, may be used to design a nucleic acid probe to identify and clone DNA encoding polypeptides having glucoamylase activity, from strains of different genera or species according to methods well known in the art. In particular, such probes can be used for hybridization with the genomic or cDNA of the genus or species of interest, following standard Southern blotting procedures, in order to identify and isolate the corresponding gene therein. Such probes can be considerably shorter than the entire sequence, but should be at least 15, preferably at least 25, and more preferably at least 35 nucleotides in length. Longer probes can also be used. Both DNA and RNA probes can be used. The probes are typically labeled for detecting the corresponding gene (for

example, with ^{32}P , ^3H , ^{35}S , biotin, or avidin). Such probes are encompassed by the present invention.

Thus, a genomic DNA or cDNA library prepared from such other organisms may be screened for DNA, which hybridizes with the probes described above and which encodes a polypeptide having glucoamylase. Genomic or other DNA from such other organisms may be separated by agarose or polyacrylamide gel electrophoresis, or other separation techniques. DNA from the libraries or the separated DNA may be transferred to and immobilised on nitrocellulose or other suitable carrier material. In order to identify a clone or DNA which is homologous with SEQ ID NO: 1, or sub-sequences thereof, the carrier material is used in a Southern blot. For purposes of the present invention, hybridisation indicates that the nucleic acid sequence hybridises to a nucleic acid probe corresponding to the nucleic acid sequence shown in SEQ ID NO: 1 its complementary strand, or a sub-sequence thereof, under very low to very high stringency conditions. Molecules to which the nucleic acid probe hybridises under these conditions are detected using X-ray film.

For long probes of at least 100 nucleotides in length, the carrier material is finally washed three times each for 15 minutes using 2 x SSC, 0.2% SDS preferably at least at 45°C (very low stringency), more preferably at least at 50°C (low stringency), more preferably at least at 55°C (medium stringency), more preferably at least at 60°C (medium-high stringency), even more preferably at least at 65°C (high stringency), and most preferably at least at 70°C (very high stringency).

For short probes which are about 15 nucleotides to about 70 nucleotides in length, stringency conditions are defined as prehybridization, hybridisation, and washing post-hybridisation at 5°C to 10°C below the calculated T_m using the calculation according to Bolton and McCarthy (1962, *Proceedings of the National Academy of Sciences USA* 48:1390) in 0.9 M NaCl, 0.09 M Tris-HCl pH 7.6, 6 mM EDTA, 0.5% NP-40, 1X Denhardt's solution, 1 mM sodium pyrophosphate, 1 mM sodium

monobasic phosphate, 0.1 mM ATP, and 0.2 mg of yeast RNA per ml following standard Southern blotting procedures.

For short probes, which are about 15 nucleotides to about 70 nucleotides in length, the carrier material is washed once
5 in 6X SCC plus 0.1% SDS for 15 minutes and twice each for 15 minutes using 6X SSC at 5°C to 10°C below the calculated T_m .

The present invention also relates to isolated nucleic acid sequences produced by (a) hybridising a DNA under very low, low, medium, medium-high, high, or very high stringency
10 conditions with the sequence of SEQ ID NO:1, or its complementary strand, or a sub-sequence thereof; and (b) isolating the nucleic acid sequence. The sub-sequence is preferably a sequence of at least 100 nucleotides such as a sequence, which encodes a polypeptide fragment, which has
15 glucoamylase activity.

Contemplated parent glucoamylases have at least 20%, preferably at least 40%, more preferably at least 60%, even more preferably at least 80%, even more preferably at least 90%, and most preferably at least 100% of the glucoamylase
20 activity of the mature glucoamylase of SEQ ID NO: 2.

Cloning A DNA Sequence Encoding A Parent Glucoamylase

The DNA sequence encoding a parent glucoamylase may be isolated from any cell or microorganism producing the
25 glucoamylase in question, using various methods well known in the art. First, a genomic DNA and/or cDNA library should be constructed using chromosomal DNA or messenger RNA from the organism that produces the glucoamylase to be studied. Then, if the amino acid sequence of the glucoamylase is known, labeled
30 oligonucleotide probes may be synthesized and used to identify glucoamylase-encoding clones from a genomic library prepared from the organism in question. Alternatively, a labelled oligonucleotide probe containing sequences homologous to another known glucoamylase gene could be used as a probe to identify
35 glucoamylase-encoding clones, using hybridization and washing conditions of very low to very high stringency. This is described above.

Yet another method for identifying glucoamylase-encoding clones would involve inserting fragments of genomic DNA into an expression vector, such as a plasmid, transforming glucoamylase-negative bacteria with the resulting genomic DNA library, and then plating the transformed bacteria onto agar containing a substrate for glucoamylase (*i.e.*, maltose), thereby allowing clones expressing the glucoamylase to be identified.

Alternatively, the DNA sequence encoding the enzyme may be prepared synthetically by established standard methods, *e.g.* the phosphoroamidite method described S.L. Beaucage and M.H. Caruthers, (1981), Tetrahedron Letters 22, p. 1859-1869, or the method described by Matthes et al., (1984), EMBO J. 3, p. 801-805. In the phosphoroamidite method, oligonucleotides are synthesized, *e.g.*, in an automatic DNA synthesizer, purified, annealed, ligated and cloned in appropriate vectors.

Finally, the DNA sequence may be of mixed genomic and synthetic origin, mixed synthetic and cDNA origin or mixed genomic and cDNA origin, prepared by ligating fragments of synthetic, genomic or cDNA origin (as appropriate, the fragments corresponding to various parts of the entire DNA sequence), in accordance with standard techniques. The DNA sequence may also be prepared by polymerase chain reaction (PCR) using specific primers, for instance as described in US 4,683,202 or R.K. Saiki et al., (1988), Science 239, 1988, pp. 487-491.

Site-directed mutagenesis

Once a glucoamylase-encoding DNA sequence has been isolated, and desirable sites for mutation identified, mutations may be introduced using synthetic oligonucleotides. These oligonucleotides contain nucleotide sequences flanking the desired mutation sites. In a specific method, a single-stranded gap of DNA, the glucoamylase-encoding sequence, is created in a vector carrying the glucoamylase gene. Then the synthetic nucleotide, bearing the desired mutation, is annealed to a homologous portion of the single-stranded DNA. The remaining

gap is then filled in with DNA polymerase I (Klenow fragment) and the construct is ligated using T4 ligase. A specific example of this method is described in Morinaga et al., (1984), *Biotechnology* 2, p. 646-639. US 4,760,025 disclose the
5 introduction of oligonucleotides encoding multiple mutations by performing minor alterations of the cassette. However, an even greater variety of mutations can be introduced at any one time by the Morinaga method, because a multitude of oligonucleotides, of various lengths, can be introduced.

10 Another method for introducing mutations into glucoamylase-encoding DNA sequences is described in Nelson and Long, (1989), *Analytical Biochemistry* 180, p. 147-151. It involves the 3-step generation of a PCR fragment containing the desired mutation introduced by using a chemically synthesized
15 DNA strand as one of the primers in the PCR reactions. From the PCR-generated fragment, a DNA fragment carrying the mutation may be isolated by cleavage with restriction endonucleases and reinserted into an expression plasmid.

Further, Sierks. et al., (1989) "Site-directed mutagenesis
20 at the active site Trp120 of *Aspergillus awamori* glucoamylase. *Protein Eng.*, 2, 621-625; Sierks et al., (1990), "Determination of *Aspergillus awamori* glucoamylase catalytic mechanism by site-directed mutagenesis at active site Asp176, Glu179, and Glu180". *Protein Eng.* vol. 3, 193-198; also describes site-
25 directed mutagenesis in an *Aspergillus* glucoamylase.

Localized random mutagenesis

The random mutagenesis may be advantageously localized to a part of the parent glucoamylase in question. This may, e.g., be
30 advantageous when certain regions of the enzyme have been identified to be of particular importance for a given property of the enzyme, and when modified are expected to result in a variant having improved properties. Such regions may normally be identified when the tertiary structure of the parent enzyme
35 has been elucidated and related to the function of the enzyme.

The localized, or region-specific, random mutagenesis is conveniently performed by use of PCR generated mutagenesis

techniques as described above or any other suitable technique known in the art. Alternatively, the DNA sequence encoding the part of the DNA sequence to be modified may be isolated, e.g., by insertion into a suitable vector, and said part may be
5 subsequently subjected to mutagenesis by use of any of the mutagenesis methods discussed above.

Alternative methods for providing variants of the invention include gene shuffling, e.g., as described in WO 95/22625 (from Affymax Technologies N.V.) or in WO 96/00343 (from Novo Nordisk
10 A/S).

Expression of glucoamylase variants

According to the invention, a DNA sequence encoding the variant produced by methods described above, or by any alternative methods known in the art, can be expressed, in enzyme
15 form, using an expression vector which typically includes control sequences encoding a promoter, operator, ribosome binding site, translation initiation signal, and, optionally, a repressor gene or various activator genes.

20

Expression vector

The recombinant expression vector carrying the DNA sequence encoding a glucoamylase variant of the invention may be any vector, which may conveniently be subjected to recombinant DNA
25 procedures, and the choice of vector will often depend on the host cell into which it is to be introduced. The vector may be one which, when introduced into a host cell, is integrated into the host cell genome and replicated together with the chromosome(s) into which it has been integrated. Examples of
30 suitable expression vectors include pMT838.

Promoter

In the vector, the DNA sequence should be operably connected to a suitable promoter sequence. The promoter may be any DNA
35 sequence, which shows transcriptional activity in the host cell of choice and may be derived from genes encoding proteins either homologous or heterologous to the host cell.

Examples of suitable promoters for directing the transcription of the DNA sequence encoding a glucoamylase variant of the invention, especially in a bacterial host, are the promoter of the *lac* operon of *E.coli*, the *Streptomyces coelicolor* agarase gene *dagA* promoters, the promoters of the *Bacillus licheniformis* alpha-amylase gene (*amyL*), the promoters of the *Bacillus stearothermophilus* maltogenic amylase gene (*amyM*), the promoters of the *Bacillus amyloliquefaciens* α -amylase (*amyQ*), the promoters of the *Bacillus subtilis* *xylA* and *xylB* genes etc. For transcription in a fungal host, examples of useful promoters are those derived from the gene encoding *A. oryzae* TAKA amylase, the TPI (triose phosphate isomerase) promoter from *S. cerevisiae* (Alber et al. (1982), J. Mol. Appl. Genet 1, p. 419-434, *Rhizomucor miehei* aspartic proteinase, *A. niger* neutral alpha-amylase, *A. niger* acid stable alpha-amylase, *A. niger* glucoamylase, *Rhizomucor miehei* lipase, *A. oryzae* alkaline protease, *A. oryzae* triose phosphate isomerase or *A. nidulans* acetamidase.

