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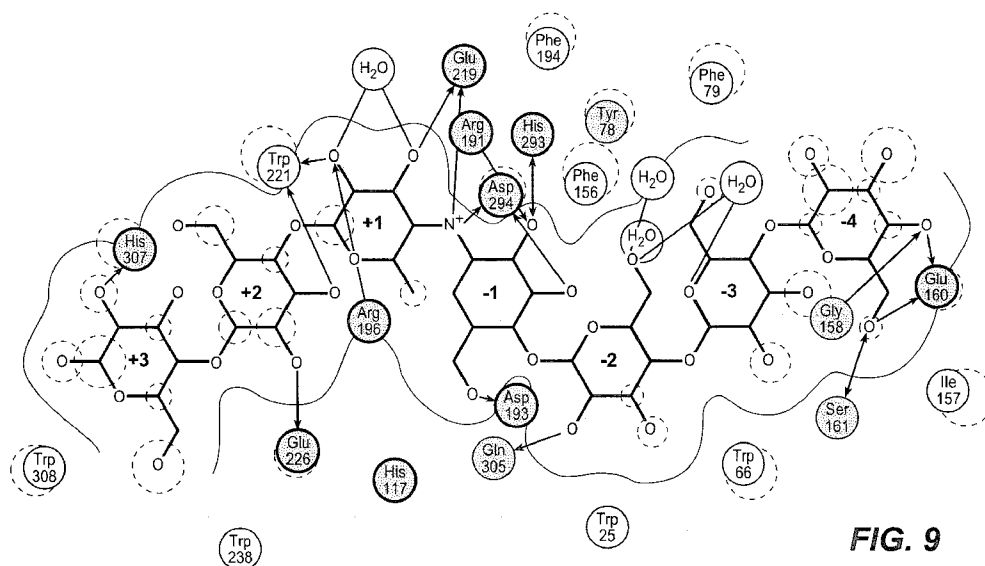
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(54) **Title:** A PROCESS OF OBTAINING ETHANOL WITHOUT GLUCOAMYLASE USING *PSEUDOMONAS SACCHAROPHILA* G4-AMYLASE AND VARIANTS THEREOF**FIG. 9**(57) **Abstract:** *Pseudomonas saccharophila* G4 forming amylase (PS4), and variants thereof, advantageously can be used in an enzyme-catalyzed high temperature liquefaction step to produce ethanol from starch, e.g., cornstarch. PS4 produces significant amounts of maltotrioses, which can be utilized by *S. cerevisiae* in a subsequent fermentation step to produce ethanol. This property of PS4 advantageously allows ethanol to be produced from liquefacted starch in the absence of a saccharification step. PS4 variants are provided that exhibit improved properties, such as thermostability and/or altered exo-specific and endo-specific amylase activity.

**A PROCESS OF OBTAINING ETHANOL WITHOUT GLUCOAMYLASE
USING *PSEUDOMONAS SACCHAROPHILA* G4-AMYLASE AND VARIANTS
THEREOF**

CROSS REFERENCE TO RELATED APPLICATION

This application claims benefit to U.S. Provisional Application No. 61/006,240 filed January 2, 2008, which is incorporated herein in its entirety.

SEQUENCE LISTING

A Sequence Listing, comprising SEQ ID NOS: 1-45, is attached and is incorporated by reference in its entirety.

FIELD OF THE INVENTION

An α -amylase from *Pseudomonas saccharophila*, thermostable mutations thereof, and nucleic acids encoding the same are useful in a process of liquefaction and saccharification of corn syrup to make ethanol, among other things.

BACKGROUND

The conversion of vegetable starches, especially cornstarch, to ethanol is a rapidly expanding industry. The current process consists of two sequential enzyme-catalyzed steps that result in the production of glucose. Yeast can then be used to ferment the glucose to ethanol.

The first enzyme-catalyzed step is starch liquefaction. Typically, a starch suspension is gelatinized by rapid heating to 85°C or more. α -Amylases (EC 3.2.1.1) are used to degrade the viscous liquefact to maltodextrins. α -amylases are endohydrolases that catalyze the random cleavage of internal α -1,4-D-glucosidic bonds. As α -amylases break down the starch, the viscosity decreases. Because liquefaction typically is conducted at high temperatures, thermostable α -amylases, such as an α -amylase from *Bacillus* sp., are preferred for this step.

The maltodextrins produced in this manner generally cannot be fermented by yeast to form alcohol. A second enzyme-catalyzed saccharification step thus is required to break down the maltodextrins. Glucoamylases and/or maltogenic α -amylases commonly are used to catalyze the hydrolysis of non-reducing ends of the maltodextrins formed after liquefaction,

releasing D-glucose, maltose and isomaltose. Debranching enzymes, such as pullulanases, can be used to aid saccharification. Saccharification typically takes place under acidic conditions at elevated temperatures, e.g., 60°C, pH 4.3.

One of the yeasts used to produce ethanol is *Saccharomyces cerevisiae*. *S. cerevisiae* contains α -glucosidase that has been shown to utilize mono-, di-, and tri-saccharides as substrates. Yoon *et al.*, *Carbohydrate Res.* 338: 1127-32 (2003). The ability of *S. cerevisiae* to utilize tri-saccharides can be improved by Mg^{2+} supplementation and over-expression of AGT1 permease (Stambuck *et al.*, *Lett. Appl. Microbiol.* 43: 370-76 (2006)), over-expression of MTT1 and MTT1alt to increase maltotriose uptake (Dietvorst *et al.*, *Yeast* 22: 775-88 (2005)), or expression of the maltase MAL32 on the cell surface (Dietvorst *et al.*, *Yeast* 24: 27-38 (2007)). The saccharification step could be omitted altogether, if the liquefaction step produced sufficient levels of mono-, di-, or tri-saccharides and *S. cerevisiae* or its genetically modified variants were used for the fermentation step.

Pseudomonas saccharophila expresses a maltotetraose-forming maltotetraohydrolase (EC 3.2.1.60; G4-forming amylase; G4-amylase; "Amy3A"; or "PS4" herein). The nucleotide sequence of the *P. saccharophila* gene encoding PS4 has been determined. Zhou *et al.*, "Nucleotide sequence of the maltotetraohydrolase gene from *Pseudomonas saccharophila*," *FEBS Lett.* 255: 37-41 (1989); GenBank Acc. No. X16732. PS4 is expressed as a precursor protein with an N-terminal 21-residue signal peptide. The mature form of PS4, as set forth in SEQ ID NO: 1, contains 530 amino acid residues with a catalytic domain at the N-terminus and a starch binding domain at the C-terminus. PS4 displays both endo- and exo- α -amylase activity. Endo- α -amylase activity is useful for decreasing the viscosity of gelatinized starch, and exo- α -amylase activity is useful for breaking down maltodextrins to smaller saccharides. The exo- α -amylase activity of PS4, however, has been thought to produce only maltotetraoses, which are not suitable substrates for the *S. cerevisiae* α -glucosidase. For this reason, PS4 has been thought to be unsuitable in a process of liquefaction of corn syrup to produce ethanol.

SUMMARY

Contrary to this notion, and from what is newly discovered as set forth herein, conditions are provided under which *P. saccharophila* G4-forming amylase (PS4)

advantageously can be used in an enzyme-catalyzed liquefaction step to produce ethanol from starch, e.g., cornstarch, wheat starch, or barley starch. In the present methods, wild-type PS4 produces significant amounts of maltotrioses, which can be utilized by *S. cerevisiae* in a subsequent fermentation step to produce ethanol. This property of PS4 advantageously
5 allows ethanol to be produced from liquefied starch in the absence of a saccharification step.

Typically, starch liquefaction is performed at ~85°C. The melting temperature (T_m) of PS4, however, is 65°C at pH 5.5. Yet, in one embodiment, PS4 can liquefy cornstarch in a process in which the starch is pre-heated to 70°C, then mixed with PS4 and rapidly heated to 85°C, and held at this temperature for 30 minutes. HPLC analysis of the products of this
10 liquefaction shows that PS4 produces significant amounts of maltotriose in addition to maltotetraose.

In another embodiment, variants of PS4 that are more thermostable than the wild-type PS4 show improved performance in liquefaction, as measured by the viscosity of the liquefact. Particular variants include a truncation of PS4, where the C-terminal starch-
15 binding domain is removed. Other thermostable variants comprise one or more amino acid modifications to the wild-type PS4 enzyme sequence, or modifications to the sequence of the C-terminal truncated PS4 variant.

Compared to wild-type PS4, PS4 variants advantageously may produce more maltotriose than maltotetraose. Further, PS4 variants can produce more glucose and maltose
20 even than currently used amylases, such as SPEZYME™ Xtra (Danisco US Inc., Genencor Division). This results in a higher observed ethanol yield from fermentation, which can exceed 2.5% v/v ethanol in embodiments using yeast that ferment glucose and maltose. It is expected that the ethanol yield can be further increased by fermenting liquefacts produced by PS4 variants with a yeast strain that can metabolize maltotrioses, such as *S. cerevisiae*.

Accordingly, the present disclosure provides a method of processing starch
25 comprising liquefying a starch and/or saccharifying a starch liquefact to form a saccharide syrup by adding a *Pseudomonas saccharophila* amylase (PS4) variant that comprises a sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% sequence identity to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID
30 NO: 1, or SEQ ID NO: 2. The PS4 variant may have an altered thermostability, an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo-

amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1-429 of
 SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may comprise one or more following
 amino acid substitutions: N33Y, D34N, G70D, K71R, V113I, G121A/D/F, G134R, A141P,
 N145D, Y146G, I157L, G158T, S161A, L178F, A179T, Y198F, G223A/E/F, S229P, H272Q,
 5 V290I, G303E, H307K/L, A309P, S334P, W339E, and/or D343E of SEQ ID NO: 1, 2, 3, 4,
 5, or 6. The PS4 variant may comprise the amino acid sequence of SEQ ID NO: 3, 4, 5, or 6.
 The PS4 variant may comprise one or more amino acid substitutions at following positions:
 7, 8, 32, 38, 49, 62, 63, 64, 67, 72, 73, 74, 75, 76, 104, 106, 107, 110, 112, 116, 119, 122,
 123, 124, 125, 126, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149, 150, 151, 154, 156,
 0 163, 164, 168, 169, 182, 183, 192, 195, 196, 200, 202, 208, 213, 220, 222, 225, 226, 227,
 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 267, 269, 271, 276, 282, 285, 295,
 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358, 367, 379, 390, of SEQ ID NO: 1, 2, 3,
 4, 5, or 6; one or more following amino acid substitutions: A3T, G9A, H13R, I46F, D68E,
 G69A/E/H/I/K/M/R/T, G70A/E/L/P/Q/S/V, K71M, G100A/S, G121I/P/R, A131T, G134C,
 5 A141S, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N,
 I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, A179S, G184Q, G188A, A199P,
 G223C/F/H/M/N/Q/W/Y, S229N, W238E/G/K/P/Q/R, G303L,
 H307D/E/F/G/K/M/P/Q/R/S/W/Y, A309E/I/M/T/V, S334A/H/K/L/M/Q/R/T, and/or H335M
 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more amino acid substitutions at positions of
 0 420, 422, and/or 424 of SEQ ID NO: 1. The presently disclosed PS4 variant may comprise
 one or more following amino acid substitutions: A3T, P7S, A8N, G9A, H13R, P32S, I38M,
 I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, D68E,
 G69A/E/H/I/K/M/R/T, G70A/E/L/P/Q/S/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S,
 G75C/E/F/R/S/W/Y, E76V, G100A/S, G104N/R, G106K, V107M, L110F, D112E, N116D,
 5 N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N,
 N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T,
 G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D,
 D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N,
 P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S,
 0 R182D/G/H/M/S, S183G, G184Q, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y,
 A199P, P200A/G, R202K, S208T, S213N, L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y,

S225E/G/V, E226C/D/G/W, Y227C/D/G/K/T, S229N, W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, V267I, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/E/F/G/K/M/P/Q/R/S/W/Y,

5 W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more substitutions of S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1. In one aspect, the PS4 variant may comprise one or more amino acid substitutions at following positions: 7, 32, 49, 62, 63, 64, 72, 73, 74,

10 75, 76, 107, 110, 112, 116, 119, 122, 123, 125, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 202, 220, 222, 226, 227, 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 269, 271, 276, 282, 285, 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358, 367, and/or 379 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, H13R, I38M, I46F,

15 T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R, G106K, G121I/P/R, D124S, E126D/N, A131T, G134C, A141S, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, G223C/F/H/M/N/Q/W/Y, S225E/G/V, W238E/G/K/P/Q/R, T295C, G303L, H307D/G/M/P/S, A309E/I/M/T/V,

20 S334A/H/K/L/M/Q/R/T, H335M, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more amino acid substitutions S420G and/or D422N/P/Q of SEQ ID NO: 1; and/or an amino acid substitution at position 424 of SEQ ID NO: 1. In another aspect, the PS4 variant may comprise one or more following amino acid substitutions: A3T, P7S, H13R, P32S, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T,

25 G70E/L/P/Q/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y,

30 F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S,

S183G, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K,
 L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/G/V, E226C/D/G/W,
 Y227C/D/G/K/T, W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G,
 W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V,
 5 K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T,
 H307D/G/M/P/S, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M,
 T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V,
 S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more
 following amino acid substitutions: S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1.

10 In a further aspect, the PS4 variant may comprise one or more amino acid substitutions at
 following positions: 49, 62, 63, 64, 72, 73, 74, 75, 76, 107, 112, 116, 119, 122, 123, 125, 128,
 130, 137, 140, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192,
 195, 196, 202, 257, 282, 285, 297, 300, 305, 308, 312, 323, and/or 325 of SEQ ID NO: 1, 2,
 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, P7S, H13R, I38M, I46F,
 15 T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R,
 G106K, L110F, G121I/P/R, D124S, E126D/N, A131T, G134C, N138D/E, D142E/G/N,
 N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N,
 I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, L220T, K222M/Y,
 G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T,
 20 W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R,
 Q239L, V253G, D255V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, T295C,
 N302K, G303L, H307D/G/M/P/S, A309E/I/M/T/V, T324L/M, S334A/H/K/L/M/Q/R/T,
 H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO:
 1, 2, 3, 4, 5, or 6; and one or more following amino acid substitutions: S420G, D422N/P/Q,
 25 and/or G424S of SEQ ID NO: 1. In yet another aspect, the PS4 variant may comprise one or
 more following amino acid substitutions: A3T, P7S, H13R, I38M, I46F, D49V, D62N,
 F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V,
 K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S,
 G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R,
 30 Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T,
 G134C, R137C, N138D/E, C140A/R, D142E/G/N, P143T, G144E, N145S, Y146D/E,

N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169E/G/K/N/R/V, I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K, L220T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/G/M/P/S, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6, and/or one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424S of SEQ ID NO: 1. The PS4 variant may have up to 25, 23, 21, 19, 17, 15, 13, or 11 amino acid deletions, additions, insertions, or substitutions compared to the amino acid sequence of SEQ ID NO: 1, 2, 3, 4, 5, or 6.

The present disclosure contemplates a PS4 variant that may comprise additional one or more amino acid substitutions at the following positions: N33, D34, G70, G121, G134, A141, Y146, I157, S161, L178, A179, G223, S229, H307, A309, and/or S334 of SEQ ID NO: 1 or 2. In one aspect, the PS4 variant comprises one or more following amino acid substitutions: N33Y, D34N, G70D, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H307K, A309P, and/or S334P of SEQ ID NO: 1 or 2.

The present disclosure also contemplates a PS4 variant that may have an altered thermostability compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may be more thermostable than the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. In one aspect, the PS4 variant that is more thermostable may comprise one or more following amino acid substitutions: A3T, I38M, G70L, Q169K/R, R182G/H, P200G, G223N, S237D, D269V, K271A/Q, S367Q/R, S379G, and/or S420G of SEQ ID NO: 1 or 2. In another aspect, the PS4 variant that is more thermostable may comprise additional one or more amino acid substitutions at following positions: G134, A141, I157, G223, H307, S334, and/or D343 of SEQ ID NO: 1 or 2. In a further aspect, the PS4 variant that is more thermostable may comprise one or more following amino acid substitutions: G134R, A141P, I157L, G223A,

H307L, S334P, and/or D343E of SEQ ID NO: 1 or 2. In yet another aspect, the PS4 variant may further comprise one or more amino acid substitutions at following positions: N33, D34, K71, L178, and/or A179 of SEQ ID NO: 1 or 2. The PS4 variant may comprises one or more amino acid substitutions: N33Y, D34N, K71R, L178F, and/or A179T of SEQ ID NO: 1 or 2.