20 Expression vector

The expression vector of the invention may also comprise a suitable transcription terminator and, in eukaryotes, polyadenylation sequences operably connected to the DNA sequence encoding the alpha-amylase variant of the invention. Termination and polyadenylation sequences may suitably be derived from the same sources as the promoter.

The vector may further comprise a DNA sequence enabling the vector to replicate in the host cell in question. Examples of such sequences are the origins of replication of plasmids pUC19, pACYC177, pUB110, pE194, pAMB1 and pIJ702.

The vector may also comprise a selectable marker, e.g. a gene the product of which complements a defect in the host cell, such as the *dal* genes from *B. subtilis* or *B. licheniformis*, or one which confers antibiotic resistance such as ampicillin, kanamycin, chloramphenicol or tetracycline resistance. Furthermore, the vector may comprise *Aspergillus*

selection markers such as *amdS*, *argB*, *niaD* and *sC*, a marker giving rise to hygromycin resistance, or the selection may be accomplished by co-transformation, e.g., as described in WO 91/17243.

5 The procedures used to ligate the DNA construct of the invention encoding a glucoamylase variant, the promoter, terminator and other elements, respectively, and to insert them into suitable vectors containing the information necessary for replication, are well known to persons skilled in the art (cf.,
10 for instance, Sambrook et al., Molecular Cloning: A Laboratory Manual, 2nd Ed., Cold Spring Harbor, 1989).

Host Cells

The cell of the invention, either comprising a DNA construct
15 or an expression vector of the invention as defined above, is advantageously used as a host cell in the recombinant production of a glucoamylase variant of the invention. The cell may be transformed with the DNA construct of the invention encoding the variant, conveniently by integrating the DNA construct (in
20 one or more copies) in the host chromosome. This integration is generally considered to be an advantage as the DNA sequence is more likely to be stably maintained in the cell. Integration of the DNA constructs into the host chromosome may be performed according to conventional methods, e.g. by homologous or
25 heterologous recombination. Alternatively, the cell may be transformed with an expression vector as described above in connection with the different types of host cells.

The cell of the invention may be a cell of a higher organism such as a mammal or an insect, but is preferably a microbial
30 cell, e.g., a bacterial or a fungal (including yeast) cell.

Examples of suitable bacteria are Gram positive bacteria such as *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus lentus*, *Bacillus brevis*, *Bacillus stearothermophilus*, *Bacillus alkalophilus*, *Bacillus amyloliquefaciens*, *Bacillus coagulans*,
35 *Bacillus circulans*, *Bacillus lautus*, *Bacillus megaterium*, *Bacillus thuringiensis*, or *Streptomyces lividans* or *Streptomyces murinus*, or gramnegative bacteria such as *E.coli*. The trans-

formation of the bacteria may, for instance, be effected by protoplast transformation or by using competent cells in a manner known *per se*.

The yeast organism may favorably be selected from a species of *Saccharomyces* or *Schizosaccharomyces*, e.g., *Saccharomyces cerevisiae*.

The host cell may also be a filamentous fungus, e.g., a strain belonging to a species of *Aspergillus*, most preferably *Aspergillus oryzae* or *Aspergillus niger*, or a strain of *Fusarium*, such as a strain of *Fusarium oxysporium*, *Fusarium graminearum* (in the perfect state named *Gibberella zeae*, previously *Sphaeria zeae*, synonym with *Gibberella roseum* and *Gibberella roseum* f. sp. *cerealis*), or *Fusarium sulphureum* (in the perfect state named *Gibberella puricaris*, synonym with *Fusarium trichothecioides*, *Fusarium bactridioides*, *Fusarium sambucium*, *Fusarium roseum*, and *Fusarium roseum* var. *graminearum*), *Fusarium cerealis* (synonym with *Fusarium crockwellense*), or *Fusarium venenatum*.

In a preferred embodiment of the invention the host cell is a protease deficient or protease minus strain.

This may for instance be the protease deficient strain *Aspergillus oryzae* JaL 125 having the alkaline protease gene named "alp" deleted. This strain is described in WO 97/35956 (Novo Nordisk), or EP patent no. 429,490.

Filamentous fungi cells may be transformed by a process involving protoplast formation and transformation of the protoplasts followed by regeneration of the cell wall in a manner known *per se*. The use of *Aspergillus* as a host micro-organism is described in EP 238,023 (Novo Nordisk A/S), the contents of which are hereby incorporated by reference.

Method Of Producing Glucoamylase Variants

In a yet further aspect, the present invention relates to a method of producing a glucoamylase variant of the invention, which method comprises cultivating a host cell under conditions conducive to the production of the variant and recovering the variant from the cells and/or culture medium.

The medium used to cultivate the cells may be any conventional medium suitable for growing the host cell in question and obtaining expression of the glucoamylase variant of the invention. Suitable media are available from commercial
5 suppliers or may be prepared according to published recipes (e.g. as described in catalogues of the American Type Culture Collection).

The glucoamylase variant secreted from the host cells may conveniently be recovered from the culture medium by well-known
10 procedures, including separating the cells from the medium by centrifugation or filtration, and precipitating proteinaceous components of the medium by means of a salt such as ammonium sulphate, followed by the use of chromatographic procedures such as ion exchange chromatography, affinity chromatography,
15 or the like.

Starch conversion

The present invention provides a method of using glucoamylase variants of the invention for producing glucose
20 and the like from starch. Generally, the method includes the steps of partially hydrolyzing precursor starch in the presence of alpha-amylase and then further hydrolyzing the release of D-glucose from the non-reducing ends of the starch or related oligo- and polysaccharide molecules in the presence of
25 glucoamylase by cleaving alpha-(1→4) and alpha-(1→6) glucosidic bonds.

The partial hydrolysis of the precursor starch utilizing α -amylase provides an initial breakdown of the starch molecules by hydrolyzing internal alpha-(1→4)-linkages. In commercial
30 applications, the initial hydrolysis using alpha-amylase is run at a temperature of approximately 105°C. A very high starch concentration is processed, usually 30% to 40% solids. The initial hydrolysis is usually carried out for five minutes at this elevated temperature. The partially hydrolyzed starch can
35 then be transferred to a second tank and incubated for

approximately one hour at a temperature of 85° to 90°C to derive a dextrose equivalent (D.E.) of 10 to 15.

The step of further hydrolyzing the release of D-glucose from the non-reducing ends of the starch or related oligo- and polysaccharides molecules in the presence of glucoamylase is normally carried out in a separate tank at a reduced temperature between 30° and 60°C. Preferably the temperature of the substrate liquid is dropped to between 55°C and 60°C. The pH of the solution is dropped from 6 to 6.5 to a range between 3 and 5.5. Preferably, the pH of the solution is 4 to 4.5. The glucoamylase is added to the solution and the reaction is carried out for 24-72 hours, preferably 36-48 hours.

By using a thermostable glucoamylase variant of the invention saccharification processes may be carried out at a higher temperature than traditional batch saccharification processes. According to the invention saccharification may be carried out at temperatures in the range from above 60-80°C, preferably 63-75°C. This applied both for traditional batch processes (described above) and for continuous saccharification processes.

Actually, continuous saccharification processes including one or more membrane separation steps, *i.e.*, filtration steps, must be carried out at temperatures of above 60°C to be able to maintain a reasonably high flux over the membrane. Therefore, the thermostable variants of the invention provides the possibility of carrying out large scale continuous saccharification processes at a fair price within and period of time acceptable for industrial saccharification processes. According to the invention the saccharification time may even be shortened.

The activity of the glucoamylase variant (*e.g.*, AMG variant) of the invention is generally substantially higher at temperatures between 60°C-80°C than at the traditionally used temperature between 30-60°C. Therefore, by increasing the temperature at which the glucoamylase operates the

saccharification process may be carried out within a shorter period of time.

Further, by improving the thermal stability the $T_{1/2}$ (half-time, as defined in the "Materials and Methods" section) is improved. As the thermal stability of the glucoamylase variants of the invention is improved a minor amount of glucoamylase need to be added to replace the glucoamylase being inactivated during the saccharification process. More glucoamylase is maintained active during saccharification process according to the present invention. Furthermore, the risk of microbial contamination is also reduced when carrying the saccharification process at temperature above 63°C.

An example of saccharification process wherein the glucoamylase variants of the invention may be used include the processes described in JP 3-224493; JP 1-191693 ;JP 62-272987; and EP 452,238.

The glucoamylase variant(s) of the invention may be used in the present inventive process in combination with an enzyme that hydrolyzes only alpha-(1→6)-glucosidic bonds in molecules with at least four glucosyl residues. Preferentially, the glucoamylase variant of the invention can be used in combination with pullulanase or isoamylase. The use of isoamylase and pullulanase for debranching, the molecular properties of the enzymes, and the potential use of the enzymes with glucoamylase is set forth in G.M.A. van Beynum et al., Starch Conversion Technology, Marcel Dekker, New York, 1985, 101-142.

In a further aspect the invention relates to the use of a glucoamylase variant of the invention in a starch conversion process.

Further, the glucoamylase variant of the invention may be used in a continuous starch conversion process including a continuous saccharification step.

The glucoamylase variants of the invention may also be used in immobilised form. This is suitable and often used for producing maltodextrins or glucose syrups or speciality

syrups, such as maltose syrups, and further for the raffinate stream of oligosaccharides in connection with the production of fructose syrups.

According to the invention the AMG variant of the
5 invention may also be used for producing ethanol, e.g., for fuel or drinking. A contemplated method is described in US patent no. 5,231,017.

MATERIALS & METHODS**Enzymes:**

AMG G1: *Aspergillus niger* glucoamylase G1 disclosed in Boel et al., (1984), EMBO J. 3 (5), 1097-1102, (SEQ ID NO: 13),
5 available from Novo Nordisk.

AMG G2: Truncated *Aspergillus niger* glucoamylase G1 shown in SEQ ID NO: 2, available from Novo Nordisk)

Solutions:

10 Buffer: 0.05M sodium acetate (6.8g in 1 l milli-Q-water), pH 4.5

Stop solution: 0.4M NaOH

GOD-perid, 124036, Boehringer Mannheim

15 Substrate:

Maltose: 29mM (1g maltose in 100ml 50mM sodium acetate, pH 4.5) (Sigma)

Maltoheptaose: 10 mM, 115 mg/10 ml (Sigma)

20 Host cell:

A. oryzae JaL 125: *Aspergillus oryzae* IFO 4177 available from Institute for Fermentation, Osaka; 17-25 Juso Hammachi 2-Chome Yodogawa-ku, Osaka, Japan, having the alkaline protease gene named "alp" (described by Murakami K et al., (1991),
25 Agric. Biol. Chem. 55, p. 2807-2811) deleted by a one step gene replacement method (described by G. May in "Applied Molecular Genetics of Filamentous Fungi" (1992), p. 1-25. Eds. J. R. Kinghorn and G. Turner; Blackie Academic and Professional), using the *A. oryzae* pyrG gene as marker. Strain JaL 125 is
30 further disclosed in WO 97/35956 (Novo Nordisk).