5 The present disclosure further contemplates a PS4 variant that may have an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may comprise one or more following amino acid substitutions: A3T, G69K, G70E, K71M, G73D/E, G75C/E, Y122A, C140A,
 0 G144E, Y146D/E, N148K, C150A, D151A/V/W, G153A, G158I/P, S161G/H/K/P/R, Q169D/E/G/N/R, R196Q/S/T, R202K, S208T, S213N, K222M, G223C/F/H/M/Q/W/Y, E226D, Y227D/G/K/T, S229N, W232Q/S/T, T295C, Q305T, W308A/C/G/Q/R/S/T, A309I/V, W323M, T324L/M, S334A/H/M/Q, and/or R358E/L/N/Q/T/V of SEQ ID NO: 1 or 2. The PS4 variant may comprise additional one or more amino acid substitutions at
 5 following positions: W66, I157, E160, S161, R196, W221, K222, E226, D254, Q305, H307, and/or W308 of SEQ ID NO: 1 or 2. The PS4 variant may comprise one or more following amino acid substitutions: W66S, E160F/G/L/P/R/S, S161A, R196H/P/V, W221A, K222T, Q305T/L, H307L, and/or W308A/L/S of SEQ ID NO: 1 or 2.

In one aspect the PS4 variant may have an increased endo-amylase activity or a
 10 decreased ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may comprise one or more following amino acid substitutions: G69K, G73D/E, Y122A, C140A, C150A, G153A, G158I/P, S161G/H/K/P/R, Q169R, S208T, S229N, T295C, Q305T, and/or R358E/L/Q/T/V of SEQ ID NO: 1 or 2. The PS4 variant may comprise additional one or
 25 more amino acid substitutions at following positions: substitutions: W66S, R196H/P/V, W221A, K222T, H307L, and/or W308 of SEQ ID NO: 1 or 2.

In another aspect, the PS4 variant may have an increased exo-amylase activity or an increased ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may
 30 comprise one or more following amino acid substitutions: A3T, G70E, K71M, G75C/E, G144E, Y146D/E, N148K, D151A/V/W, Q169D/E/G/N, R196Q/S/T, R202K, S213N,

K222M, G223C/F/H/M/Q/W/Y, E226D, Y227D/G/K/T, W232Q/S/T, W308A/C/G/Q/R/S/T, A309I/V, W323M, T324L/M, S334A/H/M/Q, and/or R358N of SEQ ID NO: 1 or 2. The PS4 variant may comprise additional one or more following amino acid substitutions: E160F/G/L/P/R/S, S161A, and/or Q305T/L of SEQ ID NO: 1 or 2.

In a further aspect, the starch processing method may further comprise adding a debranching enzyme, an isoamylase, a pullulanase, a protease, a cellulase, a hemicellulase, a lipase, a cutinase, or any combination of said enzymes, to the starch liquefact. The starch processing method may be suitable for starch from corns, cobs, wheat, barley, rye, milo, sago, cassava, tapioca, sorghum, rice, peas, bean, banana, or potatoes.

In yet another aspect, the disclosed starch processing method may comprise fermenting the saccharide syrup to produce ethanol. The disclosed method may further comprise recovering the ethanol. The ethanol may be obtained by distilling the starch, wherein the fermenting and the distilling are carried out simultaneously, separately, or sequentially.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are incorporated in and constitute a part of this specification and illustrate various embodiments. In the drawings below, “PS4” is replaced with the abbreviation “SAS.” The abbreviations refer to the same protein and are interchangeable.

FIG. 1 depicts the liquefaction performance, measured in viscosity (μNm) as a function of time (min), using wild-type Amy3A G4-amylase (SEQ ID NO: 1) or thermostable PS4 variants CF 135 (SEQ ID NO: 3 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus) and CF143 (SEQ ID NO: 4 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus).

FIG. 2 depicts the production of ethanol (% v/v) as a function of time (h), using thermostable PS4 variants CF149 (SEQ ID NO: 5 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus) and CF154 (SEQ ID NO: 6 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), compared to liquefact produced with SPEZYME™ Xtra (Danisco US Inc., Genencor Division).

FIG. 3 depicts the utilization of glucose (% w/v) as a function of time (h) under the same conditions as used in FIG. 2.

FIG. 4 depicts the change in the % w/v of di-saccharides (DP-2) as a function of time (h) under the same conditions as used in FIG. 2.

FIG. 5 depicts the rate of ethanol accumulation (% v/v) in a reaction catalyzed by CF149 (SEQ ID NO: 5 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF154 (SEQ ID NO: 6 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), or Xtra.

FIG. 6 depicts the rate of glucose utilization (% w/v) in a reaction catalyzed by CF149 (SEQ ID NO: 5 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF154 (SEQ ID NO: 6 [with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), or Xtra.

FIG. 7 depicts the rate of DP-2 utilization (% w/v) in a reaction catalyzed by CF149 (SEQ ID NO: 5 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF154 (SEQ ID NO: 6 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), or Xtra.

FIG. 8 depicts the crystal structure of PS4 with acarbose bound.

FIG. 9 depicts the interaction between PS4 and acarbose bound to the active site cleft. Sugar positions +3 through -3 of acarbose are shown.

DETAILED DESCRIPTION

PS4, a C-terminal truncated variant thereof, and thermostable variants thereof, are provided. The PS4 and variants thereof are useful in processing starch that advantageously produces significant amounts of maltotrioses, which can be utilized by *S. cerevisiae* or a genetically engineered variant thereof in a subsequent fermentation step to produce ethanol. The process of producing ethanol advantageously does not require the use of glucoamylases and/or maltogenic α -amylases in a saccharification step to convert maltodextrins to mono-, di-, and tri-saccharides. PS4 may occasionally be referred to as SAS in the specification and figures. "PS4" and "SAS" are synonymous.

1. Definitions and abbreviations

In accordance with this detailed description, the following abbreviations and definitions apply. It should be noted that as used herein, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for

example, reference to “an enzyme” includes a plurality of such enzymes, and reference to “the formulation” includes reference to one or more formulations and equivalents thereof known to those skilled in the art, and so forth.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art. The following terms are provided below.

1.1. Definitions

“Amylase” means an enzyme that is, among other things, capable of catalyzing the degradation of starch. An endo-acting amylase activity cleaves α -D-(1 $\rightarrow$ 4) O-glycosidic linkages within the starch molecule in a random fashion. In contrast, an exo-acting amylolytic activity cleaves a starch molecule from the non-reducing end of the substrate. “Endo-acting amylase activity,” “endo-activity,” “endo-specific activity,” and “endo-specificity” are synonymous, when the terms refer to PS4. The same is true for the corresponding terms for exo-activity.

A “variant” or “variants” refers to either polypeptides or nucleic acids. The term “variant” may be used interchangeably with the term “mutant.” Variants include insertions, substitutions, transversions, truncations, and/or inversions at one or more locations in the amino acid or nucleotide sequence, respectively. The phrases “variant polypeptide” and “variant enzyme” mean a PS4 protein that has an amino acid sequence that has been modified from the amino acid sequence of a wild-type PS4. The variant polypeptides include a polypeptide having a certain percent, e.g., 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99%, of sequence identity with the parent enzyme. As used herein, “parent enzymes,” “parent sequence,” “parent polypeptide,” “wild-type PS4,” and “parent polypeptides” mean enzymes and polypeptides from which the variant polypeptides are based, e.g., the PS4 of SEQ ID NO: 1. A “parent nucleic acid” means a nucleic acid sequence encoding the parent polypeptide. A “wild-type” PS4 occurs naturally and includes naturally occurring allelic variants of the PS4 of SEQ ID NO: 1. The signal sequence of a “variant” may be the same (SEQ ID NO: 8) or may differ from the wild-type PS4. A variant may be expressed as a fusion protein containing a heterologous polypeptide. For example, the variant can comprise a signal peptide of another protein or a sequence designed to aid identification or purification of the expressed fusion protein, such as a His-Tag sequence.

To describe the various PS4 variants that are contemplated to be encompassed by the present disclosure, the following nomenclature will be adopted for ease of reference. Where the substitution includes a number and a letter, e.g., 141P, then this refers to {position according to the numbering system/substituted amino acid}. Accordingly, for example, the substitution of an amino acid to proline in position 141 is designated as 141P. Where the substitution includes a letter, a number, and a letter, e.g., A141P, then this refers to {original amino acid/position according to the numbering system/substituted amino acid}. Accordingly, for example, the substitution of alanine with proline in position 141 is designated as A141P.

Where two or more substitutions are possible at a particular position, this will be designated by contiguous letters, which may optionally be separated by slash marks “/”, e.g., G303ED or G303E/D.

Sequence identity is determined using standard techniques known in the art (*see e.g.*, Smith and Waterman, *Adv. Appl. Math.* 2: 482 (1981); Needleman and Wunsch, *J. Mol. Biol.* 48: 443 (1970); Pearson and Lipman, *Proc. Natl. Acad. Sci. USA* 85: 2444 (1988); programs such as GAP, BESTHT, FASTA, and TFASTA in the Wisconsin Genetics Software Package (Genetics Computer Group, Madison, WI); and Devereux et al., *Nucleic Acid Res.*, 12: 387-395 (1984)).

The “percent (%) nucleic acid sequence identity” or “percent (%) amino acid sequence identity” is defined as the percentage of nucleotide residues or amino acid residues in a candidate sequence that are identical with the nucleotide residues or amino acid residues of the starting sequence (*e.g.*, PS4). The sequence identity can be measured over the entire length of the starting sequence.

“Sequence identity” is determined herein by the method of sequence alignment. For the purpose of the present disclosure, the alignment method is BLAST described by Altschul et al., (Altschul et al., *J. Mol. Biol.* 215: 403-410 (1990); and Karlin et al., *Proc. Natl. Acad. Sci. USA* 90: 5873-5787 (1993)). A particularly useful BLAST program is the WU-BLAST-2 program (*see* Altschul et al., *Meth. Enzymol.* 266: 460-480 (1996)). WU-BLAST-2 uses several search parameters, most of which are set to the default values. The adjustable parameters are set with the following values: overlap span = 1, overlap fraction = 0.125, word threshold (T) = 11. The HSP S and HSP S2 parameters are dynamic values and are

established by the program itself depending upon the composition of the particular sequence and composition of the particular database against which the sequence of interest is being searched. However, the values may be adjusted to increase sensitivity. A % amino acid sequence identity value is determined by the number of matching identical residues divided
5 by the total number of residues of the “longer” sequence in the aligned region. The “longer” sequence is the one having the most actual residues in the aligned region (gaps introduced by WU-Blast-2 to maximize the alignment score are ignored).

“Variant nucleic acids” can include sequences that are complementary to sequences that are capable of hybridizing to the nucleotide sequences presented herein. For example, a
0 variant sequence is complementary to sequences capable of hybridizing under stringent conditions, e.g., 50°C and 0.2X SSC (1X SSC = 0.15 M NaCl, 0.015 M sodium citrate, pH 7.0), to the nucleotide sequences presented herein. More particularly, the term variant encompasses sequences that are complementary to sequences that are capable of hybridizing under highly stringent conditions, e.g., 65°C and 0.1X SSC, to the nucleotide sequences
5 presented herein. The melting point (T_m) of a variant nucleic acid may be about 1, 2, or 3°C lower than the T_m of the wild-type nucleic acid. The variant nucleic acids include a polynucleotide having a certain percent, e.g., 80%, 85%, 90%, 95%, or 99%, of sequence identity with the nucleic acid encoding the parent enzyme.

As used herein, the term “expression” refers to the process by which a polypeptide is
10 produced based on the nucleic acid sequence of a gene. The process includes both transcription and translation.

“Isolated” means that the sequence is at least substantially free from at least one other component that the sequence is naturally associated and found in nature, e.g., genomic sequences.

15 “Purified” means that the material is in a relatively pure state, e.g., at least about 90% pure, at least about 95% pure, or at least about 98% pure.

“Thermostable” means the enzyme retains activity after exposure to elevated temperatures. The thermostability of an enzyme is measured by its half-life ($t_{1/2}$), where half of the enzyme activity is lost by the half-life. The half-life value is calculated under defined
20 conditions by measuring the residual amylase activity. To determine the half-life of the

enzyme, the sample is heated to the test temperature for 1-10 min, and activity is measured using a standard assay for PS4 activity, such as the Betamyl® assay (Megazyme, Ireland).

As used herein, “optimum pH” means the pH at which PS4 or a PS4 variant displays the activity in a standard assay for PS4 activity, measured over a range of pH’s.

As used herein, “amino acid sequence” is synonymous with the term “polypeptide” and/or the term “protein.” In some instances, the term “amino acid sequence” is synonymous with the term “peptide”; in some instances, the term “amino acid sequence” is synonymous with the term “enzyme.”

As used herein, “nucleotide sequence” or “nucleic acid sequence” refers to an oligonucleotide sequence or polynucleotide sequence and variants, homologues, fragments and derivatives thereof. The nucleotide sequence may be of genomic, synthetic or recombinant origin and may be double-stranded or single-stranded, whether representing the sense or anti-sense strand. As used herein, the term “nucleotide sequence” includes genomic DNA, cDNA, synthetic DNA, and RNA.

“Homologue” means an entity having a certain degree of identity or “homology” with the subject amino acid sequences and the subject nucleotide sequences. A “homologous sequence” includes a polynucleotide or a polypeptide having a certain percent, e.g., 80%, 85%, 90%, 95%, or 99%, of sequence identity with another sequence. Percent identity means that, when aligned, that percentage of bases or amino acid residues are the same when comparing the two sequences. Amino acid sequences are not identical, where an amino acid is substituted, deleted, or added compared to the subject sequence. The percent sequence identity typically is measured with respect to the mature sequence of the subject protein, i.e., following removal of a signal sequence, for example. Typically, homologues will comprise the same active site residues as the subject amino acid sequence. Homologues also retain amylase activity, although the homologue may have different enzymatic properties than the wild-type PS4.

As used herein, “hybridization” includes the process by which a strand of nucleic acid joins with a complementary strand through base pairing, as well as the process of amplification as carried out in polymerase chain reaction (PCR) technologies. The variant nucleic acid may exist as single- or double-stranded DNA or RNA, an RNA/DNA heteroduplex or an RNA/DNA copolymer. As used herein, “copolymer” refers to a single

nucleic acid strand that comprises both ribonucleotides and deoxyribonucleotides. The variant nucleic acid may be codon-optimized to further increase expression.

As used herein, a “synthetic” compound is produced by *in vitro* chemical or enzymatic synthesis. It includes, but is not limited to, variant nucleic acids made with optimal codon
5 usage for host organisms, such as a yeast cell host or other expression hosts of choice.

As used herein, “transformed cell” includes cells, including both bacterial and fungal cells, which have been transformed by use of recombinant DNA techniques. Transformation typically occurs by insertion of one or more nucleotide sequences into a cell. The inserted nucleotide sequence may be a heterologous nucleotide sequence, i.e., is a sequence that is not
10 natural to the cell that is to be transformed, such as a fusion protein.

As used herein, “operably linked” means that the described components are in a relationship permitting them to function in their intended manner. For example, a regulatory sequence operably linked to a coding sequence is ligated in such a way that expression of the coding sequence is achieved under condition compatible with the control sequences.

As used herein, “biologically active” refers to a sequence having a similar structural,
15 regulatory or biochemical function as the naturally occurring sequence, although not necessarily to the same degree.

As used herein the term “starch” refers to any material comprised of the complex polysaccharide carbohydrates of plants, such as corn, comprised of amylose and amylopectin
20 with the formula $(C_6H_{10}O_5)_x$, where X can be any number. The term “granular starch” refers to raw, i.e., uncooked starch, e.g., starch that has not been subject to gelatinization.

The term “liquefaction” refers to the stage in starch conversion in which gelatinized starch is hydrolyzed to give low molecular weight soluble dextrans. As used herein the term “saccharification” refers to enzymatic conversion of starch to glucose. The term “degree of
25 polymerization” (DP) refers to the number (n) of anhydroglucopyranose units in a given saccharide. Examples of DP1 are the monosaccharides glucose and fructose. Examples of DP2 are the disaccharides maltose and sucrose.

As used herein the term “dry solids content” (ds) refers to the total solids of a slurry in a dry weight percent basis. The term “slurry” refers to an aqueous mixture containing
30 insoluble solids.

The phrase “simultaneous saccharification and fermentation (SSF)” refers to a process in the production of biochemicals in which a microbial organism, such as an ethanol producing microorganism and at least one enzyme, such as PS4 or a variant thereof, are present during the same process step. SSF refers to the contemporaneous hydrolysis of granular starch substrates to saccharides and the fermentation of the saccharides into alcohol, for example, in the same reactor vessel.

As used herein “ethanologenic microorganism” refers to a microorganism with the ability to convert a sugar or oligosaccharide to ethanol.

1.2. Abbreviations

The following abbreviations apply unless indicated otherwise:

ADA	azodicarbonamide
Amy3A	a wild-type <i>P. saccharophila</i> G4-forming amylase
cDNA	complementary DNA
CGTase	cyclodextrin glucanotransferase
DEAE	diethylamino ethanol
dH ₂ O	deionized water
DNA	deoxyribonucleic acid
DP-n	degree of polymerization with n subunits
ds	dry solid
ds-DNA	double-stranded DNA
EC	enzyme commission for enzyme classification
FGSC	Fungal Genetics Stock Center
G121F	glycine (G) residue at position 121 of SEQ ID NO: 2 is replaced with a phenylalanine (F) residue, where amino acids are designated by single letter abbreviations commonly known in the art
HPLC	High Performance Liquid Chromatography
LU	Lipase Units, a measure of phospholipase activity per unit mass of enzyme
mRNA	messenger ribonucleic acid
PCR	polymerase chain reaction
PDB	Protein Database Base

PEG	polyethyleneglycol
ppm	parts per million
PS4	<i>P. saccharophila</i> G4-forming amylase
RT-PCR	reverse transcriptase polymerase chain reaction
SAS	<i>P. saccharophila</i> G4-forming amylase
SDS-PAGE	sodium dodecyl sulfate-polyacrylamide gel electrophoresis
1X SSC	0.15 M NaCl, 0.015 M sodium citrate, pH 7.0
SSF	simultaneous saccharification and fermentation
$t_{1/2}$	half life
T _m	melting temperature (°C) at which 50% of the subject protein is melted
ΔT_m	°C increase in the T _m
w/v	weight/volume
w/w	weight/weight

2. *Pseudomonas saccharophila* α -amylase (PS4) and variants thereof

An isolated and/or purified polypeptide comprising a PS4 or variant thereof is provided. In one embodiment, the PS4 is a mature form of the polypeptide (SEQ ID NO: 1), wherein the 21 amino acid leader sequence is cleaved, so that the N-terminus of the polypeptide begins at the aspartic acid (D) residue. Variants of PS4 include a PS4 in which the C-terminal starch binding domain is removed. A representative amino acid sequence of a mature PS4 variant in which the starch binding domain is removed is the one having an amino acid sequence of residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus. Other PS4 variants include variants wherein between one and about 25 amino acid residues have been added or deleted with respect to wild-type PS4 or the PS4 having an amino acid sequence of residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus. In one aspect, the PS4 variant has the amino acid sequence of residues 1 to 429 of SEQ ID NO: 1, wherein any number between one and about 25 amino acids have been substituted. Representative embodiments of these variants include CF135 (SEQ ID NO: 3 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF143 (SEQ ID NO: 4 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF149 (SEQ ID NO: 5 with

residues 419-429 of SEQ ID NO:1 fused at the C-terminus), and CF154(SEQ ID NO: 6 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus).

In another aspect, the PS4 variant has the sequence of wild-type PS4, wherein any number between one and about 25 amino acids have been substituted. Representative
5 examples of PS4 variants having single amino acid substitutions are shown in TABLE 3. Examples of PS4 variants having combinations of amino acid substitutions are shown in TABLES 4 and 7. TABLE 4 depicts various amino acids that have been modified to form a core variant sequence, which is additionally modified as indicated for the PS4 variants listed in TABLE 7. TABLE 7 further summarizes the effect of various mutations on endo- or exo-
0 amylase activity, as well as the ratio of exo- to endo-amylase activity. In addition to the amino acid residue modifications listed in TABLES 3-4, additional specific PS4 residues that may be modified include A3, S44, A93, G103, V109, G172, A211, G265, N302, G313, and G342. PS4 variants may have various combinations of the amino acid substitutions disclosed herein. A process of using a PS4 variant may comprise the use of a single PS4 variant or a
5 combination, or blend, of PS4 variants.

PS4 variants advantageously may produce more maltotriose than maltotetraose. Further, the PS4 variants can produce more glucose and maltose than currently used amylases, such as SPEZYME™ Xtra (Danisco US Inc., Genencor Division). This results in a
10 higher observed ethanol yield from fermentation, which can exceed 2.5% (v/v) ethanol in embodiments using yeast that ferment glucose and maltose. PS4 variants are provided that have substantial endo-amylase activity, compared to wild-type PS4, and/or have a lower ratio of exo- to endo-amylase activity compared to wild-type PS4. Such PS4 variants may be particularly useful in a liquefaction process, when used alone or combination with other PS4 variants, where internal cleavage of complex branching saccharides lowers the viscosity of
15 the substrate.

Representative examples of amino acid substitutions that maintain or increase thermostability include the substitutions made to the variants CF135, CF143, CF149, and CF154. The PS4 variant CF135 has an amino acid sequence of SEQ ID NO: 3 with residues 419-429 of SEQ ID NO: 1 fused at the C-terminus. This variant contains the amino acid
20 substitution A141P. The variant CF143, having an amino acid sequence of SEQ ID NO: 4 with residues 419-429 of SEQ ID NO: 1 fused at the C-terminus, has the additional

substitution G223A. The variant CF149, having an amino acid sequence of SEQ ID NO: 5 with residues 419-429 of SEQ ID NO: 1 fused at the C-terminus, has seven substitutions: G134R, A141P, G223A, I157L, H307L, S334P, and D343E. The variant CF154, having an amino acid sequence of SEQ ID NO: 6 with residues 419-429 of SEQ ID NO: 1 fused at the C-terminus, has the same seven substitutions as CF149, plus the substitutions N33Y, D34N, K71R, L178F, and A179T.

Other particularly useful variants include those in which residues affecting substrate binding are substituted. PS4 residues involved in substrate binding include those depicted in FIG. 9. Specific residues include W66, I157, E160, S161, R196, W221, K222, H307, and W308. Substitutions of residues that affect substrate binding may affect the relative degree of endo- or exo-activity of the PS4 variant. A substitution that increases exo-activity, for example, advantageously promotes the formation of DP3 saccharides, which can be metabolized by *S. cerevisiae* in a process of fermentation of cornstarch to make ethanol. Representative examples of mutations affecting substrate binding include E160G, E160P, E160F, E160R, E160S, E160L, W66S, R196V, R196H, R196P, H307L, W221A, W308A, W308S, W308L, W308S, and K222T. Mutations to residues D254, R196, and E226, which are involved in an ion-pair network with K222, also are expected to be useful, since these mutations indirectly will affect the interaction of K222 with the substrate. Specific PS4 variants are provided that affect the -4, -3, -2, +2, and +3 sugar binding sites. Variants include those that affect subsets of these sites, particularly the -3, -2, +2, or +3 sites. Processes comprising the use of combinations of mutations affecting different sugar binding sites are contemplated. Specific mutations that affect the sugar binding sites are disclosed in the Examples.

The PS4 variant may comprises a sequence having at least 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% sequence identity to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may have an altered thermostability, an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1-429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may comprise one or more following amino acid substitutions: N33Y, D34N, G70D, K71R, V113I, G121A/D/F, G134R, A141P, N145D, Y146G, I157L, G158T, S161A, L178F,

A179T, Y198F, G223A/E/F, S229P, H272Q, V290I, G303E, H307K/L, A309P, S334P, W339E, and/or D343E of SEQ ID NO: 1, 2, 3, 4, 5, or 6. The PS4 variant may comprise the amino acid sequence of SEQ ID NO: 3, 4, 5, or 6.

In some embodiments, the PS4 variant may comprise one or more amino acid
 5 substitutions at following positions: 7, 8, 32, 38, 49, 62, 63, 64, 67, 72, 73, 74, 75, 76, 104, 106, 107, 110, 112, 116, 119, 122, 123, 124, 125, 126, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 200, 202, 208, 213, 220, 222, 225, 226, 227, 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 267, 269, 271, 276, 282, 285, 295, 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358,
 0 367, 379, 390, of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, G9A, H13R, I46F, D68E, G69A/E/H/I/K/M/R/T, G70A/E/L/P/Q/S/V, K71M, G100A/S, G121I/P/R, A131T, G134C, A141S, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, A179S, G184Q, G188A, A199P, G223C/F/H/M/N/Q/W/Y, S229N,
 5 W238E/G/K/P/Q/R, G303L, H307D/E/F/G/K/M/P/Q/R/S/W/Y, A309E/I/M/T/V, S334A/H/K/L/M/Q/R/T, and/or H335M of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more amino acid substitutions at positions of 420, 422, and/or 424 of SEQ ID NO: 1.

Representative substitutions may include: A3T, P7S, A8N, G9A, H13R, P32S, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, D68E, G69A/E/H/I/K/M/R/T,
 10 G70A/E/L/P/Q/S/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104N/R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y,
 25 F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G184Q, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A/G, R202K, S208T, S213N, L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/G/V, E226C/D/G/W, Y227C/D/G/K/T, S229N, W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H,
 30 N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, V267I, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E,

N302K, G303L, Q305E/L/T, H307D/E/F/G/K/M/P/Q/R/S/W/Y, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6, and/or one or more substitutions of S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1.

In some embodiments, the PS4 variant may comprise one or more amino acid substitutions at following positions: 7, 32, 49, 62, 63, 64, 72, 73, 74, 75, 76, 107, 110, 112, 116, 119, 122, 123, 125, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 202, 220, 222, 226, 227, 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 269, 271, 276, 282, 285, 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358, 367, and/or 379 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, H13R, I38M, I46F, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R, G106K, G121I/P/R, D124S, E126D/N, A131T, G134C, A141S, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, G223C/F/H/M/N/Q/W/Y, S225E/G/V, W238E/G/K/P/Q/R, T295C, G303L, H307D/G/M/P/S, A309E/I/M/T/V, 334A/H/K/L/M/Q/R/T, H335M, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more amino acid substitutions S420G and/or D422N/P/Q of SEQ ID NO: 1; and/or an amino acid substitution at position 424 of SEQ ID NO: 1. Representative substitutions may include: A3T, P7S, H13R, P32S, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K, L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/G/V, E226C/D/G/W, Y227C/D/G/K/T,

W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/G/M/P/S, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6, and/or one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1.

In other embodiments, the PS4 variant may comprise one or more amino acid substitutions at following positions: 49, 62, 63, 64, 72, 73, 74, 75, 76, 107, 112, 116, 119, 122, 123, 125, 128, 130, 137, 140, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 202, 257, 282, 285, 297, 300, 305, 308, 312, 323, and/or 325 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, P7S, H13R, I38M, I46F, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R, G106K, L110F, G121I/P/R, D124S, E126D/N, A131T, G134C, N138D/E, D142/E/G/N, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, L220T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, T295C, N302K, G303L, H307D/G/M/P/S, A309E/I/M/T/V, T324L/M, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424S of SEQ ID NO: 1. Representative substitutions may include: A3T, P7S, H13R, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E, C140A/R, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169E/G/K/N/R/V, I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G,

G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K, L220T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/G/M/P/S, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6, and/or one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424S of SEQ ID NO: 1.

The PS4 variant may have up to 25, 23, 21, 19, 17, 15, 13, or 11 amino acid deletions, additions, insertions, or substitutions compared to the amino acid sequence of SEQ ID NO: 1, 2, 3, 4, 5, or 6.

The PS4 variant may comprise additional one or more amino acid substitutions at the following positions: N33, D34, G70, G121, G134, A141, Y146, I157, S161, L178, A179, G223, S229, H307, A309, and/or S334 of SEQ ID NO: 1 or 2. Representative substitutions may include: N33Y, D34N, G70D, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H307K, A309P, and/or S334P of SEQ ID NO: 1 or 2.

In other embodiments, the PS4 variant may have an altered thermostability compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The altered thermostability may be elevated thermostability compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant that is more thermostable may comprise one or more following amino acid substitutions: A3T, I38M, G70L, Q169K/R, R182G/H, P200G, G223N, S237D, D269V, K271A/Q, S367Q/R, S379G, and/or S420G of SEQ ID NO: 1 or 2. Moreover, the PS4 variant may comprise additional one or more amino acid substitutions at following positions: G134, A141, I157, G223, H307, S334, and/or D343 of SEQ ID NO: 1 or 2. Representative substitutions may include: G134R, A141P, I157L, G223A, H307L, S334P, and/or D343E of SEQ ID NO: 1 or 2. The PS4 variant may further comprise one or more amino acid substitutions at following positions: N33, D34, K71, L178, and/or A179 of SEQ ID NO: 1 or 2. Representative substitutions may include: N33Y, D34N, K71R, L178F, and/or A179T of SEQ ID NO: 1 or 2.

In yet other embodiments, the PS4 variant that may have an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2. The PS4 variant may comprise one or more following amino acid substitutions: A3T, G69K, G70E, K71M, G73D/E, G75C/E, Y122A, C140A, G144E, Y146D/E, N148K, C150A, D151A/V/W, G153A, G158I/P, S161G/H/K/P/R, Q169D/E/G/N/R, R196Q/S/T, R202K, S208T, S213N, K222M, G223C/F/H/M/Q/W/Y, E226D, Y227D/G/K/T, S229N, W232Q/S/T, T295C, Q305T, W308A/C/G/Q/R/S/T, A309I/V, W323M, T324L/M, S334A/H/M/Q, and/or R358E/L/N/Q/T/V of SEQ ID NO: 1 or 2. Moreover, the PS4 variant may comprise additional one or more amino acid substitutions at following positions: W66, I157, E160, S161, R196, W221, K222, E226, D254, Q305, H307, and/or W308 of SEQ ID NO: 1 or 2. Representative substitutions may include: W66S, E160F/G/L/P/R/S, S161A, R196H/P/V, W221A, K222T, Q305T/L, H307L, and/or W308A/L/S of SEQ ID NO: 1 or 2.

The present disclosure also relates to each and every core variant sequence or backbone as shown in TABLE 4 comprising the substitution patterns as shown for each variant in TABLE 7. The disclosure further relates to the exact recited variants as shown in TABLE 4 with the substitutions as recited in TABLE 7, i.e., the core variant sequence containing only the recited mutations or substitution patterns as shown in TABLE 7. The disclosure further relates to PS4 variants comprising the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2, and comprising the substitution patterns as shown in TABLE 7. Furthermore, the disclosure relates to PS4 variants comprising the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2, and containing only the substitution patterns as shown in TABLE 7.

Nucleic acids encoding the polypeptides above also are provided. In one embodiment, a nucleic acid encoding a PS4 variant is a cDNA encoding the protein comprising an amino acid sequence of residues 1-429 of SEQ ID NO: 1. For example, the cDNA may have the corresponding sequence of the native mRNA, set forth in SEQ ID NO: 7. *See* GenBank Acc. No. X16732. As is well understood by one skilled in the art, the genetic code is degenerate, meaning that multiple codons in some cases may encode the same amino acid. Nucleic acids include genomic DNA, mRNA, and cDNA that encodes a PS4 variant.

2.1. PS4 variant characterization

Enzyme variants can be characterized by their nucleic acid and primary polypeptide sequences, by three dimensional structural modeling, and/or by their specific activity. Additional characteristics of the PS4 variant include stability, pH range, oxidation stability, and thermostability, for example. Levels of expression and enzyme activity can be assessed using standard assays known to the artisan skilled in this field. In another aspect, variants demonstrate improved performance characteristics relative to the wild-type enzyme, such as improved stability at high temperatures, e.g., 65-85°C. PS4 variants are advantageous for use in liquefaction or other processes that require elevated temperatures, such as baking. For example, a thermostable PS4 variant can degrade starch at temperatures of about 55°C to about 85°C or more.

An expression characteristic means an altered level of expression of the variant, when the variant is produced in a particular host cell. Expression generally relates to the amount of active variant that is recoverable from a fermentation broth using standard techniques known in this art over a given amount of time. Expression also can relate to the amount or rate of variant produced within the host cell or secreted by the host cell. Expression also can relate to the rate of translation of the mRNA encoding the variant enzyme.

A nucleic acid complementary to a nucleic acid encoding any of the PS4 variants set forth herein is provided. Additionally, a nucleic acid capable of hybridizing to the complement is provided. In another embodiment, the sequence for use in the methods and compositions described here is a synthetic sequence. It includes, but is not limited to, sequences made with optimal codon usage for expression in host organisms, such as yeast.

3. Production of PS4 variants

The PS4 variants provided herein may be produced synthetically or through recombinant expression in a host cell, according to procedures well known in the art. The expressed PS4 variant optionally is isolated prior to use. In another embodiment, the PS4 variant is purified following expression. Methods of genetic modification and recombinant production of PS4 variants are described, for example, in U.S. Patent Nos. 7,371,552, 7,166,453; 6,890,572; and 6,667,065; and U.S. Published Application Nos. 2007/0141693; 2007/0072270; 2007/0020731; 2007/0020727; 2006/0073583; 2006/0019347; 2006/0018997; 2006/0008890; 2006/0008888; and 2005/0137111. The relevant teachings of these

disclosures, including PS4-encoding polynucleotide sequences, primers, vectors, selection methods, host cells, purification and reconstitution of expressed PS4 variants, and characterization of PS4 variants, including useful buffers, pH ranges, Ca²⁺ concentrations, substrate concentrations and enzyme concentrations for enzymatic assays, are herein
5 incorporated by reference.