Micro-organisms:

Strain: *Saccharomyces cerevisiae* YNG318: MAT α leu2- Δ 2 ura3-52 his4-539 pep4- Δ 1[cir+]

35

Plasmids:

pCAMG91: see Figure 1. Plasmid comprising the *Aspergillus niger* G1 glucoamylase (AMG G1). The construction of pCAMG91 is described in Boel et al. (1984), EMBO J. 3 (7) p.1581-1585.

pMT838: Plasmid encoding the truncated *Aspergillus niger* glucoamylase G2 (SEQ ID NO: 2).

pJS0026 (*S. cerevisiae* expression plasmid) (J.S.Okkel, (1996) "A URA3-promoter deletion in a pYES vector increases the expression level of a fungal lipase in *Saccharomyces cerevisiae*. Recombinant DNA Biotechnology III: The Integration of Biological and Engineering Sciences, vol. 782 of the Annals of the New York Academy of Sciences) More specifically, the expression plasmid pJS037, is derived from pYES 2.0 by replacing the inducible GAL1-promoter of pYES 2.0 with the constitutively expressed TPI (triose phosphate isomerase)-promoter from *Saccharomyces cerevisiae* (Albert and Karwasaki, (1982), J. Mol. Appl Genet., 1, 419-434), and deleting a part of the URA3 promoter.

METHODS:

20 Transformation of *Saccharomyces cerevisiae* YNG318

The DNA fragments and the opened vectors are mixed and transformed into the yeast *Saccharomyces cerevisiae* YNG318 by standard methods.

25 Determining Specific Activity As k_{cat} (sec.⁻¹).

750 microL substrate (1% maltose, 50 mM Sodium acetat, pH 4.3) is incubated 5 minutes at selected temperature, such as 37°C or 60°C.

50 microL enzyme diluted in sodium acetate is added.

30 Aliquots of 100 microL are removed after 0, 3, 6, 9 and 12 minutes and transferred to 100 microL 0.4 M Sodium hydroxide to stop the reaction. A blank is included.

20 microL is transferred to a Micro titre plates and 200 microL GOD-Perid solution is added. Absorbance is measured at 35 650 nm after 30 minutes incubation at room temperature.

Glucose is used as standard and the specific activity is calculated as k_{cat} (sec.^{-1}).

Determination Of AGU Activity and As AGU/mg

5 One Novo Amyloglucosidase Unit (AGU) is defined as the amount of enzyme, which hydrolyzes 1 micromole maltose per minute at 37°C and pH 4.3. A detailed description of the analytical method (AEL-SM-0131) is available on request from Novo Nordisk .

10 The activity is determined as AGU/ml by a method modified after (AEL-SM-0131) using the Glucose GOD-Perid kit from Boehringer Mannheim, 124036. Standard: AMG-standard, batch 7-1195, 195 AGU/ml.

375 microL substrate (1% maltose in 50 mM Sodium acetate, 15 pH 4.3) is incubated 5 minutes at 37°C. 25 microL enzyme diluted in sodium acetate is added. The reaction is stopped after 10 minutes by adding 100 microL 0.25 M NaOH. 20 microL is transferred to a 96 well microtitre plate and 200 microL GOD-Perid solution is added. After 30 minutes at room 20 temperature, the absorbance is measured at 650 nm and the activity calculated in AGU/ml from the AMG-standard.

The specific activity in AGU/mg is then calculated from the activity (AGU/ml) divided with the protein concentration (mg/ml) .

25

Transformation Of *Aspergillus* (general procedure)

100 ml of YPD (Sherman et al., (1981), Methods in Yeast Genetics, Cold Spring Harbor Laboratory) are inoculated with spores of *A. oryzae* and incubated with shaking for about 24 30 hours. The mycelium is harvested by filtration through miracloth and washed with 200 ml of 0.6 M MgSO_4 . The mycelium is suspended in 15 ml of 1.2 M MgSO_4 , 10 mM NaH_2PO_4 , pH 5.8. The suspension is cooled on ice and 1 ml of buffer containing 120 mg of NovozymTM 234 is added. After 5 min., 1 ml of 12 35 mg/ml BSA (Sigma type H25) is added and incubation with gentle agitation continued for 1.5-2.5 hours at 37C until a large

number of protoplasts is visible in a sample inspected under the microscope.

The suspension is filtered through miracloth, the filtrate transferred to a sterile tube and overlaid with 5 ml of 0.6 M sorbitol, 100 mM Tris-HCl, pH 7.0. Centrifugation is performed for 15 min. at 1000 g and the protoplasts are collected from the top of the MgSO_4 cushion. 2 volumes of STC (1.2 M sorbitol, 10 mM Tris-HCl, pH 7.5, 10 mM CaCl_2) are added to the protoplast suspension and the mixture is centrifuged for 5 min. at 1000 g. The protoplast pellet is resuspended in 3 ml of STC and repelleted. This is repeated. Finally, the protoplasts are resuspended in 0.2-1 ml of STC.

100 μl of protoplast suspension are mixed with 5-25 μg of p3SR2 (an *A. nidulans* amdS gene carrying plasmid described in Hynes et al., Mol. and Cel. Biol., Vol. 3, No. 8, 1430-1439, Aug. 1983) in 10 μl of STC. The mixture is left at room temperature for 25 min. 0.2 ml of 60% PEG 4000 (BDH 29576), 10 mM CaCl_2 and 10 mM Tris-HCl, pH 7.5 is added and carefully mixed (twice) and finally 0.85 ml of the same solution are added and carefully mixed. The mixture is left at room temperature for 25 min., spun at 2.500 g for 15 min. and the pellet is resuspended in 2 ml of 1.2 M sorbitol. After one more sedimentation the protoplasts are spread on minimal plates (Cove, (1966), Biochem. Biophys. Acta 113, 51-56) containing 1.0 M sucrose, pH 7.0, 10 mM acetamide as nitrogen source and 20 mM CsCl to inhibit background growth. After incubation for 4-7 days at 37C spores are picked, suspended in sterile water and spread for single colonies. This procedure is repeated and spores of a single colony after the second re-isolation are stored as a defined transformant.

Fed Batch Fermentation

Fed batch fermentation is performed in a medium comprising maltodextrin as a carbon source, urea as a nitrogen source and yeast extract. The fed batch fermentation is performed by inoculating a shake flask culture of *A. oryzae* host cells in question into a medium comprising 3.5% of the carbon source and

0.5% of the nitrogen source. After 24 hours of cultivation at pH 5.0 and 34°C the continuous supply of additional carbon and nitrogen sources are initiated. The carbon source is kept as the limiting factor and it is secured that oxygen is present in excess. The fed batch cultivation is continued for 4 days, after which the enzymes can be recovered by centrifugation, ultrafiltration, clear filtration and germ filtration.

Purification

10 The culture broth is filtrated and added ammoniumsulphate (AMS) to a concentration of 1.7 M AMS and pH is adjusted to pH 5. Precipitated material is removed by centrifugation and the solution containing glucoamylase activity is applied on a Toyo Pearl Butyl column previously equilibrated in 1.7 M AMS, 20 mM sodium acetate, pH 5. Unbound material is washed out with the equilibration buffer. Bound proteins are eluted with 10 mM sodium acetate, pH 4.5 using a linear gradient from 1.7 - 0 M AMS over 10 column volumes. Glucoamylase containing fractions are collected and dialysed against 20 mM sodium acetate, pH 4.5. The solution was then applied on a Q sepharose column, previously equilibrated in 10 mM Piperazin, Sigma, pH 5.5. Unbound material is washed out with the equilibration buffer. Bound proteins are eluted with a linear gradient of 0-0.3 M Sodium chloride in 10 mM Piperazin, pH 5.5 over 10 column volumes. Glucoamylase containing fractions are collected and the purity was confirmed by SDS-PAGE.

T_{1/2} (half-life) Method I

30 The thermal stability of variants is determined as T_{1/2} using the following method: 950 microliter 50 mM sodium acetate buffer (pH 4.3) (NaOAc) is incubated for 5 minutes at 68°C, 70°C or 75°C. 50 microliter enzyme in buffer (4 AGU/ml) is added. 2 x 40 microliter samples are taken at, e.g., 0, 5, 10, 20, 30 and 40 minutes and chilled on ice. The activity (AGU/ml) measured before incubation (0 minutes) is used as reference (100%). The decline in stability (in percent) is

calculated as a function of the incubation time. The % residual glucoamylase activity is determined at different times. $T_{1/2}$ is the period of time until which the % relative activity is decreased to 50%.

5

$T_{1/2}$ (half-life) (Method II)

The $T_{1/2}$ is measured by incubating the enzyme (ca 0.2 AGU/ml) in question in 30% glucose, 50 mM Sodium acetate at pH 4.5 at the temperature in question (e.g., 70°C). Samples are
10 withdrawn at set time intervals and chilled on ice and residual enzyme activity measured by the pNPG method (as described below).

The % residual glucoamylase activity is determined at different times. $T_{1/2}$ is the period of time until which the %
15 relative activity is decreased to 50%.

Residual Enzyme Activity (pNPG method)

pNPG reagent:

0.2 g pNPG (p-nitrophenylglucopyranoside) is dissolved in 0.1 M acetate buffer (pH 4.3) and made up to 100 ml.

20 Borate solution:

3.8g $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{ H}_2\text{O}$ is dissolved in Milli-Q water and made up to 100 ml.

25 microL samples are added 50 microL substrate and incubated 2 hr at 50°C. The reaction is stopped by adding 150
25 micoL ml borate solution. The optical density is measured at 405 nm, and the residual activity calculated.

Construction Of pAMGY

The pAMGY vector was constructed as follows: The lipase
30 gene in pJSO026 was replaced by the AMG gene, which was PCR amplified with the forward primer; FG2: 5'-CAT CCC CAG GAT CCT TAC TCA GCA ATG-3' (SEQ ID NO: 10) and the reverse primer: RG2: 5'-CTC AAA CGA CTC ACC AGC CTC TAG AGT-3' (SEQ ID NO: 11) using the template plasmid pLAC103 containing the AMG gene. The
35 pJSO026 plasmid was digested with XbaI and SmaI at 37°C for 2 hours and the PCR amplicon was blunt ended using the Klenow

fragment and then digested with XbaI. The vector fragment and the PCR amplicon were ligated and transformed into *E.coli* by electrotransformation. The resulting vector is designated pAMGY.