In another embodiment, suitable host cells include a Gram positive bacterium selected from the group consisting of *Bacillus subtilis*, *B. licheniformis*, *B. lentus*, *B. brevis*, *B. stearothermophilus*, *B. alkalophilus*, *B. amyloliquefaciens*, *B. coagulans*, *B. circulans*, *B. lautus*, *B. thuringiensis*, *Streptomyces lividans*, or *S. murinus*; or a Gram negative bacterium,
10 wherein said Gram negative bacterium is *Escherichia coli* or a *Pseudomonas* species. In one embodiment, the host cell is *B. subtilis*, and the expressed protein is engineered to comprise a *B. subtilis* signal sequence, as set forth in further detail below.

In some embodiments, a host cell is genetically engineered to express an PS4 variant with an amino acid sequence having at least about 80%, 85%, 90%, 91%, 92%, 93%, 94%,
15 95%, 96%, 97%, 98% or 99% identity with the wild-type PS4. In some embodiments, the polynucleotide encoding a PS4 variant will have a nucleic acid sequence encoding the protein of SEQ ID NO: 1 or 2 or a nucleic acid sequence having at least about 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% sequence identity with a nucleic acid encoding the protein of SEQ ID NO: 1 or 2. In one embodiment, the nucleic acid sequence has at least about 80%, 85%, 90%,
20 95%, 96%, 97%, 98% or 99% sequence identity to the nucleic acid of SEQ ID NO: 7.

3.1. Vectors

In some embodiments, a DNA construct comprising a nucleic acid encoding a PS4 variant is transferred to a host cell in an expression vector that comprises regulatory sequences operably linked to a PS4 encoding sequence. The vector may be any vector that
25 can be integrated into a fungal host cell genome and replicated when introduced into the host cell. The FGSC Catalogue of Strains, University of Missouri, lists suitable vectors. Additional examples of suitable expression and/or integration vectors are provided in Sambrook *et al.*, MOLECULAR CLONING: A LABORATORY MANUAL, 3rd ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York (2001); Bennett *et al.*, MORE GENE
30 MANIPULATIONS IN FUNGI, Academic Press, San Diego (1991), pp. 396-428; and U.S. Patent No. 5,874,276. Exemplary vectors include pFB6, pBR322, PUC18, pUC100 and pENTR/D,

pDONTM201, pDONRTM221, pENTRTM, pGEM[®]3Z and pGEM[®]4Z. Exemplary for use in bacterial cells include pBR322 and pUC19, which permit replication in *E. coli*, and pE194, for example, which permits replication in *Bacillus*.

In some embodiments, a nucleic acid encoding a PS4 variant is operably linked to a suitable promoter, which allows transcription in the host cell. The promoter may be derived from genes encoding proteins either homologous or heterologous to the host cell. Suitable non-limiting examples of promoters include *cbh1*, *cbh2*, *egl1*, and *egl2* promoters. In one embodiment, the promoter is one that is native to the host cell. For example, when *P. saccharophila* is the host, the promoter is a native *P. saccharophila* promoter. An “inducible promoter” is a promoter that is active under environmental or developmental regulation. In another embodiment, the promoter is one that is heterologous to the host cell.

In some embodiments, the coding sequence is operably linked to a DNA sequence encoding a signal sequence. A representative signal peptide is SEQ ID NO: 8, which is the native signal sequence of the PS4 precursor. In other embodiments, the DNA encoding the signal sequence is replaced with a nucleotide sequence encoding a signal sequence from a species other than *P. saccharophila*. In this embodiment, the polynucleotide that encodes the signal sequence is immediately upstream and in-frame of the polynucleotide that encodes the polypeptide. The signal sequence may be selected from the same species as the host cell. In one non-limiting example, the signal sequence is a cyclodextrin glucanotransferase (CGTase; EC 2.4.1.19) signal sequence from *Bacillus* sp., and the PS4 variant is expressed in a *B. subtilis* host cell. A methionine residue may be added to the N-terminus of the signal sequence.

In additional embodiments, a signal sequence and a promoter sequence comprising a DNA construct or vector to be introduced into a fungal host cell are derived from the same source. In some embodiments, the expression vector also includes a termination sequence. In one embodiment, the termination sequence and the promoter sequence are derived from the same source. In another embodiment, the termination sequence is homologous to the host cell.

In some embodiments, an expression vector includes a selectable marker. Examples of suitable selectable markers include those that confer resistance to antimicrobial agents, e.g., hygromycin or phleomycin. Nutritional selective markers also are suitable and include

amdS, *argB*, and *pyr4*. In one embodiment, the selective marker is the *amdS* gene, which encodes the enzyme acetamidase; it allows transformed cells to grow on acetamide as a nitrogen source. The use of an *A. nidulans amdS* gene as a selective marker is described in Kelley *et al.*, *EMBO J.* 4: 475-479 (1985) and Penttila *et al.*, *Gene* 61: 155-164 (1987).

5 A suitable expression vector comprising a DNA construct with a polynucleotide encoding a PS4 variant may be any vector that is capable of replicating autonomously in a given host organism or integrating into the DNA of the host. In some embodiments, the expression vector is a plasmid. In some embodiments, two types of expression vectors for obtaining expression of genes are contemplated. The first expression vector comprises DNA
0 sequences in which the promoter, PS4 coding region, and terminator all originate from the gene to be expressed. In some embodiments, gene truncation is obtained by deleting undesired DNA sequences, e.g., DNA encoding the C-terminal starch-binding domain, to leave the domain to be expressed under control of its own transcriptional and translational regulatory sequences. The second type of expression vector is preassembled and contains
5 sequences required for high-level transcription and a selectable marker. In some embodiments, the coding region for a PS4 gene or part thereof is inserted into this general-purpose expression vector, such that it is under the transcriptional control of the expression construct promoter and terminator sequences. In some embodiments, genes or part thereof are inserted downstream of the strong *cbhl* promoter.

20 3.2. Transformation, expression and culture of host cells

Introduction of a DNA construct or vector into a host cell includes techniques such as transformation; electroporation; nuclear microinjection; transduction; transfection, e.g., lipofection mediated and DEAE-Dextrin mediated transfection; incubation with calcium phosphate DNA precipitate; high velocity bombardment with DNA-coated microprojectiles;
25 and protoplast fusion. General transformation techniques are known in the art. *See, e.g.*, Ausubel *et al.* (1987), *supra*, chapter 9; Sambrook *et al.* (2001), *supra*; and Campbell *et al.*, *Curr. Genet.* 16: 53-56 (1989). The expression of heterologous protein in *Trichoderma* is described, for example, in U.S. Patent No. 6,022,725; U.S. Patent No. 6,268,328; Harkki *et al.*, *Enzyme Microb. Technol.* 13: 227-233 (1991); Harkki *et al.*, *BioTechnol.* 7: 596-603
30 (1989); EP 244,234; and EP 215,594. In one embodiment, genetically stable transformants are constructed with vector systems whereby the nucleic acid encoding a PS4 variant is stably

integrated into a host cell chromosome. Transformants are then purified by known techniques.

In one non-limiting example, stable transformants including an *amdS* marker are distinguished from unstable transformants by their faster growth rate and the formation of circular colonies with a smooth, rather than ragged outline on solid culture medium containing acetamide. Additionally, in some cases a further test of stability is conducted by growing the transformants on solid non-selective medium, e.g., a medium that lacks acetamide, harvesting spores from this culture medium and determining the percentage of these spores that subsequently germinate and grow on selective medium containing acetamide. Other methods known in the art may be used to select transformants.

3.3. Identification of PS4 activity

To evaluate the expression of a PS4 variant in a host cell, assays can measure the expressed protein, corresponding mRNA, or α -amylase activity. For example, suitable assays include Northern and Southern blotting, RT-PCR (reverse transcriptase polymerase chain reaction), and *in situ* hybridization, using an appropriately labeled hybridizing probe. Suitable assays also include measuring PS4 activity in a sample. Suitable assays of the exo-activity of the PS4 variant include, but are not limited to, the Betamyl® assay (Megazyme, Ireland). Suitable assays of the endo-activity of the PS4 variant include, but are not limited to, the Phadebas blue assay (Pharmacia and Upjohn Diagnostics AB). Assays also include HPLC analysis of liquefact prepared in the presence of the PS4 variant. HPLC can be used to measure amylase activity by separating DP-3 and DP-4 saccharides from other components of the assay.

3.4. Methods for purifying PS4

In general, a PS4 variant produced in cell culture is secreted into the medium and may be purified or isolated, e.g., by removing unwanted components from the cell culture medium.

In some cases, a PS4 variant may be recovered from a cell lysate. In such cases, the enzyme is purified from the cells in which it was produced using techniques routinely employed by those of skill in the art. Examples include, but are not limited to, affinity chromatography, ion-exchange chromatographic methods, including high resolution ion-exchange, hydrophobic interaction chromatography, two-phase partitioning, ethanol precipitation, reverse phase HPLC, chromatography on silica or on a cation-exchange resin, such as DEAE,

chromatofocusing, SDS-PAGE, ammonium sulfate precipitation, and gel filtration using Sephadex G-75, for example.

4. Compositions and uses of PS4 variants

A PS4 variant produced and purified by the methods described above is useful for a variety of industrial applications. In one embodiment, the PS4 variant is useful in a starch conversion process, particularly in a liquefaction process of a starch, e.g., cornstarch, wheat starch, or barley starch. The desired end-product may be any product that may be produced by the enzymatic conversion of the starch substrate. For example, the desired product may be a syrup rich in saccharides useful for fermentation, particularly maltotriose, glucose, and/or maltose. The end product then can be used directly in a fermentation process to produce alcohol for fuel or drinking (i.e., potable alcohol). The skilled artisan is aware of various fermentation conditions that may be used in the production of ethanol or other fermentation end-products. A microbial organism capable of fermenting maltotrioses and/or less complex sugars, such as *S. cerevisiae* or a genetically modified variant thereof, is particularly useful. Suitable genetically altered variants of *S. cerevisiae* particularly useful for fermenting maltotrioses include variants that express AGT1 permease (Stambuck *et al.*, *Lett. Appl. Microbiol.* 43: 370-76 (2006)), MTT1 and MTT1alt (Dietvorst *et al.*, *Yeast* 22: 775-88 (2005)), or MAL32 (Dietvorst *et al.*, *Yeast* 24: 27-38 (2007)). PS4 variants also are useful in compositions and methods of food preparation, where enzymes that express amylase activity at high temperatures are desired.

The desirability of using a particular PS4 variant will depend on the overall properties displayed by the PS4 variant relative to the requirements of a particular application. As a general matter, PS4 variants useful for a starch conversion process have substantial endo-amylase activity compared to wild-type PS4, and/or have a lower exo- to endo-amylase activity compared to wild-type PS4. Such PS4 variants may be particularly useful in a liquefaction process, when used alone or combination with other PS4 variants, where internal cleavage of complex branching saccharides lowers the viscosity of the substrate. Some PS4 variants useful for liquefaction, however, are expected to have an endo-amylase activity comparable or even lower than wild-type PS4. Useful PS4 variants include those with more or less exo-amylase activity than the wild-type PS4, depending on the application.

Compositions may include one or a combination of PS4 variants, each of which may display a different set of properties.

4.1. Preparation of starch substrates

Those of skill in the art are well aware of available methods that may be used to prepare starch substrates for use in the processes disclosed herein. For example, a useful starch substrate may be obtained from tubers, roots, stems, legumes, cereals or whole grain. More specifically, the granular starch comes from plants that produce high amounts of starch. For example, granular starch may be obtained from corns, cobs, wheat, barley, rye, milo, sago, cassava, tapioca, sorghum, rice, peas, bean, banana, or potatoes. Corn contains about 60-68% starch; barley contains about 55-65% starch; millet contains about 75-80% starch; wheat contains about 60-65% starch; and polished rice contains 70-72% starch. Specifically contemplated starch substrates are cornstarch, wheat starch, and barley starch. The starch from a grain may be ground or whole and includes corn solids, such as kernels, bran and/or cobs. The starch may be highly refined raw starch or feedstock from starch refinery processes. Various starches also are commercially available. For example, cornstarch is available from Cerestar, Sigma, and Katayama Chemical Industry Co. (Japan); wheat starch is available from Sigma; sweet potato starch is available from Wako Pure Chemical Industry Co. (Japan); and potato starch is available from Nakaari Chemical Pharmaceutical Co. (Japan).

The starch substrate can be a crude starch from milled whole grain, which contains non-starch fractions, e.g., germ residues and fibers. Milling may comprise either wet milling or dry milling. In wet milling, whole grain is soaked in water or dilute acid to separate the grain into its component parts, e.g., starch, protein, germ, oil, kernel fibers. Wet milling efficiently separates the germ and meal (i.e., starch granules and protein) and is especially suitable for production of syrups. In dry milling, whole kernels are ground into a fine powder and processed without fractionating the grain into its component parts. Dry milled grain thus will comprise significant amounts of non-starch carbohydrate compounds, in addition to starch. Most ethanol comes from dry milling. Alternatively, the starch to be processed may be a highly refined starch quality, for example, at least about 90%, at least 95%, at least 97%, or at least 99.5% pure.

4.2. Gelatinization and liquefaction of starch

As used herein, the term “liquefaction” or “liquefy” means a process by which starch is converted to less viscous and shorter chain dextrans. This process involves gelatinization of starch simultaneously with or followed by the addition of a PS4 variant. A thermostable PS4 variant is preferably used for this application. Additional liquefaction-inducing enzymes optionally may be added.

In some embodiments, the starch substrate prepared as described above is slurried with water. The starch slurry may contain starch as a weight percent of dry solids of about 10-55%, about 20-45%, about 30-45%, about 30-40%, or about 30-35%. The α -amylase is usually supplied, for example, at about 1500 units per kg dry matter of starch. To optimize α -amylase stability and activity, the pH of the slurry may be adjusted to the optimal pH for the PS4 variant. Other α -amylases may be added and may require different optimal conditions. Bacterial α -amylase remaining in the slurry following liquefaction may be deactivated by lowering pH in a subsequent reaction step or by removing calcium from the slurry.

The slurry of starch plus the PS4 variant may be pumped continuously through a jet cooker, which is steam heated from about 85°C to up to 105°C. Gelatinization occurs very rapidly under these conditions, and the enzymatic activity, combined with the significant shear forces, begins the hydrolysis of the starch substrate. The residence time in the jet cooker is very brief. The partly gelatinized starch may be passed into a series of holding tubes maintained at about 85-105°C and held for about 5 min. to complete the gelatinization process. These tanks may contain baffles to discourage back mixing. As used herein, the term “secondary liquefaction” refers the liquefaction step subsequent to primary liquefaction, when the slurry is allowed to cool to room temperature. This cooling step can be about 30 minutes to about 180 minutes, e.g. about 90 minutes to 120 minutes.

4.3. Processes of fermentation

Yeast typically from *Saccharomyces spp.* is added to the mash and the fermentation is ongoing for 24-96 hours, such as typically 35-60 hours. The temperature is between about 26-34°C, typically at about 32°C, and the pH is from about pH 3-6, typically around about pH 4-5.

In one embodiment, a batch fermentation process is used in a closed system, where the composition of the medium is set at the beginning of the fermentation and is not altered

during the fermentation. At the beginning of the fermentation, the medium is inoculated with the desired microbial organism(s). In this method, fermentation is permitted to occur without the addition of any components to the system. Typically, a batch fermentation qualifies as a “batch” with respect to the addition of the carbon source, and attempts are often made to control factors such as pH and oxygen concentration. The metabolite and biomass compositions of the batch system change constantly up to the time the fermentation is stopped. Within batch cultures, cells progress through a static lag phase to a high growth log phase and finally to a stationary phase, where growth rate is diminished or halted. If untreated, cells in the stationary phase eventually die. In general, cells in log phase are responsible for the bulk of production of product.

A suitable variation on the standard batch system is the “fed-batch fermentation” system. In this variation of a typical batch system, the substrate is added in increments as the fermentation progresses. Fed-batch systems are useful when catabolite repression likely inhibits the metabolism of the cells and where it is desirable to have limited amounts of substrate in the medium. Measurement of the actual substrate concentration in fed-batch systems is difficult and is therefore estimated on the basis of the changes of measurable factors, such as pH, dissolved oxygen and the partial pressure of waste gases, such as CO₂. Batch and fed-batch fermentations are common and well known in the art.

Continuous fermentation is an open system where a defined fermentation medium is added continuously to a bioreactor, and an equal amount of conditioned medium is removed simultaneously for processing. Continuous fermentation generally maintains the cultures at a constant high density, where cells are primarily in log phase growth. Continuous fermentation allows for the modulation of one or more factors that affect cell growth and/or product concentration. For example, in one embodiment, a limiting nutrient, such as the carbon source or nitrogen source, is maintained at a fixed rate and all other parameters are allowed to moderate. In other systems, a number of factors affecting growth can be altered continuously while the cell concentration, measured by media turbidity, is kept constant. Continuous systems strive to maintain steady state growth conditions. Thus, cell loss due to medium being drawn off should be balanced against the cell growth rate in the fermentation. Methods of modulating nutrients and growth factors for continuous fermentation processes,

as well as techniques for maximizing the rate of product formation, are well known in the art of industrial microbiology.

Following the fermentation, the mash is distilled to extract the ethanol. The ethanol obtained according to the process of the disclosure may be used as, *e.g.*, fuel ethanol; drinking ethanol, *i.e.*, potable neutral spirits or industrial ethanol. Left over from the fermentation is the grain, which is typically used for animal feed, either in liquid form or dried. Further details on how to carry out liquefaction, saccharification, fermentation, distillation, and recovery of ethanol are well known to the skilled person. According to the process of the disclosure, the saccharification and fermentation may be carried out simultaneously or separately.

5. Textile desizing compositions and use

Also contemplated are compositions and methods of treating fabrics (*e.g.*, to desize a textile) using PS4 variant. Fabric-treating methods are well known in the art (*see, e.g.*, U.S. Patent No. 6,077,316). For example, in one aspect, the feel and appearance of a fabric is improved by a method comprising contacting the fabric with a PS4 variant in a solution. In one aspect, the fabric is treated with the solution under pressure.

In one aspect, a PS4 variant is applied during or after the weaving of a textile, or during the desizing stage, or one or more additional fabric processing steps. During the weaving of textiles, the threads are exposed to considerable mechanical strain. Prior to weaving on mechanical looms, warp yarns are often coated with sizing starch or starch derivatives to increase their tensile strength and to prevent breaking. A PS4 variant can be applied during or after the weaving to remove these sizing starch or starch derivatives. After weaving, a PS4 variant can be used to remove the size coating before further processing the fabric to ensure a homogeneous and wash-proof result.

A PS4 variant can be used alone or with other desizing chemical reagents and/or desizing enzymes to desize fabrics, including cotton-containing fabrics, as detergent additives, *e.g.*, in aqueous compositions. A PS4 variant also can be used in compositions and methods for producing a stonewashed look on indigo-dyed denim fabric and garments. For the manufacture of clothes, the fabric can be cut and sewn into clothes or garments, which are afterwards finished. In particular, for the manufacture of denim jeans, different enzymatic finishing methods have been developed. The finishing of denim garment normally is initiated

with an enzymatic desizing step, during which garments are subjected to the action of amylolytic enzymes to provide softness to the fabric and make the cotton more accessible to the subsequent enzymatic finishing steps. A PS4 variant can be used in methods of finishing denim garments (e.g., a “bio-stoning process”), enzymatic desizing and providing softness to fabrics, and/or finishing process.

EXAMPLES

EXAMPLE 1

Determination of thermal melting points. Differential scanning calorimetry was used to characterize the thermal unfolding midpoint (T_m) of wild-type PS4 and the PS4 variants: CF135 (SEQ ID NO: 3 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF143 (SEQ ID NO: 4 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), CF149 (SEQ ID NO: 5 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus), and CF154 (SEQ ID NO: 6 with residues 419-429 of SEQ ID NO:1 fused at the C-terminus). The T_m was used as an indicator of the thermal stability of the various enzymes. Excess heat capacity curves were measured using an ultrasensitive scanning high-throughput microcalorimeter, VP-Cap DSC (MicroCal, Inc., Northampton, MA). Approximately 500 μ L of 500 ppm of protein was needed per DSC run, and the samples were scanned over a 30-120 $^{\circ}$ C temperature range using a scan rate of 200 $^{\circ}$ C/hr. The same sample was then rescanned to check the reversibility of the process. For the wild-type and variant proteins, the thermal unfolding process was irreversible. The buffer was 10 mM sodium acetate, pH 5.5, with 0.002 % Tween-20. T_m values for the wild-type PS4 and PS4 variants, as well as the increase in the T_m due to the mutations (ΔT_m), are shown in TABLE 1.

TABLE 1

	T_m ($^{\circ}$ C)	ΔT_m ($^{\circ}$ C) increase relative to wild type PS4
PS4 wild-type	66.5	
PS4 CF135	72.6	+ 6.1
PS4 CF143	73.3	+ 6.9
PS4 CF149	79.7	+ 13.3

	T _m (°C)	ΔT _m (°C) increase relative to wild type PS4
PS4 CF154	85.9	+ 19.5

All the PS4 variants showed an increase in the thermal unfolding midpoint relative to the wild-type PS4. The T_m for the wild-type PS4 relative to the mutations was wild-type PS4 < PS4 CF 135 < PS4 CF143 < PS4 CF149 < PS4 CF154.

5 **Measurement of thermostability.** Alternatively, the thermostability of a given PS4 variant was evaluated by measuring its half-life under an elevated temperature, because heat inactivation follows a 1st order reaction. For this, the residual amylase activity of a given variant was measured after it was incubated for 1-30 minutes at 72°C, 75°C, 80°C, or 85°C in (1) 50 mM sodium citrate, 5 mM calcium chloride, pH 6.5, (2) 50 mM sodium citrate, 0.5 M sodium chloride, 5 mM calcium chloride, pH 6.5, or (3) 50 mM sodium acetate, 0.5 M sodium chloride, 2 mM calcium chloride, pH 5.0. The Betamyl® assay (Megazyme, Ireland) was used to determine the residual amylase activity. The assay mix contains 50 μL of 50 mM sodium citrate, 5 mM calcium chloride, pH 6.5, with 25 μL enzyme sample and 25 μL Betamyl substrate (paranitrophenol(PNP)-coupled maltopentaose (Glc5) and alpha-glucosidase). One Betamyl unit is defined as activity degrading 0.0351 mole/min of PNP-coupled maltopentaose. The assay contained 50 μL of 50 mM sodium citrate, 5 mM calcium chloride, pH 6.5, and 25 μL of Betamyl substrate. The assay mixture was incubated for 30 min at 40°C, then stopped by the addition of 150 μL of 4% Tris. Absorbance at 420 nm was measured using an ELISA-reader, and the Betamyl activity was calculated according to the formula Activity = A₄₂₀ x d in Betamyl units/ml of enzyme sample assayed, with “d” being the dilution factor of the enzyme sample. The half-lives of various PS4 variants are shown in TABLE 7.

EXAMPLE 2

25 **Determination of starch liquefaction performance.** Starch liquefaction performance was measured for the wild-type PS4 and thermostable PS4 variants by the rate of reduction in viscosity of a starch liquefact. A Thermo VT550 viscometer was used to determine viscosity. A slurry comprising starch substrate and an appropriate amount of enzyme was poured into the viscometer vessel. The temperature and viscosity were recorded

during heating to 85°C, and incubation was continued for additional 60 to 120 minutes. Viscosity was measured as μNm as a function of time.

Wild-type PS4 liquefied starch at high temperature, e.g., 70-85 °C. This result was significant, in view of the melting temperature of the wild-type PS4 of 66.5 °C. The relatively high final viscosity obtained with the wild-type PS4, however, suggests that the wild-type PS4 has limited performance at these temperatures.

Liquefaction performance was compared between the full length, wild-type PS4 (“Amy3A”) and the PS4 variants CF135 and CF143. As shown in FIG. 1, the PS4 variants liquefied cornstarch at a rate comparable to Amy3A. Further, the final viscosity of the liquefact was lower using CF135 and CF143, indicating that these PS4 variants exhibited a superior performance to Amy3A in this assay.

Starch liquefaction with CF149 and CF154 versus SPEZYME™ Xtra. To test the ability of yeast to produce ethanol from corn liquefact generated using PS4 as an α -amylase, the thermostable PS4 variants CF135, CF143, CF149, and CF154 were compared to SPEZYME™ Xtra (Danisco US Inc., Genencor Division) in a conventional ethanol fermentation process run on liquefacts generated in a viscometer. A solution of Xtra at 4.86 mg/mL was added to 2.0 $\mu\text{g/g}$ dry solids. PS4 variant CF149 (purified, 32.7 mg/mL) was added to 46.7 $\mu\text{g/g}$ dry solids, and PS4 variant CF154 (purified, 15.9 mg/mL) was added to 46.7 $\mu\text{g/g}$ dry solids. The starch solution was 30% dry solids corn flour (15 g total dry solids), pH 5.8, where the pH was adjusted with H_2SO_4 or NH_4OH , as necessary. The starch solution was preincubation for 10 min at 70°C before the enzyme was added. The viscometer holding the reaction was held 1 min at 70°C, 100 rpm rotation. The temperature was ramped to 85°C over 12 min, with 75 rpm rotation. The reaction then proceeded at 85°C for 20 min at 75 rpm rotation.

Fermentation using the CF149, CF154, or SPEZYME™ Xtra liquefacts. Two viscometer runs were performed for each enzyme in order to generate enough liquefact for one 50 g fermentation. After each viscometer run, liquefact was collected; liquefact from each pair of viscometer runs was pooled. Fermentations were run in duplicate in 125 mL Erlenmeyer flasks. Replicate fermentations were started on separate days due to timing constraints.

For each individual 50 g fermentation, the pH was adjusted to pH 4.3. The % dry solids was left unadjusted. Urea was added at 400 ppm final concentration. Red Star Ethanol Red yeast were added at a ratio of 0.33% (w/w); the yeast were prehydrated as a 33% (w/v) slurry before aliquoting 500 μ L into flasks.

5 Flasks were incubated at 32 °C with stirring at 400 rpm for 48 h fermentation. The PS4 liquefact fermentations slowed slow stirring, whereas the Xtra liquefact fermentations did not stir at all. Samples were taken at t = 0, 14 h, 23 h, 39 h, and 48 h and analyzed by HPLC.

Results. Final ethanol yields from the fermentations using PS4 liquefacts averaged 10 3.2% and 3.3% (v/v), whereas the final ethanol yields from the fermentations using Xtra liquefact averaged 2.2% (v/v). See FIG. 2, TABLE 2. Ethanol levels were higher throughout the fermentations for the PS4 liquefacts than for the Xtra liquefact. Fermentations on the PS4 liquefacts appeared to start with both more glucose and maltose, both of which diminished by 14 hours as ethanol levels increased, as apparent from a comparison of FIG. 2 and FIG. 3.

15 **TABLE 2**

Sample	Final EtOH (v/v)%
Xtra liquefact	2.20
PS4 CF149 liquefact	3.26
PS4 CF154 liquefact	3.19

HPLC analysis of the liquefaction reaction was used to determine levels of high-DP sugars. FIG. 4 depicts the decrease in concentration of DP-2 sugars over time. FIGS. 5-7 show the full range of DP-n sugars produced over time (hours) from the initiation of the reaction. PS4 variant liquefacts started with significantly lower amounts of DP-4 sugars than 20 the Xtra liquefact, and relatively higher amounts of DP-2, DP-3, and DP-4 sugars. DP-3 levels remained fairly constant for the PS4 liquefacts throughout the fermentations, and appeared to drop slightly for the Xtra liquefact. DP-4 peaks also remained fairly constant for all three liquefacts. The major carbohydrate produced by the PS4 variants was maltotriose 25 (DP-3).

EXAMPLE 3

Crystallization and structure determination of native PS4. Crystals were obtained for the wild-type PS4 catalytic core using the Hampton PEG6000 screen. Large single crystals were obtained in 10-30% PEG6000, over the pH range 6-8. Crystals with similar morphology also were obtained by storing the protein stock solution at 4°C without precipitant.

Data were collected at room temperature with an R-AXIS IV using CuK α radiation from an RU200 generator, and processed with d*TREK (MSC, The Woodland, Texas). The cell dimensions were almost identical to those of crystal form II of the *P. stutzeri* G4-amylase. See Yoshioka *et al.*, *J. Mol. Biol.* 271: 619-28 (1997); Hasegawa *et al.*, *Protein Eng.* 12: 819-24 (1999). Molecular replacement calculations thus were not necessary, and rigid body refinement was used to begin structure refinement. The G4-amylase structure from RCSB Protein Database Base (PDB) Accession No. 1JDC was used with the ligand deleted. The amino acid differences between each homologue were readily apparent in 2Fo-Fc difference maps, and the correct *P. saccharophila* structure was built manually using COOT. The structure was subsequently refined using REFMAC5, included in the Collaborative Computational Project, Number 4 (CCP4) suite of programs. See CCP4, "The CCP4 Suite: Programs for Protein Crystallography," *Acta Cryst.* D50: 760-63 (1994). Water molecules were identified using COOT, and refinement was completed with REFMAC5. Ligand atom labels and the geometry file for REFMAC5 were generated using PRODRG, available at the Dundee PRODRG2 Server.

EXAMPLE 4

Overall structure of PS4. The native structure of the PS4 catalytic core consists of 418 amino acids, 2 calcium atoms and 115 water molecules. The structure of native PS4 with acarbose, a pseudo-tetra-saccharide, consists of 418 amino acids, 2 calcium atoms, 76 water molecules, and an acarbose derived inhibitor with 7 sugar residues. The catalytic core of PS4 has a conserved 3 domain structure common to GH13 enzymes. Domain A consists of a (β/α)₈ barrel. Domain B is an insertion into this barrel, between β -sheet 3 and α -helix 3, which is relatively unstructured in this enzyme, and which contains the conserved calcium ion. Domain C is a five-stranded anti-parallel β -sheet in a Greek key motif. Domain C packs

against the C-terminus of Domain A. In common with *P. stutzeri* MO-19 G4-amylase, there is a second calcium ion bound at the N-terminal region.

EXAMPLE 5

Preparation of inhibitor-bound PS4. Acarbose was added to the mother liquor of crystals grown in storage buffer, and the liquor was left to incubate at 4°C for 24 hours. Data were collected at room temperature and processed as described above. The ligand was fitted manually into the observed difference density, and the protein ligand complex was refined with REFMAC5. See FIG. 8.

EXAMPLE 6

Analysis of enzyme inhibitor interactions. Enzyme-inhibitor interactions were analyzed and characterized using the Chemical Computing Group (Montreal, Canada) Molecular Operating Environment (MOE) program, according to the parameters and instructions supplied with the program. Inhibitor binding to PS4 is depicted at FIG. 8. The nomenclature for sugar binding sub-sites of the enzyme is that of Davies *et al. Biochem J.* 321: 661-72 (1997) and is superimposed on the depiction of the bound inhibitor in FIG. 9. The inhibitor was found in a deep cleft in the surface of the molecule, at the C-terminal end of the (β/α)₈ barrel. Inspection of difference Fourier maps of data collected from native crystals of PS4 and crystals soaked for 24 hours with acarbose revealed a very clear and continuous difference density for at least seven sugar residues bound to the -4 to +3 sugar sub-sites in the enzyme active-site. This indicates that crystalline PS4 reacts with acarbose, resulting in a transglycosylation product that binds across the active-site of the enzyme. The nature of the transglycosylated inhibitor was deduced by the presence or absence of difference density for O6 atoms and the conformation of the sugar rings. The difference density for an O6 atom was evident at the +3, +2, -1, -2, -3, and -4 sugars, but not at the +1 sugar. Additionally, the sugars at +3, +2, -2, -3, and -4 had the chair conformation, indicating that glucose residues were bound at these sugar sub-sites. At the -1 sugar sub-site, the sugar was in a boat conformation, indicating that it is the cyclitol sugar. At the +1 sugar sub-site, the chair conformation and lack of a difference density for an O6 atom indicated that this sugar is the dideoxy sugar. The boat conformation of the cyclitol sugar resulted in a distinct bend in the

inhibitor. The only clear differences in the structure of the protein with and without bound inhibitor were changes in the conformation of Glu 219 and Asp 294 and displacement of water molecules upon inhibitor binding.

EXAMPLE 7

Conformation of the inhibitor at the non-reducing end. A bifurcation in the positive difference density in the Fo-Fc difference map was seen when the data obtained for PS4 without inhibitor was refined to the data obtained with the bound inhibitor. In the -4 sugar conformation, there was a positive density corresponding to the C1, O1, C3, O3, and O6 atoms, but not the C2, O2, C4, O5, and C6 atoms. *See* FIG. 9. This information revealed that there were apparently two conformations of the -4 sugar. The first conformation corresponded to exo-specificity, as seen in the *P. stutzeri* enzyme. *See* Hasegawa *et al.*, *Protein Eng.* 12: 819-24 (1999). The second conformation appeared to correspond to endo-specificity, as no recognition of the reducing end of the inhibitor was seen.