5

Construction Of pLaC103

The *A. niger* AMGII cDNA clone (Boel et al., (1984), supra) is used as source for the construction of pLaC103 aimed at *S. cerevisiae* expression of the GII form of AMG.

10 The construction takes place in several steps, out lined below.

pT7-212 (EP37856/ US patent no. 5162498) is cleaved with XbaI, blunt-ended with Klenow DNA polymerase and dNTP. After cleavage with EcoRI the resulting vector fragment is purified
15 from an agarose gel-electrophoresis and ligated with the 2.05 kb EcoRI-EcoRV fragment of pBoel53, thereby recreating the XbaI site in the EcoRV end of the AMG encoding fragment in the resulting plasmid pG2x.

In order to remove DNA upstream of the AMG cds, and furnish
20 the AMG encoding DNA with an appropriate restriction endonuclease recognition site, the following construct was made:

The 930 bp EcoRI-PstI fragment of p53 was isolated and subjected to AluI cleavage, the resulting 771 bp Alu-PstI
25 fragment was ligated into pBR322 with blunt-ended EcoRI site (see above) and cleaved with PstI. In the resulting plasmid pBR-AMG', the EcoRI site was recreated just 34 bp from the initiation codon of the AMG cds.

From pBR-AMG' the 775 bp EcoRI - PstI fragment was isolated
30 and joined with the 1151 bp PstI - XbaI fragment from pG2x in a ligation reaction including the XbaI - EcoRI vector fragment of pT7-212.

The resulting plasmid pT7GII was submitted to a BamHI cleavage in presence of alkaline phosphatase followed by
35 partial SphI cleavage after inactivation of the phosphatase. From this reaction was the 2489 bp SphI-BamHI fragment, encompassing the S.c. TPI promoter linked to the AMGII cds.

The above fragment together with the 1052 bp BamHI fragment of pT7GII was ligated with the alkaline phosphatase treated vector fragment of pMT743 (EP37856/US 5162498), resulting from SphI-BamHI digestion. The resulting plasmid is pLaC103.

5

Screening For Thermostable AMG Variants

The libraries are screened in the thermostable filter assay described below.

10 **Filter Assay For Thermostability**

Yeast libraries are plated on a sandwich of cellulose acetate (OE 67, Schleicher & Schuell, Dassel, Germany) - and nitrocellulose filters (Protran-Ba 85, Schleicher & Schuell, Dassel, Germany) on SCFura agar plates with 100 µg/ml
15 ampicillin at 30°C for at least 72 hrs. The colonies are replica plated to PVDF filters (Immobilon-P, Millipore, Bedford) activated with methanol for 1 min or alternatively a Protran filter (no activation) and subsequently washed in 0.1 M NaAc and then incubated at room temperature for 2 hours.
20 Colonies are washed from PVDF/Protran filters with tap water. Each filter sandwiches and PVDF/Protran filters are specifically marked with a needle before incubation in order to be able to localise positive variants on the filters after the screening. The PVDF filters with bound variants are
25 transferred to a container with 0.1 M NaAc, pH 4.5 and incubated at 47°C or alternatively 67-69°C in case of Protran filters for 15 minutes. The sandwich of cellulose acetate and nitrocellulose filters on SC ura-agar plates are stored at room temperature until use. After incubation, the residual
30 activities are detected on plates containing 5% maltose, 1% agarose, 50 mM NaAc, pH 4.5. The assay plates with PVDF filters are marked the same way as the filter sandwiches and incubated for 2 hrs. at 50°C. After removal of the PVDF filters, the assay plates are stained with Glucose GOD perid
35 (Boehringer Mannheim GmbH, Germany). Variants with residual activity are detected on assay plates as dark green spots on

white background. The improved variants are located on the storage plates. Improved variants are rescreened twice under the same conditions as the first screen.

5 **General Method For Random Mutagenesis By Use Of The DOPE Program**

The random mutagenesis may be carried out by the following steps:

1. Select regions of interest for modification in the
10 parent enzyme,
2. Decide on mutation sites and non-mutated sites in the selected region,
3. Decide on which kind of mutations should be carried out, e.g., with respect to the desired stability and/or
15 performance of the variant to be constructed,
4. Select structurally reasonable mutations,
5. Adjust the residues selected by step 3 with regard to step 4.
6. Analyze by use of a suitable dope algorithm the
20 nucleotide distribution.
7. If necessary, adjust the wanted residues to genetic code realism, e.g. taking into account constraints resulting from the genetic code, e.g. in order to avoid introduction of stop codons; the skilled person will be aware that some codon
25 combinations cannot be used in practice and will need to be adapted
8. Make primers
9. Perform random mutagenesis by use of the primers
10. Select resulting glucoamylase variants by screening
30 for the desired improved properties.

Dope Algorithm

Suitable dope algorithms for use in step 6 are well known in the art. One such algorithm is described by Tomandl, D. et
35 al., 1997, Journal of Computer-Aided Molecular Design 11:29-38. Another algorithm is DOPE (Jensen, LJ, Andersen, KV, Svendsen,

A, and Kretzschmar, T (1998) Nucleic Acids Research 26:697-702).

EXAMPLES

5

EXAMPLE 1

Construction of AMG G2 variants

Site-directed mutagenesis

For the construction of variants of a AMG G2 enzyme (SEQ ID
10 NO: 2) the commercial kit, Chameleon double-stranded, site-directed mutagenesis kit was used according to the manufacturer's instructions.

The gene encoding the AMG G2 enzyme in question is located on pMT838 prepared by deleting the DNA between G2 nt. 1362 and
15 G2 nt. 1530 in plasmid pCAMG91 (see Figure 1) comprising the AMG G1 form.

In accordance with the manufacturer's instructions the ScaI site of the Ampicillin gene of pMT838 was changed to a MluI site by use of the following primer:

20 7258: 5'p gaa tga ctt ggt tga cgc gtc acc agt cac 3' (SEQ ID NO: 3).

(Thus changing the ScaI site found in the ampicillin resistance gene and used for cutting to a MluI site). The pMT838 vector comprising the AMG gene in question was then
25 used as a template for DNA polymerase and oligo 7258 (SEQ ID NO: 3) and 21401 (SEQ ID NO: 4).

Primer no. 21401 (SEQ ID NO: 4) was used as the selection primer.

21401: 5'p gg gga tca tga tag gac tag cca tat taa tga agg gca
30 tat acc acg cct tgg acc tgc gtt ata gcc 3'

(Changes the ScaI site found in the AMG gene without changing the amino acid sequence).

The desired mutation (e.g., the introduction of a cystein residue) is introduced into the AMG gene in question by
35 addition of an appropriate oligos comprising the desired mutation.

The primer 107581 was used to introduce T12P

107581: 5` pgc aac gaa gcg ccc gtg gct cgt ac 3` (SEQ ID NO: 5)

5

The mutations are verified by sequencing the whole gene. The plasmid was transformed into *A. oryzae* using the method described above in the "Materials and Methods" section. The variant was fermented and purified as described above in the
10 "Materials & Methods" section.

EXAMPLE 2

Construction, by localized random, doped mutagenesis, of *A. niger* AMG variants having improved thermostability compared to
15 the parent enzyme

To improve the thermostability of the *A. niger* AMG random mutagenesis in pre-selected region was performed.

Residue:

Region: L19-G35

20 Region: A353-V374

The DOPE software (see Materials and Methods) was used to determine spiked codons for each suggested change in the above regions minimizing the amount of stop codons (see table 1). The exact distribution of nucleotides was calculated in the
25 three positions of the codon to give the suggested population of amino acid changes. The doped regions were doped specifically in the indicated positions to have a high chance of getting the desired residues, but still allow other possibilities.

30 The first column is the amino acid to be mutated, the second column is the percentage of wild type and the third column defined the new amino acid(s).

Table 1

Doping in L19-G35

35 L19	90%	N
N20	95%	T
N21	Constant	
I22	Constant	

	G23	95%	A
	A24	90%	S,T
	D25	93%	S,T,R
	G26	95%	A
5	A27	90%	S,T
	W28	<80%	R,Y
	V29	Constant	
	S30	93%	T,N
	G31	95%	A
10	A32	95%	V
	D33	80%	R,K,H
	S34	90%	N
	G35	Constant	

The resulting doped oligonucleotide strand is shown in
 15 table 2 as sense strand: with the primer sequence, the wild
 type nucleotide sequence, the parent amino acid sequence and
 the distribution of nucleotides for each doped position.

Table 2:

20	Position:	19	20	21	22	23	24	25	26	27
	A.a. seq.:	L	N	N	I	G	A	D	G	A
	primer:	12T	A3T	AAC	ATC	G4G	5CG	67C	G4T	8CT
	wt. seq.:	CTG	AAT	AAC	ATC	GGG	GCG	GAC	GGT	GCT
25	Pos. (cont.):	28	29	30	31	32	33	34	35	
	A.a. (cont.):	W	V	S	G	A	D	S	G	
	primer:	91010	GTG	1112C	G4C	G13G	141516	1718T	GGC	
	Wt seq.:	TGG	GTG	TCG	GGC	GCG	GAC	TCT	GGC	

30 Distribution of nucleotides for each doped position.

1: A10,C90

2: A6, T94

3: A95,C5

4:G95,C5

35 5:G91,A3,T3,C3

6:G95,A3,C2

7:G3,A95,C2

8:G92,A4,T4

9:A3,T97

40 10:G95,T5

11:G3,A97

12:G95,A2,C3

39

13:T5,C95
 14:G88,A8,C4
 15:G7,A93
 16:G4,C96
 5 17:G4,A96
 18:G95,A2,C3

Forward primer (SEQ ID NO: 6):

FAMGII '5-C GAA GCG ACC GTG GCT CGT ACT GCC ATC 12T A3T AAC ATC
 10 G4G 5CG 67C G4T 8CT 91010 GTG 1112C G4C G13G 141516 1718T GGC
 ATT GTC GTT GCT AGT CCC AGC ACG GAT AAC-3'

Reverse primer (SEQ ID NO: 7):

RAMG1: 5'-GAT GGC AGT ACG AGC CAC GGT CGC TTC G-3'

15

Table 3

Doping in region A353-V374:

	A353	<80%	D,E,Q,N,Y
	L354	90%	Q,E
20	Y355	90%	N,Q
	S356	90%	T,D,N
	G357	80%	P,A,S,T
	A358	93%	S
	A359	90%	S,T,N
25	T360	90%	R,K
	G361	85%	A,S,T
	T362	90%	S
	Y363	Constant	
	S364	93%	D
30	S365	93%	N,Q,K
	S366	93%	P,D
	S367	Constant	
	S368	93%	D,N,T
	T369	93%	Q,E
35	Y370	Constant	
	S371	93%	N
	S372	93%	N,T
	I373	Constant	
	V374	93%	N,Y,H

40

The resulting doped oligonucleotide strand is shown in table 4 as sense strand: with the primer sequence, wild type nucleotide sequence, the parent amino acid sequence and the distribution of nucleotides for each doped position.

45

Table 4:

Position: 353 354 355 356 357 358 359 360 361 362

40

A.a. seq.: A L Y S D A A T G T
 primer: 123 45A 6AC 78C 910T 11CT 1213T 1415A 1617C 18CC
 Wt. seq.: GCA CTG TAC AGC GAT GCT GCT ACT GGC ACC
 Pos. (cont.): 363 364 365 366 367 368 369

5 370

A.a. seq. (cont.): Y S S S S S T Y
 primer (cont.): TAC 1920T A2122 2324C AGT 1425C 2627G T28T
 wt. Seq. (cont.): TAC TCT TCG TCC AGT TCG ACT TAT
 Pos. (cont.): 371 372 373 374

10 A.a. pos. (cont.): S S I V
 primer (cont.) A16T 2930T ATT 313233
 wt. Seq. (cont.): AGT AGC ATT GTA

Distribution of nucleotides for each doped position.

1:G91,A3,T3,C3

15 2:A13,C87

3:A40,T60

4:G3,A3,C94

5:A6,T94

6:G4,A4,T92

20 7:G2,A96,C2

8:G93,A3.5,C3.5

9:G87,A8,C5

10:A84,C16

11:G93,T7

25 12:G92,A5,T3

13:A3,C97

14:G3,A97

15:G2,A2,T4,C92

16:G93,A7

30 17:G93,C7

18:A90,T10

19:G4,A96

20:G95,A5

21:G96,A4

35 22:G3,C97

23:G2,A1,T95,C2

24:A3,C97

25:G95,A3,C2

26:G2,A96,C2

27:A5,C95

28:A95,T5

5 29:G2,A98

30:G94,A4,C2

31:G94,A3,T1,C2

32:A4,T96

33:A20,C80

10

Primer: FAMGIV (SEQ ID NO: 8)

5'-GTG TCG CTG GAC TTC TTC AAG 123 45A 6AC 78C 910T 11CT 1213T
1415A 1617C 18CC TAC 1920T A2122 2324C AGT 1425C 2627G T28T
A16T 2930C ATT 313233 GAT GCC GTG AAG ACT TTC GCC GA-3'

15

Primer RAMGVI (SEQ ID NO: 9)

5'-ctt gaa gaa gtc cag cga cac-3'

Random mutagenesis

20 The spiked oligonucleotides apparent from Table 2 and 3
(which by a common term is designated FAMG) and reverse primers
RAMG for the L19-G35 region and specific SEQ ID NO: 2 primers
covering the N-terminal (FG2: 5'- CAT CCC CAG GAT CCT TAC TCA
GCA ATG-3' (SEQ ID NO: 10) and C-terminal (RG2: 5'- CTC AAA CGA
25 CTC ACC AGC CTC TAG AGT (SEQ ID NO: 11) are used to generate
PCR-library-fragments by the overlap extension method (Horton
et al., Gene, 77 (1989), pp. 61-68) with an overlap of 21 base
pairs. Plasmid pAMGY is template for the Polymerase Chain
Reaction. The PCR fragments are cloned by homologous
30 recombination in the *E. coli*/yeast shuttle vector pAMGY (see
Materials and Methods).

Screening

The library was screened in the thermostability filter
35 assays using a Protran filter and incubating at 67-69°C as
described in the "Material & Methods" section above

EXAMPLE 2Thermostability at 68°C

AMG G2 variants were constructed using the approach
5 described in Example 1.

The thermostability was determined as T½ using Method
I at 68°C as described in the "Materials & Methods" section
and compared to the wild-type *A. niger* AMG G2 under the same
conditions.

10

Enzyme	T½
AMG G2 (wild type)	8.5
T72I+A246T	11.3
A495P	11.0
A425T+S465P+E408R+A495T	8.6
T379A+S386K+A393R+T2E	18.4
L66V+S394P+Y402F+T2R+RL	11.1
S386R+A393R+T2R	14.1
S386N+E408R	12.6
A1V+L66R+Y402F+N427S+S486G	

T2K+S30P+N427M+S444G+V470M

A393R+T490A+V59A+PLASD(N-terminal extension)

S119P+Y312Q+Y402F+S416H,

T379A+S386K+A393R+T2E,

15 S386P+S340G+D357S+T360V.

EXAMPLE 3Specific Activity

AMG G2 variants were constructed as described above in
20 Example 1. The specific activity as k_{cat} or AGU/mg was measured
at pH 4.5, 37°C, using maltose as substrates as described in
the "Materials & Methods" section above.

Enzyme	AGU/mg	kCat (Sec. ⁻¹)
AMG G2 (wild-type)		5.6
I189T+Y223F+F227Y+Y402F+S119P		9.3

EXAMPLE 4Thermostability at 75°C

5 AMG G2 variants were constructed using the approach described in Example 1.

The thermostability was determined as T_½ using method I at 75°C, pH 4.5, as described in the "Materials & Methods" section and compared to the wild-type *A. niger* AMG G2 under
10 the same conditions.

AGR No.	Mutations	T _½ (Minutes)
	G2 (reference)	4
136	V59A+A393R+T490A	6
109	S56A+V59A+N313G+S356G+A393R+S394R+Y402F	9
111	A11E+V59A+T72I+S119P+F237H+S240G+A246T+N313G+S340G+K352R+A393R+S394R+Y402F+E408R	10
120	T2H+A11P+V59A+T72I+S119P+A246T+N313G+D336S+T360V+A393R+Y402F+E408R+N427M	12
122	T2H+V59A+T72I+S119P+S240G+N313G+T360V+S368P+A393R+Y402F+E408R+N427M	10
124	N9A+S56A+V59A+S119P+A246T+N313G+E342T+A393R+S394R+Y402F+E408R	21
130	V59A+L66R+T72I+S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M	29
132	T2H+N9A+V59A+S56A+L66R+T72I+S119P+N313G+F318Y+E342T+S356G+T390R+Y402F+E408R+N427M	9
141	T2H+A11E+V59A+S119P+N313G+E342T+S356P+A393R+S394I+Y402F+L410R+N427S	13
142	T2H+A11P+V59A+S119P+N313G+S340G+S356G+E408R+N427M	9
151	T2H+A11E+V59A+L66R+S119P+N313G+S340G+D357S+A393R+S394R+Y402F+E408R	20
154	T2H+N9A+S56A+V59A+L66R+T72I+S119P+S240G+N313G+S340G+K352R+A393R+S394R+Y402F+E408R+N427S	19

EXAMPLE 515 Saccharification performance of AMG variant AGR 130

Saccharification performance of the variant AGR 130 (V59A+L66R+T72I+S119P+N313G+S340G+S356G+A393R+Y402F+E408R+N427M) having improved thermostability (see Example 4) is tested at 70°C as described below.

20 Reference enzyme is the wild-type *A. niger* AMG G2. Saccharification is run under the following conditions:

	Substrate	10 DE Maltodextrin, approx. 30% DS
	(w/w)	
	Temperature	70°C
	Initial pH	4.3 (at 70°C)
5	Enzyme dosage	0.24 AGU/g DS

Saccharification

The substrate for saccharification is made by dissolving maltodextrin (prepared from common corn) in boiling Milli-Q
10 water and adjusting the dry substance to approximately 30% (w/w). pH is adjusted to 4.3. Aliquots of substrate corresponding to 15 g dry solids are transferred to 50 ml blue cap glass flasks and placed in a water bath with stirring. Enzymes are added and pH re-adjusted if necessary. The
15 experiment is run in duplicate. Samples are taken periodically and analysed at HPLC for determination of the carbohydrate composition.

SEQUENCE LISTING

<110> Novo Nordisk A/S
 <120> Glucoamylase Variant
 <130> 5967.204-WO
 <160> 13
 <170> FastSEQ for Windows Version 3.0
 <210> 1
 <211> 1605
 <212> DNA
 <213> *Aspergillus niger*
 <220>
 <221> sig_peptide
 <222> (1)...(72)
 <221> mat_peptide
 <222> (73)...(1602)
 <221> CDS
 <222> (1)...(1602)

<400> 1
 atg tcg ttc cga tct cta ctc gcc ctg agc ggc ctc gtc tgc aca ggg 48
 Met Ser Phe Arg Ser Leu Leu Ala Leu Ser Gly Leu Val Cys Thr Gly
 -20 -15 -10
 ttg gca aat gtg att tcc aag cgc gcg acc ttg gat tca tgg ttg agc 96
 Leu Ala Asn Val Ile Ser Lys Arg Ala Thr Leu Asp Ser Trp Leu Ser
 -5 1 5
 aac gaa gcg acc gtg gct cgt act gcc atc ctg aat aac atc ggg gcg 144
 Asn Glu Ala Thr Val Ala Arg Thr Ala Ile Leu Asn Asn Ile Gly Ala
 10 15 20
 gac ggt gct tgg gtg tcg ggc gcg gac tct ggc att gtc gtt gct agt 192
 Asp Gly Ala Trp Val Ser Gly Ala Asp Ser Gly Ile Val Val Ala Ser
 25 30 35 40
 ccc agc acg gat aac ccg gac tac ttc tac acc tgg act cgc gac tct 240
 Pro Ser Thr Asp Asn Pro Asp Tyr Phe Tyr Thr Trp Thr Arg Asp Ser
 45 50 55
 ggt ctc gtc ctc aag acc ctc gtc gat ctc ttc cga aat gga gat acc 288
 Gly Leu Val Leu Lys Thr Leu Val Asp Leu Phe Arg Asn Gly Asp Thr
 60 65 70
 agt ctc ctc tcc acc att gag aac tac atc tcc gcc cag gca att gtc 336
 Ser Leu Leu Ser Thr Ile Glu Asn Tyr Ile Ser Ala Gln Ala Ile Val
 75 80 85
 cag ggt atc agt aac ccc tct ggt gat ctg tcc agc ggc gct ggt ctc 384
 Gln Gly Ile Ser Asn Pro Ser Gly Asp Leu Ser Ser Gly Ala Gly Leu
 90 95 100
 ggt gaa ccc aag ttc aat gtc gat gag act gcc tac act ggt tct tgg 432