EXAMPLE 8

Enzyme/inhibitor interactions. The types of interactions between the PS4 enzyme and the inhibitor can be divided into hydrogen bonding, hydrophobic interactions, and water-mediated interactions. There were 20 hydrogen bonds between the protein and the inhibitor. The conserved GH13 catalytic residues, D193, E219, and D294, were found clustered around the -1 and +1 sugars. *See* FIG. 9 The side-chain positions of E219 and D294 were slightly different from the native structure, and likely are due to small conformational changes induced by inhibitor binding. The OE2 of E219 was 2.7 Å from the nitrogen atom of the inhibitor, which mimicked the oxygen atom of the glycosidic bond. The OD2 of D194 formed a hydrogen bond to the O6 of the -1 sugar. The third invariant acidic amino-acid, D294, hydrogen bonded to the O2 and O3 hydroxyls of the -1 sugar in a bidentate interaction.

Enzyme recognition of the -4 sugar at the non-reducing end of the inhibitor occurred via hydrogen bonding between (1) the side chain carboxylate oxygen OE1 of E160 and the O1 and O6 of the -4 sugar residue, (2) the OG of S161 and the O6, and (3) the main-chain nitrogen of G158 to O1 of the same sugar residue. Other key hydrogen bond interactions were hydrogen bonds between the backbone carbonyl oxygen of H307 and the O3 oxygen of

the +3 sugar, OE2 of E226 and O1 of the +2 sugar, NH1 of R196 and O3 of the -1 sugar, OE1 of E219 and O2 of the -1 sugar, NE2 of H293 to O3 of the -1 sugar, and OE1 of Q305 to O2 of the -2 sugar. *See* FIG. 9.

Five water molecules mediated further hydrogen bonds from the protein to the inhibitor. In the crystal structure, H₂O number 456 hydrogen bonded to the O2 and O3 of the +1 sugar, the backbone carbonyl oxygen atom of E219, and the backbone nitrogen atom of W221. H₂O number 464 hydrogen bonded to the O5 and O6 of the -3 sugar, the O6 of the -2 sugar, and the OG of 564. H₂O number 472 hydrogen bonded to the O6 of the -2 sugar, the NE1 of W66, and OE1 of E76. H₂O number 516 hydrogen bonded to the O6 of the -2 sugar, the OD2 of D62, and the OE1 of E76. *See* FIG. 9.

There were nine significant hydrophobic interactions. Of these, four were co-planar stacking interactions between sugar residues +3, +2, -1, and -3 with W308, W221, Y78 and W66, respectively. There were four additional non-planar interactions of the inhibitor with W25, F79, F156, I157, and F194. Notably, F156 and I157 formed a hydrophobic peninsula around which the inhibitor wraps, allowing its non-reducing end to hydrogen bond to the protein. *See* FIG. 9.

EXAMPLE 9

Altering the exo- and endo-activity of PS4 by protein engineering. Enzymes with exo-activity generally have an active-site cleft that is blocked at one end, only allowing substrate binding at the ends of macromolecular chains. In PS4, the non-reducing end of the active-site was restricted by the large loop between S64 and G75, but it was not completely blocked. There was indeed sufficient space for an amylose chain to pass between this loop and the loop formed by residues 155-163. In PS4, the exo-amylase activity appeared to be driven by hydrogen bonding of the non-reducing end of the amylose chain to G158, E160, and S161, which was very similar to that seen in the *P. stutzeri* G4-amylase. Given the total number of interactions between the substrate, as mimicked by the enzyme inhibitor complex, the energy involved in recognition of the non-reducing end of the amylase chain appeared small compared to the total energy involved in binding, amounting to only four hydrogen bonds out of a total of 23, as well as four coplanar stacking interactions. The F(acarbose)-F(native) difference map showed two conformations for the inhibitor at the non-reducing end.

Together this suggested that the hydrogen bonding to the non-reducing end of the amylose chain was insufficiently strong to provide for 100% exo-specificity, which was reported in the enzymological characterization of the enzyme. Thus, the crystal structure of an inhibitor complex of PS4 provided additional evidence for mixed exo-and endo-cleavage of starch by this enzyme. This further suggested that protein engineering can be used to alter the exo-and endo-activity of the enzyme, and thus the products of the reaction.

EXAMPLE 10

Site-directed mutagenesis. Site-directed mutagenesis was used to produce PS4

variants. Representative examples of PS4 variants having single amino acid substitutions are shown in TABLE 3. Mutations were introduced into a nucleic acid encoding the PS4 enzyme, using the Quick Change™ method (Stratagene, California), according to instructions supplied with the kit with some modifications. Briefly, a single colony was picked and inoculated in 3 ml LB (22 g/l Lennox L Broth Base, Sigma) supplemented with 50 µg/ml kanamycin (Sigma) in a 10 ml Falcon tube. After overnight incubation at 37°C at 200 rpm, the culture was spin down at 5000 rpm for 5 min. The medium was removed and the double-stranded DNA template was prepared using QIAGEN columns (QIAGEN). Primers were designed according to the manufacturers' protocol. For example, TABLE 5 lists primers that were used to generate backbone pMS382 based on the sequence of PS4 as shown in SEQ ID NO: 1 or 2; and TABLE 6 lists primers that were used to generate variants of pMS382 at position E223.

Next, PCR was performed to synthesize the mutant strand. The PCR reaction mix contained the following:

2.5 µl	10 X QuickChange Multi reaction buffer
0.75 µl	QuickSolution
X µl	primers (10 pmol for primers of 28-35 nt; 7 pmol for primers of 24-27 nt; or 5 pmol for primers of 20-23 nt)
1 µl	dNTP mix
X µl	ds-DNA template (200 ng)
1 µl	QuickChange Multi enzyme blend (2.5 U/µl) (<i>PfuTurbo</i> DNA polymerase)

X μ l dH₂O (to a final volume of 25 μ l)

The PCR reaction was performed in an Eppendorf thermal cycler for 35 cycles of denaturation (96°C for 1 min), primer annealing (62.8°C for 1 min), and elongation (65°C for 15 min), and then hold at 4°C. For each amplification reaction, 2 μ l of *DpnI* restriction enzyme (10 U/ μ l) was added, and the mixture was incubated at 37°C for ~3 hr.

The *DpnI*-treated DNA was then used to transform XL10-Gold® Ultracompetent cells (Stratagene). XL10-Gold® cells were thawed on ice. For each mutagenesis reaction, 45 μ l cells were added to a pre-chilled Falcon tube. Subsequently, 2 μ l of beta-mercaptoethanol mix was added to each tube. The mixture was incubated on ice for 10 min with swirling every 2 min. Then, 1.5 μ l *DpnI*-treated DNA was added to each aliquot of cells, and the mixture was incubated on ice for 30 min. The sample was subject to a heat-pulse of 30 sec at 42°C, and was placed on ice for another 2 min. 0.5 ml of preheated NZY⁺ broth was added to each sample, and incubation was carried at 37°C for 1 hr with shaking at 225-250 rpm. 200 μ l of each transformation reaction were plated on LB plates (33.6 g/l Lennox L Agar, Sigma) supplemented with 1% starch and 50 μ g/ml kanamycin. The plates were incubated overnight at 37°C. Individual colonies harboring the desired mutations were identified by DNA sequencing and subjected to plasmid preps to harvest plasmids with the desired mutations.

Transformation into *Bacillus subtilis*. *Bacillus subtilis* (strain DB104A; Smith et al., *Gene* 70, 351-361 (1988)) is transformed with the mutated plasmid DNA according to the following protocol.

A. Media for protoplasting and transformation

2 x SMM	per litre: 342 g sucrose (1 M); 4.72 g sodium maleate (0.04 M); 8.12 g MgCl ₂ ·6H ₂ O (0.04 M); pH 6.5 with concentrated NaOH. Distribute in 50-ml portions and autoclave for 10 min.
4 x YT (1/2 NaCl)	2 g Yeast extract + 3.2 g Tryptone + 0.5 g NaCl per 100 ml.
SMMP	mix equal volumes of 2 x SMM and 4 x YT.
PEG	10 g polyethyleneglycol 6000 (BDH) or 8000 (Sigma) in 25 ml 1 x SMM (autoclave for 10 min.).

B. Media for plating/regeneration

agar	4% Difco minimal agar. Autoclave for 15 min.
sodium succinate	270 g/l (1 M), pH 7.3 with HCl. Autoclave for 15 min.

phosphate buffer 3.5 g K_2HPO_4 + 1.5 g KH_2PO_4 per 100ml. Autoclave for 15 min.

$MgCl_2$ 20.3 g $MgCl_2 \cdot 6H_2O$ per 100 ml (1 M).

casamino acids 5% (w/v) solution. Autoclave for 15 min.

5 yeast extract 10 g per 100 ml, autoclave for 15 min.

glucose 20% (w/v) solution. Autoclave for 10 min.

DM3 regeneration medium: mix at 60°C (water bath; 500-ml bottle):

250 ml sodium succinate

50 ml casamino acids

10 25 ml yeast extract

50 ml phosphate buffer

15 ml glucose

10 ml $MgCl_2$

100 ml molten agar

15 Add appropriate antibiotics: chloramphenicol and tetracycline, 5 µg/ml; erythromycin, 1 µg/ml. Selection on kanamycin is problematic in DM3 medium: concentrations of 250 µg/ml may be required.

C. *Preparation of protoplasts*

20 Use detergent-free plastic or glassware throughout.

Inoculate 10 ml of 2 x YT medium in a 100-ml flask from a single colony. Grow an overnight culture at 25-30°C in a shaker (200 rev/min).

Dilute the overnight culture 20 fold into 100 ml of fresh 2 x YT medium (250-ml flask) and grow until $OD_{600} = 0.4-0.5$ (approx. 2 h) at 37°C in a shaker (200-250 rev/min).

25 Harvest the cells by centrifugation (9000 g, 20 min, 4°C).

Remove the supernatant with pipette and resuspend the cells in 5 ml of SMMP + 5 mg lysozyme, sterile filtered.

Incubate at 37°C in a waterbath shaker (100 rpm).

30 After 30 min and thereafter at 15 min intervals, examine 25 µl samples by microscopy. Continue incubation until 99% of the cells are protoplasted (globular

appearance). Harvest the protoplasts by centrifugation (4000 g, 20 min, RT) and pipet off the supernatant. Resuspend the pellet gently in 1-2 ml of SMMP.

The protoplasts are now ready for use. Portions (e.g. 0.15 ml) can be frozen at -80°C for future use (glycerol addition is not required). Although this may result in some reduction of transformability, 106 transformants per ug of DNA can be obtained with frozen protoplasts).

D. Transformation

Transfer 450 µl of PEG to a microtube.

Mix 1-10 µl of DNA (0.2 µg) with 150 µl of protoplasts and add the mixture to the microtube with PEG. Mix immediately, but gently.

Leave for 2 min at room temperature, and then add 1.5 ml of SMMP and mix.

Harvest protoplasts by microfuging (10 min, 13,000 rpm (10,000-12,000 g)) and pour off the supernatant. Remove the remaining droplets with a tissue.

Add 300 µl of SMMP (do not vortex) and incubate for 60-90 min at 37°C in a waterbath shaker (100 rpm) to allow for expression of antibiotic resistance markers. (The protoplasts become sufficiently resuspended through the shaking action of the waterbath.) Make appropriate dilutions in 1 x SSM and plate 0.1 ml on DM3 plates

Fermentation of PS4 Variants in Shake Flasks. The shake flask substrate is prepared by dissolving the following in water:

Yeast extract	2% (w/v)
Soy Flour	2% (w/v)
NaCl	0.5% (w/v)
Dipotassium phosphate	0.5% (w/v)
Antifoam agent	0.05% (w/v).

The substrate is adjusted to pH 6.8 with 4 N sulfuric acid or sodium hydroxide before autoclaving. 100 ml of substrate is placed in a 500 ml flask with one baffle and autoclaved for 30 minutes. Subsequently, 6 ml of sterile dextrose syrup is added. The dextrose syrup is prepared by mixing one volume of 50% w/v dextrose with one volume of water followed by autoclaving for 20 minutes.

The shake flasks are inoculated with the variants and incubated for 24 hours at 35°C and 180 rpm in an incubator. After incubation cells are separated from broth by

centrifugation (10.000 g in 10 minutes) and finally, the supernatant is made cell free by microfiltration at 0.2 μm . The cell free supernatant is used for assays and application tests.

Enzymatic characterization of PS4 variants. Exo-amylase activity of PS4 variants produced by mutagenesis was assayed using the Betamyl® assay (Megazyme, Ireland). One Betamyl unit is defined as activity degrading 0.0351 mole/min of PNP-coupled maltopentaose. The assay contained 50 μL of 50 mM sodium citrate, 5 mM calcium chloride, pH 6.5, and 25 μL of Betamyl substrate. The assay mixture was incubated for 30 min at 40°C, then stopped by the addition of 150 μL of 4% Tris. Absorbance at 420 nm was measured using an ELISA-reader, and the Betamyl activity was calculated according to the formula $\text{Activity} = A_{420} \times d$ in Betamyl units/ml of enzyme sample assayed, with “d” being the dilution factor of the enzyme sample. Endo-amylase activity was determined using the Phadebas blue assay (Pharmacia and Upjohn Diagnostics AB), performed according to the manufacturer’s instructions. The exo-activity index is the ratio of Betamyl activity to Phadebas activity. The wild-type PS4 had a Betamyl/Phadebas activity ratio of 50. Variants with ratios lower than 50 are more endo-specific than the wild-type. Those with a ratio greater than 50 are more exo-specific. The Betamyl and Phadebas activity measured for the PS4 variants and their ratios of Betamyl to Phadebas activity are listed in TABLE 7. The mutations in the above TABLE 7 are listed with reference to the sequence of the respective backbone that is noted at the upper left corner of each table. “Na-Acet.” stands for sodium acetate; “Na-citr.” stands for sodium citrate; 72, 75, 80, or 85 indicates the temperature in °C at which the half-lives have been determined as described in Example 1; “Beta” stands for the Betamyl activity as described in Example 10; “Phad” stands for the Phadebas activity as described in Example 10; and “B/P” stands for the ratio of Betamyl activity to Phadebas activity.

EXAMPLE 11

Protein engineering of PS4. Active site residues close to the hydrolyzed glycosidic bond between the +1 and –1 residues were not mutated, as changes to these residues would be expected to affect the catalytic reaction itself, rather than the degree of exo-specificity. *See* FIG. 9. The residues W66, I157, E160, S161, R196, W221, K222, H307, and W308, were

targeted for mutagenesis and characterization, based on the enzyme inhibitor complex information disclosed above. K222 is part of a salt-bridge network that includes R196 and E226, which interact with the substrate. These residues were chosen for mutagenesis, as changes to these residues may alter substrate binding. Mutant libraries of the whole PS4 protein also were prepared, using error-prone PCR libraries of the gene, made according to procedures well known in the art.

Mutations to the -4 binding-site. An analysis of the mutant E160D revealed no effect on the Betamyl/Phadebas activity ratio. To test if exo-activity required non-reducing sugar recognition by residue 160, the mutant E160G also was made. In this case, the Betamyl/Phadebas ratio was 12, representing a significant increase in endo-activity. Confirmation that an E or D at residue 160 was critical for exo-specificity was confirmed by the mutations of E160 to P, F, R, S, and L, which significantly increased endo-specificity. This clearly demonstrated the requirement of recognition of the non-reducing end sugar by E/D160 for exo-specificity. The mutation S161A likewise had a significant effect on endo-activity, with a Betamyl/Phadebas ratio of 18.

Mutations to the -3 binding-site. Five mutations of W66 were obtained. The conservative mutations to L, V, F, and M had little effect on exo-specificity. The mutation W66S, however, increased exo-specificity and exhibited a lower expressed activity.

Mutations to the -2 binding site. Three mutations to Q305 were made. Mutations Q305T and Q305L reduced exo-specificity significantly. By contrast, Q305E had no appreciable effect on exo-specificity.

Mutations to the +2 binding-site. Three mutations at R196 exhibited a large increase in exo-specificity. R196V had greatest exo-specificity, followed by R196H and R196P. The mutant H307L had a similar exo-specificity to these R196 mutants.

Mutations to the +3 binding-site. Mutations to W221 had very low expressed activity. Only W221A had sufficient expressed activity for characterization, and it had modestly increased exo-activity. Four mutations to W308, W308A, W308S, W308L and W308S, had significant expressed activity. All four mutations showed significant improvement in exo-specificity, the best being W308S.

The mutation K222T exhibited the most exo-activity. The side-chain of K222 did not interact directly with the substrate, yet mutation of this residue gave the largest positive

increase in exo-specificity. The increase in exo-activity was not likely an effect on the neighboring W221, as mutation of W221 had only a modest effect on specificity. An analysis of the region around K222 revealed that it was part of an ion-pair network. K222 ion-paired with D254, which also ion-paired with R196. R196 in turn ion-paired with E226. R196 was positioned to hydrogen bond with the O2 and O3 of the +2 sugar. E226 hydrogen bonded to the +2 sugar. Accordingly, the large increase in exo-specificity of the K222T mutation may be due to a simultaneous reorientation of R196 and E226, which weakens substrate binding to the +2 sugar.