2

Gly 105	Glu	Pro	Lys	Phe	Asn 110	Val	Asp	Glu	Thr	Ala 115	Tyr	Thr	Gly	Ser	Trp 120	
gga	cgg	ccg	cag	cga	gat	ggt	ccg	gct	ctg	aga	gca	act	gct	atg	atc	480
Gly	Arg	Pro	Gln	Arg	Asp	Gly	Pro	Ala	Leu	Arg	Ala	Thr	Ala	Met	Ile	
				125					130					135		
ggc	ttc	ggg	cag	tgg	ctg	ctt	gac	aat	ggc	tac	acc	agc	acc	gca	acg	528
Gly	Phe	Gly	Gln	Trp	Leu	Leu	Asp	Asn	Gly	Tyr	Thr	Ser	Thr	Ala	Thr	
			140					145					150			
gac	att	gtt	tgg	ccc	ctc	gtt	agg	aac	gac	ctg	tcg	tat	gtg	gct	caa	576
Asp	Ile	Val	Trp	Pro	Leu	Val	Arg	Asn	Asp	Leu	Ser	Tyr	Val	Ala	Gln	
		155					160					165				
tac	tgg	aac	cag	aca	gga	tat	gat	ctc	tgg	gaa	gaa	gtc	aat	ggc	tcg	624
Tyr	Trp	Asn	Gln	Thr	Gly	Tyr	Asp	Leu	Trp	Glu	Glu	Val	Asn	Gly	Ser	
	170					175					180					
tct	ttc	ttt	acg	att	gct	gtg	caa	cac	cgc	gcc	ctt	gtc	gaa	ggc	agt	672
Ser	Phe	Phe	Thr	Ile	Ala	Val	Gln	His	Arg	Ala	Leu	Val	Glu	Gly	Ser	
185					190					195					200	
gcc	ttc	gcg	acg	gcc	gtc	ggc	tcg	tcc	tgc	tcc	tgg	tgt	gat	tct	cag	720
Ala	Phe	Ala	Thr	Ala	Val	Gly	Ser	Ser	Cys	Ser	Trp	Cys	Asp	Ser	Gln	
				205					210					215		
gca	ccc	gaa	att	ctc	tgc	tac	ctg	cag	tcc	ttc	tgg	acc	ggc	agc	ttc	768
Ala	Pro	Glu	Ile	Leu	Cys	Tyr	Leu	Gln	Ser	Phe	Trp	Thr	Gly	Ser	Phe	
			220					225					230			
att	ctg	gcc	aac	ttc	gat	agc	agc	cgt	tcc	ggc	aag	gac	gca	aac	acc	816
Ile	Leu	Ala	Asn	Phe	Asp	Ser	Ser	Arg	Ser	Gly	Lys	Asp	Ala	Asn	Thr	
		235					240					245				
ctc	ctg	gga	agc	atc	cac	acc	ttt	gat	cct	gag	gcc	gca	tgc	gac	gac	864
Leu	Leu	Gly	Ser	Ile	His	Thr	Phe	Asp	Pro	Glu	Ala	Ala	Cys	Asp	Asp	
	250					255					260					
tcc	acc	ttc	cag	ccc	tgc	tcc	ccg	cgc	gcg	ctc	gcc	aac	cac	aag	gag	912
Ser	Thr	Phe	Gln	Pro	Cys	Ser	Pro	Arg	Ala	Leu	Ala	Asn	His	Lys	Glu	
265					270					275					280	
gtt	gta	gac	tct	ttc	cgc	tca	atc	tat	acc	ctc	aac	gat	ggc	ctc	agt	960
Val	Val	Asp	Ser	Phe	Arg	Ser	Ile	Tyr	Thr	Leu	Asn	Asp	Gly	Leu	Ser	
				285				290						295		
gac	agc	gag	gct	gtt	gcg	gtg	ggt	cgg	tac	cct	gag	gac	acg	tac	tac	1008
Asp	Ser	Glu	Ala	Val	Ala	Val	Gly	Arg	Tyr	Pro	Glu	Asp	Thr	Tyr	Tyr	
			300					305					310			
aac	ggc	aac	ccg	tgg	ttc	ctg	tgc	acc	ttg	gct	gcc	gca	gag	cag	ttg	1056
Asn	Gly	Asn	Pro	Trp	Phe	Leu	Cys	Thr	Leu	Ala	Ala	Ala	Glu	Gln	Leu	
		315					320					325				
tac	gat	gct	cta	tac	cag	tgg	gac	aag	cag	ggg	tcg	ttg	gag	gtc	aca	1104
Tyr	Asp	Ala	Leu	Tyr	Gln	Trp	Asp	Lys	Gln	Gly	Ser	Leu	Glu	Val	Thr	
	330					335					340					
gat	gtg	tcg	ctg	gac	ttc	ttc	aag	gca	ctg	tac	agc	gat	gct	gct	act	1152
Asp	Val	Ser	Leu	Asp	Phe	Phe	Lys	Ala	Leu	Tyr	Ser	Asp	Ala	Ala	Thr	
345					350					355					360	
ggc	acc	tac	tct	tcg	tcc	agt	tcg	act	tat	agt	agc	att	gta	gat	gcc	1200

3

Gly	Thr	Tyr	Ser	Ser	Ser	Ser	Ser	Thr	Tyr	Ser	Ser	Ile	Val	Asp	Ala	
				365					370					375		
gtg	aag	act	ttc	gcc	gat	ggc	ttc	gtc	tct	att	gtg	gaa	act	cac	gcc	1248
Val	Lys	Thr	Phe	Ala	Asp	Gly	Phe	Val	Ser	Ile	Val	Glu	Thr	His	Ala	
			380					385					390			
gca	agc	aac	ggc	tcc	atg	tcc	gag	caa	tac	gac	aag	tct	gat	ggc	gag	1296
Ala	Ser	Asn	Gly	Ser	Met	Ser	Glu	Gln	Tyr	Asp	Lys	Ser	Asp	Gly	Glu	
		395					400					405				
cag	ctt	tcc	gct	cgc	gac	ctg	acc	tgg	tct	tat	gct	gct	ctg	ctg	acc	1344
Gln	Leu	Ser	Ala	Arg	Asp	Leu	Thr	Trp	Ser	Tyr	Ala	Ala	Leu	Leu	Thr	
	410					415					420					
gcc	aac	aac	cgt	cgt	aac	tcc	gtc	gtg	cct	gct	tct	tgg	ggc	gag	acc	1392
Ala	Asn	Asn	Arg	Arg	Asn	Ser	Val	Val	Pro	Ala	Ser	Trp	Gly	Glu	Thr	
425					430					435					440	
tct	gcc	agc	agc	gtg	ccc	ggc	acc	tgt	gcg	gcc	aca	tct	gcc	att	ggc	1440
Ser	Ala	Ser	Ser	Val	Pro	Gly	Thr	Cys	Ala	Ala	Thr	Ser	Ala	Ile	Gly	
				445					450					455		
acc	tac	agc	agt	gtg	act	gtc	acc	tcg	tgg	ccg	agt	atc	gtg	gct	act	1488
Thr	Tyr	Ser	Ser	Val	Thr	Val	Thr	Ser	Trp	Pro	Ser	Ile	Val	Ala	Thr	
			460					465					470			
ggc	ggc	acc	act	acg	acg	gct	acc	ccc	act	gga	tcc	ggc	agc	gtg	acc	1536
Gly	Gly	Thr	Thr	Thr	Thr	Ala	Thr	Pro	Thr	Gly	Ser	Gly	Ser	Val	Thr	
		475					480					485				
tcg	acc	agc	aag	acc	acc	gcg	act	gct	agc	aag	acc	agc	acc	acg	acc	1584
Ser	Thr	Ser	Lys	Thr	Thr	Ala	Thr	Ala	Ser	Lys	Thr	Ser	Thr	Thr	Thr	
	490					495					500					
cgc	tct	ggc	atg	tca	ctg	tga										1605
Arg	Ser	Gly	Met	Ser	Leu											
505					510											

<210> 2
 <211> 534
 <212> PRT
 <213> Aspergillus niger

<220>
 <221> SIGNAL
 <222> (1)...(24)

<400> 2															
Met	Ser	Phe	Arg	Ser	Leu	Leu	Ala	Leu	Ser	Gly	Leu	Val	Cys	Thr	Gly
				-20					-15					-10	
Leu	Ala	Asn	Val	Ile	Ser	Lys	Arg	Ala	Thr	Leu	Asp	Ser	Trp	Leu	Ser
		-5						1				5			
Asn	Glu	Ala	Thr	Val	Ala	Arg	Thr	Ala	Ile	Leu	Asn	Asn	Ile	Gly	Ala
	10					15					20				
Asp	Gly	Ala	Trp	Val	Ser	Gly	Ala	Asp	Ser	Gly	Ile	Val	Val	Ala	Ser
25					30					35				40	
Pro	Ser	Thr	Asp	Asn	Pro	Asp	Tyr	Phe	Tyr	Thr	Trp	Thr	Arg	Asp	Ser
			45				50						55		
Gly	Leu	Val	Leu	Lys	Thr	Leu	Val	Asp	Leu	Phe	Arg	Asn	Gly	Asp	Thr
		60					65					70			
Ser	Leu	Leu	Ser	Thr	Ile	Glu	Asn	Tyr	Ile	Ser	Ala	Gln	Ala	Ile	Val
	75					80						85			