In summary, mutations to the – binding sub-sites increased the endo-specificity of the enzyme. The data also revealed that mutations to the + binding sub-sites could greatly increase exo-specificity. Strong interactions between the substrate binding-site and the amylose chain end promoted exospecificity. Similarly, weakening these interactions increased the endo-specificity of the enzyme. The effect of mutations to the “+” binding sub-sites revealed a delicate balancing of interactions throughout the substrate binding-site. Further, the relative strength of substrate interactions in the – binding sub-sites versus the strength of interactions in the + binding sub-sites determined the degree of exo-specificity of the enzyme. Changes that decrease the affinity of the “–” binding sub-sites relative to the + binding sub-sites increased endo-specificity. Conversely, changes that decrease the affinity of the + binding sub-sites relative to the – binding sub-sites increased exo-specificity.

It will be apparent to those skilled in the art that various modifications and variation can be made to the compositions and methods of using the same without departing from the spirit or scope of the intended use. Thus, it is the modifications and variations provided they come within the scope of the appended claims and their equivalents.

TABLE 3 Single amino acid substitutions in representative PS4 variants.

A3S	G70D	V113I	G134C	G158T	A179N	G223P	W232P	G303L	R316P
A3T	G70K	N116D	R137C	G158F	A179R	G223I	W232Q	G303E	R316K
P7S	G70E	N119S	N138D	G158P	A179E	G223L	W232R	G303D	W323M
A8N	G70S	N119G	N138E	G158I	A179T	G223V	W232S	Q305E	T324L
G9A	G70Q	N119Y	N138S	G158A	R182S	G223C	W232Y	Q305T	T324M
H13R	G70A	N119E	C140R	G158V	R182H	G223T	W232T	Q305L	T324A
N26E	G70V	G121W	C140A	G158L	R182M	G223S	R233H	H307D	S325G
N26D	G70L	G121A	A141S	G158Q	R182D	G223Y	N234R	H307L	S334R
P32S	G70P	G121F	A141P	G158C	R182G	G223W	A236E	H307R	S334Q
N33Y	K71R	G121L	D142N	E160D	S183G	G223Q	S237G	H307K	S334H
D34N	K71M	G121T	D142G	S161V	G184Q	G223N	S237D	H307G	S334A
I38M	S72E	G121S	D142E	S161A	G188A	G223D	W238Q	H307P	S334M
I46F	S72K	G121E	P143T	S161T	G188H	G223H	W238G	H307I	S334L
D49V	S72N	G121K	G144E	S161K	G188T	G223K	W238K	H307S	S334P
D62N	S72T	G121R	N145D	S161P	G188S	G223R	W238R	H307M	H335M
F63L	G73M	G121H	N145S	S161G	F192Y	G223M	W238P	H307Q	W339E
F63A	G73S	G121M	Y146G	S161R	F192F	G223A	W238E	H307V	W339A
F63D	G73T	G121V	Y146E	S161H	F192M	G223E	Q239L	H307W	Y341E
F63E	G73N	G121P	Y146D	L163M	V195D	G223F	V253G	H307Y	Y341C
F63V	G73L	G121I	N148S	N164R	R196P	S225G	D255V	H307C	D343E
S64T	G73E	G121D	N148K	G166N	R196Q	S225E	A257V	H307F	R353T
S64N	G73D	Y122W	D149V	P168L	R196T	S225V	E260R	H307E	R358A
T67V	G74S	Y122A	D149L	Q169R	R196K	E226W	E260K	W308C	R358T
T67K	G75C	Y122Q	D149H	Q169K	R196Y	E226C	N264D	W308T	R358L
T67Q	G75S	Y122E	C150A	Q169V	R196S	E226D	V267I	W308K	R358V
T67H	G75R	P123S	D151W	Q169G	R196G	E226G	D269V	W308N	R358Q
T67R	G75Y	D124S	D151A	Q169E	R196A	Y227G	D269S	W308R	R358E
T67G	G75F	K125E	D151V	Q169N	R196V	Y227T	D269N	W308S	R358N
T67N	G75W	K125G	G153D	Q169D	Y198W	Y227D	K271L	W308G	R358G
D68C	G75E	K125A	S334K	I170M	Y198F	Y227K	K271Q	W308Q	S367R
D68E	E76V	K125W	S334T	I170E	A199P	Y227C	K271A	W308A	S367Q
G69M	G100A	K125D	G153A	I170L	P200G	S229N	H272Q	A309T	S379G
G69I	G100S	K125Q	D154G	I170K	P200A	S229P	G276R	A309E	D390E
G69H	G104R	K125P	D154E	I170N	R202K	W232F	W282S	A309M	S399P
G69E	G104N	E126N	D154Y	L178N	S208T	W232G	V285A	A309V	S420G
G69A	G106K	E126D	F156Y	L178W	S213N	W232H	V290I	A309I	D422N
G69R	V107M	N128E	I157L	L178Q	L220A	W232I	T295C	A309P	D422Q
G69P	L110F	P130S	I157V	L178F	L220T	W232K	Y297H	D312E	D422P
G69T	D112E	A131T	I157M	A179P	K222Y	W232L	G300E	R316Q	G424S
G69K		G134R	G158S	A179S	K222M	W232N	N302K	R316S	G424D

TABLE 4

Backbone	Mutations
J2	V113I, G134R, A141P, I157L, Y198F, G223A, V290I, H307L, S334P, D343E
d3	N33Y, D34N, K71R, G134R, A141P, I157L, L178F, A179T, G223A, H307L, S334P, D343E
pMD3	N33Y, D34N, G121D, G134R, A141P, I157L, L178F, A179T, G223A, H307L, S334P
pMD55	N33Y, D34N, G121F, G134R, A141P, I157L, L178F, A179T, G223A, H307L, S334P
pMD74	N33Y, D34N, G121A, G134R, A141P, I157L, L178F, A179T, G223A, H307L, S334P
pMD85	N33Y, D34N, G121F, G134R, A141P, I157L, L178F, A179T, G223E, H307L, S334P
pMD86	N33Y, D34N, G121A, G134R, A141P, I157L, L178F, A179T, G223E, H307L, S334P
pMD96	N33Y, D34N, G121F, G134R, A141P, I157L, S161A, L178F, A179T, G223E, H307L, S334P
pMD153	N33Y, D34N, G121F, G134R, A141P, Y146G, I157L, G158T, S161A, L178F, A179T, G223E, S229P, H307L, A309P, S334P
pMD153d1	N33Y, D34N, G121F, G134R, A141P, Y146G, I157L, G158T, S161A, L178F, A179T, G223E, S229P, H307L, A309P, S334P
pMD172	N33Y, D34N, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, G303E, H307L, A309P, S334P
pMD212	N33Y, D34N, G70D, G121F, G134R, A141P, N145D, Y146G, I157L, G158T, S161A, L178F, A179T, G223E, S229P, H307L, A309P, S334P, W339E
pMD230	N33Y, D34N, G121F, G134R, A141P, N145D, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H272Q, G303E, H307L, A309P, S334P

TABLE 4

Backbone	Mutations
pMD248	N33Y, D34N, G121F, G134R, A141P, N145D, Y146G, I157L, L178F, A179T, G223E, S229P, H272Q, G303E, H307L, S334P
pMD253	N33Y, D34N, G121D, G134R, A141P, Y146G, I157L, L178F, A179T, G223E, S229P, H272Q, G303E, H307L, A309P, S334P
pMS281	N33Y, G121F, G134R, A141P, N145D, Y146G, I157L, S161A, L178F, A179T, G223F, S229P, H272Q, G303E, H307L, A309P, S334P
pMS284	N33Y, D34N, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H272Q, G303E, H307L, A309P, S334P
pMS292	N33Y, D34N, G121F, G134R, A141P, N145D, Y146G, I157L, S161A, L178F, A179T, G223F, S229P, H272Q, H307L, A309P, S334P
pMS382	N33Y, D34N, G70D, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H307K, A309P, S334P
pMS382d1	N33Y, D34N, G70D, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H307K, A309P, S334P

TABLE 5. Primers used for pMS382 backbone.

SEQ ID NO:	Mutation	5' Oligo Sequence 3'	modification	Strand	Purpose
9	N33Y, D34N	GCGAAGCGCCCTACAACTGGTACAA C	5' phosphate	(+)	MSDM
10	G7OK	CTGGACGGATGGAgatAAAAGCGGAG GCGGC	5' phosphate	(+)	MSDM
11	G121F	CCAATCACATGAACCGCttcTACCCGG ACAAGGAG	5' phosphate	(+)	MSDM
12	G134R	CTGCCGGCCGGCCAGcGCTTCTGGCG		(+)	SDM
13	G134R-	cgccagaagcgctggccggccggcag		(-)	SDM
14	A141P	CGCAACGACTGCGCCGACCCGGG	5' phosphate	(+)	MSDM
15	Y146G	GATCCGGGCAACggcCCCAACGACT GCG	5' phosphate	(+)	MSDM
16	I157L	GACGGTGACCGCTTCcTgGGCGGCGA GTCG		(+)	SDM
17	I157L-	cgactcgccgccaggaagcggtcaccgtc		(-)	SDM
18	S161A	GGGCGGCGAGGcgGACCTGAACA	5' phosphate	(+)	MSDM
19	L178F, A179T	CGCGACGAGTTTACCAACCTGCG	5' phosphate	(+)	MSDM
20	G223E (gag)	GGCGAGCTGTGGAAAGDNCCTTCT GAATATCCGAG	5' phosphate	(+)	MSDM
21	S229P	GCCTTCTGAATATCCGccgTGGGACT GGCGCAAC	5' phosphate	(+)	MSDM
22	L307K	CAAAATGAAGGACAACATaaaTGGC CGCTTCAAGATGGCC	5' phosphate	(+)	MSDM
23	A309P	GCACCTGTGGccgCTGCAGGACG	5' phosphate	(+)	MSDM
24	S334P, D343E	GTA CTGGccgCACATGTACGACTGG GGCTACGGCgaaTTCATC		(+)	SDM
25	S334P, D343E-	gatgaattcgccgtagccccagtcgtacatgtcgccg ccagtac		(-)	SDM
26	E343D	GGGCTACGGCGACTTCATCCGCCAG	5' phosphate	(+)	MSDM

TABLE 6. Primers used to generate PS4 variants of pMS382 at position E223.

SEQ ID NO:	Mutation	5' Oligo Sequence 3'	modification	Strand	Purpose
27	E223A	CGTCGGCGAACTTTGGAAAgcaCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
28	E223G	CGGCGAACTTITGGAAAggaCCGAGCGAATATCCG	5' phosphate	(+)	MSDM
29	E223S	CGTCGGCGAACTTTGGAAAagcCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
30	E223K	GGCGAACTTTGGAAAaaaCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
31	E223I	CGTCGGCGAACTTTGGAAAatcCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
32	E223L	CGTCGGCGAACTTTGGAAAActgCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
33	E223V	GGCGAACTTTGGAAAgtcCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
34	E223F	CGTCGGCGAACTTTGGAAAtttCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
35	E223C	CGTCGGCGAACTTTGGAAAAtgcCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
36	E223P	GGCGAACTTTGGAAAaccgCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
37	E223T	CGTCGGCGAACTTTGGAAAacgCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
38	E223Y	CGTCGGCGAACTTTGGAAAAtatCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
39	E223W	CGTCGGCGAACTTTGGAAAAtggCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM
40	E223Q	GGCGAACTTTGGAAAacagCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
41	E223N	GGCGAACTTTGGAAAaacCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
42	E223D	CGGCGAACTTITGGAAAgatCCGAGCGAATATCCG	5' phosphate	(+)	MSDM
43	E223H	GGCGAACTTTGGAAAcatCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
44	E223R	GGCGAACTTTGGAAAagaCCGAGCGAATATCCGCC	5' phosphate	(+)	MSDM
45	E223M	CGTCGGCGAACTTTGGAAAatgCCGAGCGAATATCCGC	5' phosphate	(+)	MSDM

TABLE 7

J2	Mutation				Na-citr. pH 6.5		Betamyl	Phad	
	1	2	3	4	72	75			
J2 avg.					4.2	1.1			B/P
S304	D34N	G188A				4.8	144	ND	ND
SSM93 A12	K71R	D269S			5.3	1.6	108	3.16	34
SSM59 E4	N234R	V285A	S420G		5.9	1.9	107	3.00	36
SSM91 E10	D269V				4.4	1.5	105	2.97	35
SSM84 G4	K271L	S325G	S420G	G424S		2.2	40	0.73	55
SSM83 H7	K271Q				5.6	2.1	116	2.60	45
SSM85 A8	K271A				4.4	2.6	114	2.26	50
SSM52 G11	S379G				5.0	1.5	94	2.77	34
SSM90 C11	S420G				5.0	1.7	149	3.54	42

d3	Mutation					Na-citr. pH 6.5			Betamyl	Phad	B/P
	1	2	3	4		72	75	80			
d3 avg						24.8	8.9	2.9	336	10	35
SSM144 G2	D49V	G121R	Q169R	A374V					27	0.41	67
MG044	G106K							3.0	339	7.57	45
SSM134 C10	V107M	G121S					9.1	3.0	103	1.38	75
MG042	G121W	D112E							27	0.17	157
SSM142 E7	121S	P130S	D142N					0.9	41	0.48	85
SSM142 E10	G121A	P141S						0.6	60	0.37	164
SSM142 E10	G121A	P141S					1.6	0.7	63	0.36	175
SSM142 C9	G121F						12.6	4.6	136	2.34	58
SSM142 C9	G121F								220	3.75	59
MG041	G121L							2.4	195	3.47	56
SSM142 E4	G121T							0.0	22	0.10	220
SSM142 C9	G121F								164	3.17	52
SSM144 C4	G121S							2.7	188	2.72	69
SSM144 D1	G121E							2.4	268	4.42	61
SSM144 D3	G121K							2.2	ND	ND	ND

d3	Mutation						Na-citr. pH 6.5			Betamyl	Phad	B/P
	ID	1	2	3	4		72	75	80			
SSM144 D3		G121K							2.0	243	3.97	61
MG047		A131T	G303L						2.1	291	4.89	59
MG045		G166N	A257V						0.0	280	6.40	44
SSM122 B9		G188H						8.6	3.3	246	6.67	37
MG046		G188T							2.1	200	4.09	49

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID										
pMD3 avg				8.0	2.7		0.8	355	5.54	63
pMD4	H13R	G424D			2.6			305	4.58	67
pMD5	H13R				2.5			250	3.35	75
pMD51 a	D62N							10	0.32	32
pMD51 b	D62N							35	1.25	28
S388	F63L	N145D			0.9			212	2.27	93
pMD50 a	S64T				1.2			237	3.75	63
pMD47 a	S64N				1.6			113	1.96	57
pMD47 b	S64N							301	4.45	68
PMD38 b	G100A				2.2			434	7.50	58
QCSS1 A5	N119S				0.3			684	9.97	69
QCSS1 A12	N119G				0.0			707	6.02	117
QCSS1 B5	N119N							874	10.33	85
QCSS1 C11	N119N							982	13.57	72
QCSS1 G5	N119N							830	10.93	76
QCSS1 H12	N119N							792	10.01	79

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID										
QCSS3 A1	N119N				2.7			685	11.97	57
QCSS3 A3	N119N							701	11.01	64
QCSS3 A7	N119N				2.7			641	10.72	60
QCSS3 C3	N119Y				2.3			714	10.20	70
QCSS3 D8	N119N							697	10.52	66
QCSS3 E10	N119N							728	12.05	60
QCSS3 F8	N119N				3.2			897	16.64	54
QCSS3 G11	N119N							672	9.87	68
pMD61 a	D121F	D269S	D422N		4.1			411	8.90	46
pMD64 a	D121F	D269S			4.7			405	7.68	53
pMD42 a	D121T				2.4			313	3.11	101
pMD42 b	D121T				2.6			294	3.03	97
pMD55 a	D121F				5.2			284	5.01	57
pMD55 b	D121F				6.8	5.1	1.6	246	4.76	52
pMD44 a	D121W				5.2	3.7		420	9.14	46
pMD44 b	D121W				4.4			390	8.33	47
pMD43 a	D121H				3.7			221	5.50	40
pMD41 a	D121M				3.3			334	5.27	63