Gln	Gly	Ile	Ser	Asn	Pro	Ser	Gly	Asp	Leu	Ser	Ser	Gly	Ala	Gly	Leu
	90					95					100				
Gly	Glu	Pro	Lys	Phe	Asn	Val	Asp	Glu	Thr	Ala	Tyr	Thr	Gly	Ser	Trp
105					110					115					120
Gly	Arg	Pro	Gln	Arg	Asp	Gly	Pro	Ala	Leu	Arg	Ala	Thr	Ala	Met	Ile
				125					130					135	
Gly	Phe	Gly	Gln	Trp	Leu	Leu	Asp	Asn	Gly	Tyr	Thr	Ser	Thr	Ala	Thr
			140					145					150		
Asp	Ile	Val	Trp	Pro	Leu	Val	Arg	Asn	Asp	Leu	Ser	Tyr	Val	Ala	Gln
	155						160					165			
Tyr	Trp	Asn	Gln	Thr	Gly	Tyr	Asp	Leu	Trp	Glu	Glu	Val	Asn	Gly	Ser
	170					175					180				
Ser	Phe	Phe	Thr	Ile	Ala	Val	Gln	His	Arg	Ala	Leu	Val	Glu	Gly	Ser
185					190					195					200
Ala	Phe	Ala	Thr	Ala	Val	Gly	Ser	Ser	Cys	Ser	Trp	Cys	Asp	Ser	Gln
				205					210					215	
Ala	Pro	Glu	Ile	Leu	Cys	Tyr	Leu	Gln	Ser	Phe	Trp	Thr	Gly	Ser	Phe
			220					225					230		
Ile	Leu	Ala	Asn	Phe	Asp	Ser	Ser	Arg	Ser	Gly	Lys	Asp	Ala	Asn	Thr
	235						240					245			
Leu	Leu	Gly	Ser	Ile	His	Thr	Phe	Asp	Pro	Glu	Ala	Ala	Cys	Asp	Asp
	250					255					260				
Ser	Thr	Phe	Gln	Pro	Cys	Ser	Pro	Arg	Ala	Leu	Ala	Asn	His	Lys	Glu
265					270					275					280
Val	Val	Asp	Ser	Phe	Arg	Ser	Ile	Tyr	Thr	Leu	Asn	Asp	Gly	Leu	Ser
				285					290					295	
Asp	Ser	Glu	Ala	Val	Ala	Val	Gly	Arg	Tyr	Pro	Glu	Asp	Thr	Tyr	Tyr
			300					305					310		
Asn	Gly	Asn	Pro	Trp	Phe	Leu	Cys	Thr	Leu	Ala	Ala	Ala	Glu	Gln	Leu
	315						320					325			
Tyr	Asp	Ala	Leu	Tyr	Gln	Trp	Asp	Lys	Gln	Gly	Ser	Leu	Glu	Val	Thr
	330					335					340				
Asp	Val	Ser	Leu	Asp	Phe	Phe	Lys	Ala	Leu	Tyr	Ser	Asp	Ala	Ala	Thr
345					350					355					360
Gly	Thr	Tyr	Ser	Ser	Ser	Ser	Ser	Thr	Tyr	Ser	Ser	Ile	Val	Asp	Ala
				365					370					375	
Val	Lys	Thr	Phe	Ala	Asp	Gly	Phe	Val	Ser	Ile	Val	Glu	Thr	His	Ala
			380					385					390		
Ala	Ser	Asn	Gly	Ser	Met	Ser	Glu	Gln	Tyr	Asp	Lys	Ser	Asp	Gly	Glu
		395					400					405			
Gln	Leu	Ser	Ala	Arg	Asp	Leu	Thr	Trp	Ser	Tyr	Ala	Ala	Leu	Leu	Thr
	410					415					420				
Ala	Asn	Asn	Arg	Arg	Asn	Ser	Val	Val	Pro	Ala	Ser	Trp	Gly	Glu	Thr
425					430					435					440
Ser	Ala	Ser	Ser	Val	Pro	Gly	Thr	Cys	Ala	Ala	Thr	Ser	Ala	Ile	Gly
				445					450					455	
Thr	Tyr	Ser	Ser	Val	Thr	Val	Thr	Ser	Trp	Pro	Ser	Ile	Val	Ala	Thr
			460					465					470		
Gly	Gly	Thr	Thr	Thr	Thr	Ala	Thr	Pro	Thr	Gly	Ser	Gly	Ser	Val	Thr
	475					480						485			
Ser	Thr	Ser	Lys	Thr	Thr	Ala	Thr	Ala	Ser	Lys	Thr	Ser	Thr	Thr	Thr
	490					495					500				
Arg	Ser	Gly	Met	Ser	Leu										
505					510										

<210> 3
 <211> 30
 <212> DNA
 <213> Artificial Sequence

<220>
 <223> Primer 7258

<400> 3

5

gaatgacttg gttgacgct caccagtcac 30

<210> 4
<211> 68
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer 21401

<400> 4
ggggatcatg ataggactag ccatattaat gaagggcata taccacgcct tggacctgcg 60
ttatagcc 68

<210> 5
<211> 25
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer 107581

<400> 5
gcaacgaagc gcccgaggct cgtac 25

<210> 6
<211> 88
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer FAMGII

<400> 6
cgaagcgacc gtggctcgta ctgccatcta taacatcggc gcgtctgtgc gcggtggcat 60
tgtcggtgct agtcccagca cggataac 88

<210> 7
<211> 28
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer RAMG1

<400> 7
gatggcagta cgagccacgg tcgcttcg 28

<210> 8
<211> 75
<212> DNA
<213> Artificial Sequence

<220>
<223> PRIMER FAMGIV

<400> 8
gtgtcgctgg acttcttcaa gaacctctta ccctactaca gtcggttatca ttgatgccgt 60
gaagactttc gccga 75

<210> 9
<211> 21
<212> DNA
<213> PRIMER RAMGVI

<400> 9
cttgaagaag tccagcgaca c 21

<210> 10
<211> 27
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer FG2

<400> 10
catccccagg atccttactc agcaatg 27

<210> 11
<211> 27
<212> DNA
<213> Artificial Sequence

<220>
<223> Primer RG2

<400> 11
ctcaaacgac tcaccagcct ctagagt 27

<210> 12
<211> 2602
<212> DNA
<213> ASPERGILLUS NIGER

<400> 12
ttcgtcgcct aatgtctcgt ccgttcacaa actgaagagc ttgaagtggc gagatgtctc 60
tgcaggaatt caagctagat gctaagcgat attgcatggc aatatgtgtt gatgcatgtg 120
cttcttcctt cagcttcccc tcgtgcgagt gaggtttggc tataaattga agtggttggt 180
cgggggttccg tgaggggctg aagtgccttc tcccttttag gcgcaactga gagcctgagc 240
ttcatcccca gcatcattac acctcagcaa tgctcgttccg atctctactc gccctgagcg 300
gcctcgtctg cacaggggtg gcaaatgtga tttccaagcg cgcgaccttg gattcatggt 360
tgagcaacga agcgcacgtg gctcgtactg ccaccttgaa taacatcggg gcggacgggtg 420
cttgggtgtc gggcgcgagc tctggcattg tcgttgctag tcccagcacg gataaccggg 480
actgtatgtt tcgagctcag atttagtatg agtgtgtcat tgattgattg atgctgactg 540
gcgtgtcgtt tgttgtagac ttctacacct ggactcgcga ctctgggtctc gtcctcaaga 600
ccctcgtcga tctcttccga aatggagata ccagtctcct ctccaccatt gagaactaca 660
tctccgcccc ggcaattgtc caggggtatca gtaaccctc tgggtgatctg tccagcggcg 720
ctgggtctcgg tgaacccaag ttcaatgtcg atgagactgc ctacactggg tcttgggggac 780
ggcgcgagcg agatgggtccg gctctgagag caactgctat gatcgggttc gggcagtggc 840
tgcttgtagt ttctccaccc ccttgcgctc gatctgtgac atatgtagct gactgggtcag 900
gacaatggct acaccagcac cgcaacggac attgtttggc ccctcgttag gaacgacctg 960
tcgtatgtgg ctcaatactg gaaccagaca ggatatgggt tgtttggttt attttaaatt 1020
tccaaagatg cgccagcaga gctaaccgac gatcgcagat ctctgggaag aagtcaatgg 1080
ctcgtctttc ttacgattg ctgtgcaaca ccgcgccctt gtcgaaggta gtgccttcgc 1140
gacggccgtc ggctcgtcct gctcctgggt tgattctcag gcacccgaaa ttctctgcta 1200
cctgcagtcc ttctggaccg gcagcttcat tctggccaac ttcgatagca gccgttccgg 1260
caaggacgca aacaccctcc tgggaagcat ccacaccttt gatcctgagg ccgcatgcga 1320
cgactccacc ttccagccct gctccccgcg cgcgctcgcc aaccacaagg aggttgtaga 1380
ctctttccgc tcaatctata ccctcaacga tgggtctcagt gacagcgagg ctgttgcggt 1440
gggtcggtag cctgaggaca cgtactacaa cggcaaccgg tgggtcctgt gcacctggg 1500
tgccgcagag cagttgtacg atgctctata ccagtgggac aagcaggggt cgttggaggt 1560
cacagatgtg tcgctggact tcttcaaggc actgtacagc gatgctgcta ctggcaccta 1620
ctcttcgtcc agttcgactt atagtagcat tgtagatgcc gtgaagactt tcgccgatgg 1680
cttcgtctct attgtggtaa gtctacgcta gacaagcgct catgttgaca gaggtgctg 1740
actaacagaa gtaggaaact cacgccgcaa gcaacggctc catgtccgag caatacgaca 1800
agtctgatgg cgagcagctt tccgctcgcg acctgacctg gtcttatgct gctctgctga 1860
ccgccaacaa ccgtcgtaac tccgctcgtg ctgcttcttg gggcgagacc tctgccagca 1920

```

gcgtgcccgg cacctgtgcg gccacatctg ccattggtac ctacagcagt gtgactgtca 1980
cctcgtggcc gagtatcgtg gctactggcg gcaccactac gacggctacc cccactggat 2040
ccggcagcgt gacctcgacc agcaagacca ccgcgactgc tagcaagacc agcaccagta 2100
cgtcatcaac ctccctgtacc actcccaccg ccgtggctgt gactttcgat ctgacagcta 2160
ccaccaccta cggcgagAAC atctacctgg tcggatcgat ctctcagctg ggtgactggg 2220
aaaccagcga cggcatagct ctgagtgtcg acaagtacac ttccagcgac ccgctctggt 2280
atgtcactgt gactctgccg gctgggtgagt cgtttgagta caagtttata cgcattgaga 2340
gcgatgactc cgtggagtgg gagagtgatc ccaaccgaga atacaccgtt cctcaggcgt 2400
gcggaacgtc gaccgcgacg gtgactgaca cctggcggtg acaatcaatc catttcgcta 2460
tagttaaagg atggggatga gggcaattgg ttatatgatc atgtatgtag tgggtgtgca 2520
taatagtagt gaaatggaag ccaagtcatg tgattgtaat cgaccgacgg aattgaggat 2580
atccggaaat acagacaccg gg 2602

```

<210> 13

<211> 640

<212> PRT

<213> ASPERGILLUS NIGER

<400> 13

```

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

```

		355					360				365						
Asp	Val	Ser	Leu	Asp	Phe	Phe	Lys	Ala	Leu	Tyr	Ser	Asp	Ala	Ala	Thr		
	370					375					380						
Gly	Thr	Tyr	Ser	Ser	Ser	Ser	Ser	Thr	Tyr	Ser	Ser	Ile	Val	Asp	Ala		
385					390					395					400		
Val	Lys	Thr	Phe	Ala	Asp	Gly	Phe	Val	Ser	Ile	Val	Glu	Thr	His	Ala		
				405				410						415			
Ala	Ser	Asn	Gly	Ser	Met	Ser	Glu	Gln	Tyr	Asp	Lys	Ser	Asp	Gly	Glu		
			420				425						430				
Gln	Leu	Ser	Ala	Arg	Asp	Leu	Thr	Trp	Ser	Tyr	Ala	Ala	Leu	Leu	Thr		
	435					440						445					
Ala	Asn	Asn	Arg	Arg	Asn	Ser	Val	Val	Pro	Ala	Ser	Trp	Gly	Glu	Thr		
	450				455						460						
Ser	Ala	Ser	Ser	Val	Pro	Gly	Thr	Cys	Ala	Ala	Thr	Ser	Ala	Ile	Gly		
465				470					475					480			
Thr	Tyr	Ser	Ser	Val	Thr	Val	Thr	Ser	Trp	Pro	Ser	Ile	Val	Ala	Thr		
			485					490						495			
Gly	Gly	Thr	Thr	Thr	Thr	Ala	Thr	Pro	Thr	Gly	Ser	Gly	Ser	Val	Thr		
		500					505					510					
Ser	Thr	Ser	Lys	Thr	Thr	Ala	Thr	Ala	Ser	Lys	Thr	Ser	Thr	Ser	Thr		
	515					520					525						
Ser	Ser	Thr	Ser	Cys	Thr	Thr	Pro	Thr	Ala	Val	Ala	Val	Thr	Phe	Asp		
	530				535					540							
Leu	Thr	Ala	Thr	Thr	Thr	Tyr	Gly	Glu	Asn	Ile	Tyr	Leu	Val	Gly	Ser		
545				550				555						560			
Ile	Ser	Gln	Leu	Gly	Asp	Trp	Glu	Thr	Ser	Asp	Gly	Ile	Ala	Leu	Ser		
			565					570						575			
Ala	Asp	Lys	Tyr	Thr	Ser	Ser	Asp	Pro	Leu	Trp	Tyr	Val	Thr	Val	Thr		
		580					585					590					
Leu	Pro	Ala	Gly	Glu	Ser	Phe	Glu	Tyr	Lys	Phe	Ile	Arg	Ile	Glu	Ser		
	595					600					605						
Asp	Asp	Ser	Val	Glu	Trp	Glu	Ser	Asp	Pro	Asn	Arg	Glu	Tyr	Thr	Val		
	610				615					620							
Pro	Gln	Ala	Cys	Gly	Thr	Ser	Thr	Ala	Thr	Val	Thr	Asp	Thr	Trp	Arg		
625				630					635					640			

CLAIMS

1. A variant of a parent glucoamylase, comprising an alteration at one or more of the following positions: 59, 66, 72, 119,
5 189, 223, 227, 313, 340, 342, 352, 379, 386, 393, 395, 402, 408, 416, 425, 427, 444, 486, 490, 494

wherein (a) the alteration is independently

(i) an insertion of an amino acid downstream of the amino acid which occupies the position,

10 (ii) a deletion of the amino acid which occupies the position, or

(iii) a substitution of the amino acid which occupies the position with a different amino acid,

(b) the variant has glucoamylase activity and (c) each
15 position corresponds to a position of the amino acid sequence of the parent glucoamylase having the amino acid sequence of SEQ ID NO: 2.

2. A variant of a parent glucoamylase, comprising one or more
20 of the following: V59A, L66V/R, T72I, S119P, I189T, Y223F, F227Y, N313G, S340G, K352R, S356G, T379A, S386K,N,R,P, A393R, S395R, Y402F, E408R, T416A,R,D,N,C,Q,G,H,I,L,K,M,F,P,S,E,W,Y,V preferably T416H, A425T, N427S/M, S444G S486G, T490A, T494P/A, wherein (a) the variant has glucoamylase activity and (b) each
25 position corresponds to a position of the amino acid sequence of the parent glucoamylase having the amino acid sequence of SEQ ID NO: 2.

3. The variant of claim 1 or 2, wherein the parent
30 glucoamylase has an amino acid sequence which has a degree of identity to the amino acid sequence of SEQ ID NO: 2 of at least about 65%, preferably at least about 70%, more preferably at least about 80%, even more preferably at least about 90%, most preferably at least about 95%, and even most preferably at
35 least about 97%.

4. The variant of claims 1-3, wherein the parent glucoamylase is encoded by a nucleic acid sequence which hybridizes under very low stringency conditions, with the nucleic acid sequence of SEQ ID NO: 1 or its complementary strand.

5

5. The variant of any of claims 1-4, wherein the parent glucoamylase is obtained from the genus *Aspergillus*, in particular *A. niger*, or *Talaromyces*, in particular *Talaromyces emersonii*.

10

6. The variant of any of claims 1-5, wherein the parent glucoamylase is the *A. niger* G1 or G2 glucoamylase from *A. niger*.

15 7. The variant of any of claims 1-6, wherein the alteration(s) are substitution(s).

8. The variant of any of claims 1-7, wherein the alteration(s) are insertion(s).

20

9. The variant of any of claims 1-8, wherein the alteration(s) are deletion(s).

10. The variant of any of claims 1-9, wherein the variant has
25 improved thermal stability when compared with the parent glucoamylase.

11. The variant of any of claims 1-10, wherein the variant has increased specific activity when compared with the parent
30 glucoamylase.

12. A DNA construct comprising a DNA sequence encoding a glucoamylase variant according to any one of claims 1-11.

35 13. A recombinant expression vector which carries a DNA construct according to claim 12.

14. A cell which is transformed with a DNA construct according to claim 12 or a vector according to claim 13.

15. A cell according to claim 14, which is a microorganism, in particular a bacterium or a fungus.

16. The cell according to claims 14-15, which is a strain from *Aspergillus*, in particular *A. niger*.

17. The cell according to claims 14-16, which is a strain from *Talaromyces*, in particular *Talaromyces emersonii*.

18. A process for converting starch or partially hydrolyzed starch into a syrup containing dextrose, said process including the step saccharifying starch hydrolyzate in the presence of a glucoamylase variant according to any of claims 1-11.

19. The process of claim 18, wherein the dosage of glucoamylase variant is present in the range from 0.05 to 0.5 AGU per gram of dry solids.

20. The process of any claims 18 or 19, comprising saccharification of a starch hydrolyzate of at least 30 percent by weight of dry solids.

25

21. The process of any of claims 18-20, wherein the saccharification is conducted in the presence of a debranching enzyme selected from the group of pullulanase and isoamylase, preferably a pullulanase derived from *Bacillus acidopullulyticus* or *Bacillus deramificans* or an isoamylase derived from *Pseudomonas amyloclavata*.

22. The process of any of claims 18-21, wherein the saccharification is conducted at a pH of 3 to 5.5 and at a temperature of 60-80°C, preferably 63-75°C, for 24 to 72 hours, preferably for 36-48 hours at a pH from 4 to 4.5.

23. Use of a glucoamylase variant of any of claims 1-11 in a starch conversion process.

5 24. Use of a glucoamylase variant of any one of claim 1-11 in a continuous starch conversion process.

25. Use of a glucoamylase variant according to any of claims 1-11 in a process for producing oligosaccharides.

10

26. Use of a glucoamylase variant according to any of claims 1-11 in a process for producing maltodextrins or glucose syrups.

15 27. Use of a glucoamylase variant according to any one of claim 1-11 in a process for producing fuel or drinking ethanol.

28. Use of a glucoamylase variant according to any one of claim 1-11 in a process for producing a beverage.

20 29. Use of a glucoamylase variant according to any one of claim 1-11 in a fermentation process for producing organic compounds, such as citric acid, ascorbic acid, lysine, glutamic acid.

25 30. A method for improving the thermal stability and/or specific activity of a parent glucoamylase by making an alteration in one or more of the following position(s) defined in claims 1-11.

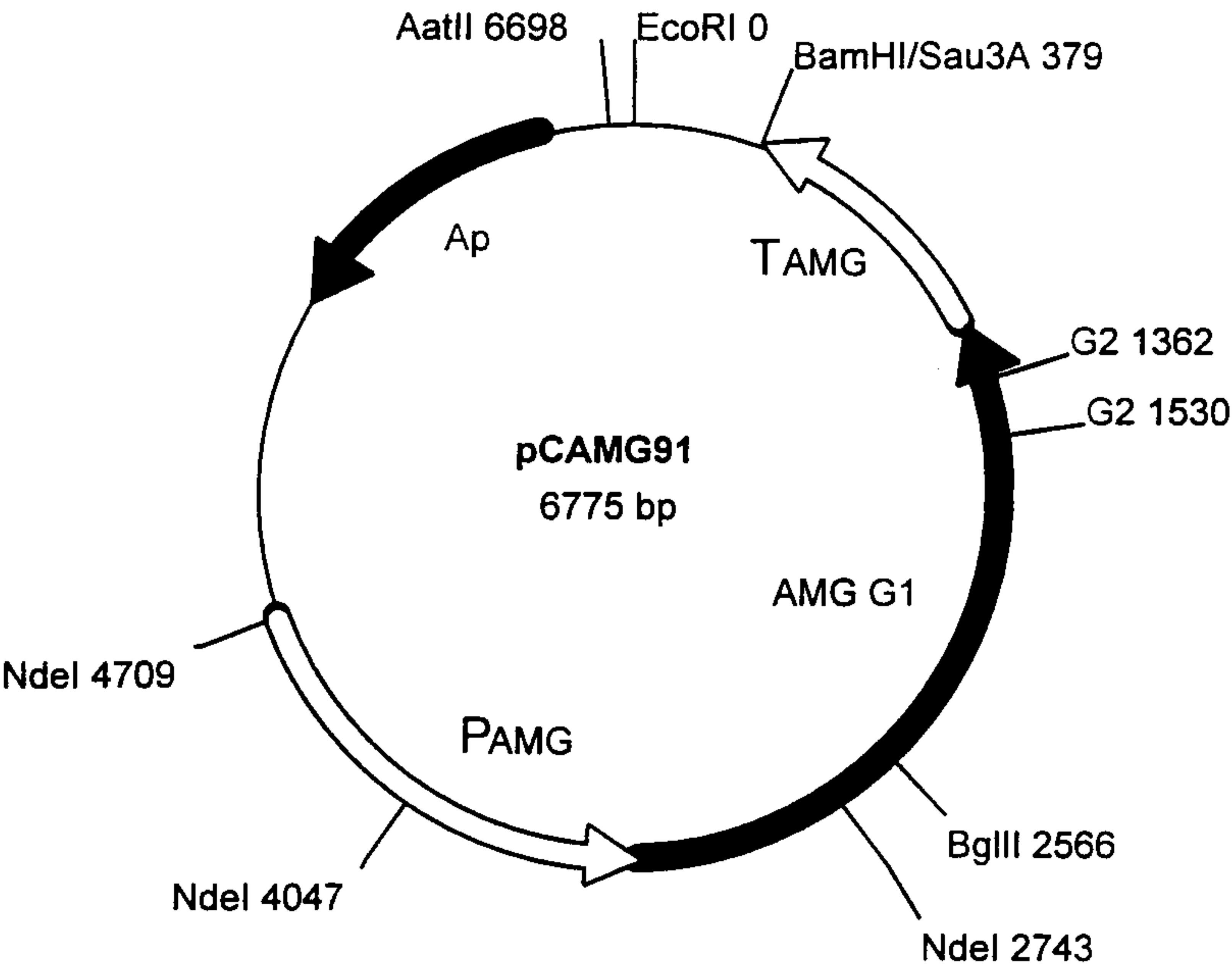


Fig. 1