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID	1	2	3	75	80	75	80	Betamyl	Phad	B/P
PMD74 a	D121A							260	2.99	87
PMD74 a	D121A				3.3	2.8		282	2.69	105
PMD74 b	D121A							319	3.40	94
SSM167 H7	D121V				1.8			199	4.74	42
PMD74 a	D121A							633	6.91	92
PMD55 a	D121F							575	9.96	58
PMD55 a	D121F							525	10.57	50
PMD55 a	D121F				4.8	4.8	1.5	467	8.48	55
S389	K125E	Y297H			0.5			183	1.63	112
pMD70 a	A131T				1.7			304	4.55	67
SSM175 E3	G134R							258	3.46	75
SSM177 C3	R134R							534	6.26	85
SSM177 C11	R134R							470	8.87	53
pMD32 a	P141A			2.0	0.9	1.2		315	4.75	66
pMD32 b	P141A							274	4.27	64
pMD48 a	F156Y							25	1.35	19
pMD48 b	F156Y							10	1.05	10
pMD31 a	L157I				1.1	0.8		306	3.06	100

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID										
pMD31 b	L157I							276	2.83	98
pMD68 a	G158S				2.8			400	10.24	39
pMD68 b	G158S				3.0			361	8.37	43
PMD69	S161V				1.2			324	6.00	54
pMD71 a	I170M				0.9			301	4.66	65
SSM267 M1	F178N				0.4			139	3.74	37
SSM267 O17	F178W				1.8			275	4.02	68
SSM267 P22	F178Q				0.8			309	4.18	74
SSM181 B12	T179P				0.7			303	3.79	80
SSM181 G3	T179S				2.2			436	5.91	74
SSM182 E2	T179N				2.7			645	8.94	72
SSM182 H11	T179R							688	10.21	67
SSM269 B3	T179P				0.8			198	2.57	77
SSM269 E15	T179E				2.6			342	4.89	70
SSM211 D12	R196P	K222Y						60	0.15	414
SSM211B9	R196Q			7.9				217	1.35	161
SSM211B9	R196Q			7.9	2.0			181	1.48	123
SSM212A8	R196T			1.9				176	1.86	95

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID										
SSM213 H7	R196Q							69	0.36	193
SSM211 B9	R196Q							256	1.79	143
SSM213 H7	R196Q							74	0.39	190
pMD49 a	A223V			2.4	0.6			301	2.62	115
SSM171 G11	A223E			10.5	3.0			574	5.52	104
SSM171 G11	A223E							684	5.59	122
SSM171 G11	A223E				2.7			364	3.54	103
SSM171 G11	A223E				2.5			ND	ND	ND
SSM158 D10	E226W				0.7			196	1.35	145
pMD52 c	D255V				2.5			279	4.24	66
pMD54 b	D269N				1.9			247	4.26	58
pMD60 a	D269S				2.2			440	6.45	68
SSM180 G6	P334R							131	1.27	103
SSM180 G6	P334R							125	1.31	96
SSM180 H10	P334R				0.3			86	1.07	80
SSM179 D11	P334K							113	1.50	75
SSM280 K4	P334T				0.4			379	4.48	85
SSM280 M11	P334S				0.6			382	4.82	79

pMD3	Mutation			Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Betamyl	Phad	B/P
	1	2	3	75	80	75	80			
ID										
pMD46 a	S399P				2.4			215	3.12	69
pMD46 b	S399P							388	6.35	61
pMD59 a	D422N				3.0			523	6.58	79
pMD34 a	G424S				2.3			411	6.03	68

pMD55	Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl					
	1	2	3	4	80	85	75	80	85	Betamyl	Phad	B/P
pMD55 avg					5.6	1.5	4.9	1.5	0.6	419	7.76	54
S427	P7S	N26D			3.2					235	2.87	82
PMD77	A8N				5.8					174	2.45	71
PMD78	G9A				5.2					173	2.56	68
SSM220 C6	N26E				6.1	1.5		1.5	0.5	295	3.54	83
SSM220 G11	N26E				5.0					483	6.96	69
SSM222 D5	N26E				4.7					521	7.03	74
SSM219 B3	N26E									147	1.57	94
SSM222 H4	N26E				5.6					332	3.93	85
S428	P32S	G153D			0.1					196	2.16	91
SSM228 C7	F63A									327	5.10	64
SSM228 E11	F63D				4.6	0.9	4.2	1.5	0.6	389	6.43	61
SSM229 D9	F63E				3.8					436	6.60	66
SSM229 E10	F63D									381	6.34	60
SSM230 C9	F63D									431	7.24	60
SSM230 D7	F63V									277	4.41	63

pMD55	Mutation					Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Betamyl	Phad	B/P
	1	2	3	4		80	85		75	80	85			
ID														
S424	T67V	Q239L				2.0						276	4.11	67
SSM217 A4	D68C					5.6				1.7	0.6	182	2.96	61
SSM217 B5	D68E					5.2						335	7.49	45
PMD81	G100S					5.1						191	2.85	67
SSM249 L12	N119E					0.8						136	2.27	60
SSM249 M13	N119E					0.7						244	4.79	51
SSM249 B20	N119E					0.9						315	5.72	55
SSM249 E9	N119E					0.5						334	5.90	57
SSM249 J13	N119E					0.3						310	8.27	37
SSM249 O14	N119E					0.3						331	7.55	44
PMD93	F121P					0.7						620	6.70	93
S426	F121I					0.7						299	2.25	133
SSM234 C9	Y122W					3.0						396	4.04	98
S423	P123S	N138S	C140R	P143T		0.0						236	2.11	112
SSM225 B5	K125G					1.6						104	1.30	80
SSM226 D6	K125G					1.5						468	6.60	71
SSM225 F4	K125A					2.2						474	6.80	70
SSM233 B17	K125W											329	5.62	59

pMD55		Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl					
ID	1	2	3	4	80	85	75	80	85	Betamyl	Phad	B/P	
SSM233 D13	K125G									449	6.69	67	
SSM233 H14	K125W									346	4.62	75	
SSM233 N10	K125W				0.8					393	5.64	70	
SSM233 P15	K125D									452	7.99	57	
SSM304 B17	R134C					0.4				307	2.54	121	
S425	R137C	P334S			0.0					205	2.63	78	
S430	N138D	N145S	G300E		0.1					231	2.29	101	
SSM246 H24	N138E				0.4					389	6.35	61	
PMD76	D142G				0.2					187	12.76	15	
S431	N148S				0.4					255	3.55	72	
SSM238 A14	D154G				1.0					222	2.68	83	
SSM238 H15	D154G				0.8					220	2.72	81	
SSM239 C17	D154E				0.8					233	2.78	84	
SSM239 D18	D154Y				0.7					109	0.81	135	
SSM288 K2	L157V	L307D				1.4				526	3.99	132	
SSM299 K9	L157V	L307L				0.5				311	3.62	86	
SSM279 B1	L157M				6.2	1.3	6.2	1.9		449	7.34	61	
SSM237 P2	G158T				7.7	1.7	5.8	2.0	0.7	309	7.89	39	

pMD55	Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl					
	1	2	3	4	80	85	75	80	85	Betamyl	Phad	B/P
ID												
SSM243 I3	E160D	S161A			3.8					346	2.93	118
SSM243 A14	E160D	S161A			3.7					366	3.09	118
SSM243 C23	E160D	S161A			3.5					465	4.39	106
SSM235 C8	S161A				5.5					446	4.56	98
SSM235 E20	S161A				5.5					467	4.12	113
SSM235 G8	S161T				5.2					375	6.44	58
SSM235 P6	S161A				5.4					307	2.74	112
SSM235 P12	S161A				6.2		4.1	1.4	0.7	371	3.15	118
SSM235 P12	S161A									261	2.29	114
SSM276 A2	I170E				1.1					299	4.99	60
SSM276 A3	I170L				2.9					397	7.47	53
SSM276 A4	I170K									44	2.53	17
SSM276 A5	I170N				2.9					346	4.10	84
S433	S183G	E226G			0.5					161	0.63	255
PMD79	G184Q				5.3					155	2.23	70
SSM201 E9	R196K				1.3					321	6.61	49
SSM202 A11	R196Y									186	1.91	97
PMD80	S213N				6.3					155	2.10	74

pMD55	Mutation					Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl					
	1	2	3	4	80	85	75	80	85	Betamyl	Phad	B/P	
ID													
SSM244 I17	L220A				0.5					321	5.35	60	
SSM244 P7	L220T				0.6					204	4.41	46	
pMD85	A223E				5.1	1.5		1.5	0.5	452	4.29	105	
PMD85	A223E									572	5.06	113	
SSM302 D15	E226C	L157L	L307L			0.2				66	0.59	113	
SSM281 A18	E226D					0.7				179	0.68	261	
SSM281 C6	E226D				2.7	0.4				26	0.12	217	
SSM281 H14	E226D					0.6				187	0.70	267	
SSM240 N17	A236E				0.5					234	3.37	70	
SSM240 K4	A236E				0.5					215	3.13	69	
SSM236 H18	W238Q									289	4.27	68	
SSM236 B15	W238G				0.7					266	3.37	79	
SSM236 E9	W238G				0.6					211	2.57	82	
SSM236 G8	W238K				0.7					239	3.48	69	
SSM268 B3	W238R				3.3					207	3.59	58	
SSM268 D10	W238P				1.7					189	3.92	48	
SSM268 E4	W238E				2.2					203	3.44	59	
SSM268 L10	W238Q				2.0					235	4.34	54	

pMD55 ID	Mutation				Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Betamyl	Phad	B/P
	1	2	3	4	80	85		75	80	85			
SSM245 A12	V253G				1.6						367	5.21	70
SSM204E10	E260R				1.5						221	3.99	55
SSM205G1	E260K										110	1.44	76
SSM206D2	E260K										94	1.25	75
S429	N264D				3.9						256	4.22	61
PMD82	T295C	W308C			0.5						103	2.71	38
PMD83	T295C				0.4						93	4.79	19
SSM247 C10	Q305E				1.6						299	5.22	57
SSM247 E3	Q305T				2.2						211	5.61	38
SSM207F2	W308C				1.9								ND
SSM207F2	W308C				1.5						197	1.54	128
SSM208B5	W308C				1.6						229	1.86	123
PMD84	W308C				1.9						294	1.88	156
SSM210 G5	W308T				0.4						158	1.71	92

pMD74	Mutation	Na-citr. pH 6.5			
ID	1	80	Betamyl	Phad	B/P
pMD74 avg		3.3	287	3.03	95
SSM253 F23	F63E		62	0.64	98
SSM253 J9	F63D		53	0.55	97
SSM253 O8	F63E	2.2	71	0.65	109
SSM253 F23	F63E	1.9	394	3.43	115
SSM253 J9	F63D	2.4	364	2.97	123
SSM253 O8	F63E		383	3.19	120
SSM263 C11	Y122A	1.1	633	16.26	39
SSM263 O21	Y122Q	0.7	651	9.81	66
SSM264 H20	Y122E	0.2	743	7.44	100
SSM264 K20	Y122E	0.3	728	6.93	105
SSM265 C10	K125D	0.0	328	3.65	90
SSM265 E3	K125Q	0.1	452	4.23	107
SSM265 I13	K125W	0.0	354	3.35	106
SSM265 K17	K125P	0.1	339	3.12	109
SSM265 M16	K125P	0.0	471	5.26	90
SSM256 F18	R196S	0.4	162	1.04	156
SSM256 C9	R196G	0.4	213	1.65	129
SSM256 D3	R196A	0.4	103	0.83	124
SSM256 M11	R196G	0.5	187	1.25	149
SSM256 O22	R196A		87	0.59	146
SSM256 P11	R196G	0.5	195	0.92	212
SSM256 O16	R196V	0.4	268	1.61	167
SSM252 F14	K222M	0.0	37	0.16	231
SSM252 F14	K222M	0.0	266	1.93	138
PMD86	A223E	3.6	112	0.70	160
PMD86	A223E		297	1.92	154
SSM255 A8	A223D	2.9	90	0.65	139

pMD74	Mutation	Na-citr. pH 6.5			
ID	1	80	Betamyl	Phad	B/P
SSM255 D21	A223P	2.5	59	0.16	369
SSM255 N20	A223D		61	0.30	204
SSM255P11	A223K		70	0.39	180
SSM255 P21	A223V		64	0.31	207
SSM255 A8	A223D		441	3.11	142
SSM255D21	A223P	1.9	353	1.59	222
SSM255 N20	A223D	2.1	339	2.50	135
SSM255 P11	A223K	2.5	439	2.93	150
SSM255 P21	A223V	0.8	299	3.08	97
SSM257 E17	Y227G	0.0	183	0.40	462
SSM257 K22	Y227T	0.0	316	1.08	294
SSM257 O18	Y227D	0.0	139	0.53	261
SSM257 P4	Y227K	0.0	113	0.10	1130

pMD85	Mutation				Na-citr. pH 6.5	Na-acet.+ NaCl	Betamyl	Phad	B/P
	1	2	3	4					
ID					80	80	512	4.68	109
pMD85 avg					5.1	0.5	81	0.26	312
PMD94	N26E	D68C	S161A		6.1	0.7	62	0.21	295
PMD110	N26E	D68C	S161A	R196Q	4.5		168	0.43	391
PMD98	N26E	S161A	R196Q		3.2		219	0.58	377
PMD98	N26E	S161A	R196Q		3.9		244	0.84	291
PMD98	N26E	S161A	R196Q		3.3		220	0.68	324
pMD98	N26E	S161A	R196Q		3.8		253	0.86	294
PMD100	N26E	S161A			5.8		376	1.30	290
PMD100	N26E	S161A			5.5		94	0.47	200
PMD99	N26E	R196Q			3.5		206	1.37	150
PMD97	N26E				4.8	0.3	212	1.56	136
PMD116	F63D	D142D	W308C		0.7		216	1.75	124
PMD114	F63D	S213N	E223P	W308C	0.8		425	2.86	149
PMD121	F63D	S213N	E223P		2.8		269	1.98	136
PMD111	F63D	S213N	W308C		0.8		252	1.82	139
PMD115	F63D	S213N	W308C		1.0				

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pMD85	Mutation				Na-citr. pH 6.5	Na-acet.+ NaCl	Betamyl	Phad	B/P
	1	2	3	4					
PMD120	F63D	S213N			4.5		505	5.57	91
PMD113	F63D	W308C			0.9		242	1.80	135
PMD118	F63D	W308C			1.1		296	1.90	155
PMD119	F63D				4.8		501	5.63	89
PMD101	D68C	S161A	R196Q		5.6	0.5	30	0.09	333
PMD103	D68C	S161A			5.4	1.1	58	0.27	215
PMD95	S161A	R196Q			3.8		148	0.60	247
PMD96	S161A				6.6		99	0.43	230
PMD96	S161A				6.3		335	1.68	199
PMD96	S161A				5.5		366	2.75	133
PMD96	S161A				5.5		364	2.37	154
PMD87	R196Q				4.3		61	0.51	119
PMD88	R196Q				3.8		61	0.52	118
PMD102	R196Q				4.3	0.6	127	0.83	153
PMD117	S213N				5.2	0.6	510	3.37	151
PMD112	W308C				0.7		253	2.39	106

pMD86	Mutation			Na-citr. pH 6.5			
ID	1	2	3	80	Betamyl	Phad	B/P
pMD86 avg				3.6	204	1.31	157
PMD107	N26E	D68C	S161A	2.0	94	0.43	219
PMD105	N26E	S161A	R196Q	1.7	158	0.41	385
PMD104	N26E	S161A		1.7	280	0.81	346
PMD106	S161A	R196Q		1.8	124	0.43	288
PMD109	S161A			2.2	310	1.69	183
PMD89	R196Q			2.3	72	0.48	149
PMD90	R196Q			2.5	78	0.41	189
PMD108	R196Q			1.9	192	0.86	223
PMD91	S208T			2.8	758	6.86	110
PMD92	S229N			1.9	662	6.36	104

pMD96	Mutation							Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl					
	ID	1	2	3	4	5/6/7		80	85		75	80	85		80	85	Beta	Phad	B/P
pMD96 avg								6.0	1.4		4.6	1.7	0.6		0.7		302	1.93	172
SSM354 C8	I38M							5.2			6.6	1.6					548	2.67	206
SSM347 B12	I46F											1.8					413	2.33	177
SSM328 B5	K71M													0.6			361	1.49	242
SSM406 C12	G104R							5.0				1.9	0.7				278	1.82	153
SSM406 A6	G104N											1.7	0.5				456	2.29	199
PMD135	N116D	G153A		L157M	A309P					1.0							184	0.58	317
PMD134	N116D	G153A		A309P						0.0							7	0.10	70
PMD182	N116D	G153A		A309P								0.0					202	0.49	413
PMD136	N116D	G153A								0.0							3	0.10	30
PMD138	N116D	L157M		A309P													296	1.27	232
PMD143	N116D	L157M								1.0							330	1.87	177
pMD143	N116D	L157M															268	1.93	139
PMD137	N116D	A309P											0.0				289	1.00	291
PMD139	N116D													0.0			116	0.42	276
PMD183	N116D											0.0			0.0		362	1.13	319
SSM329 H2	D124S							0.6			4.1						379	2.96	128
pMD126	E126N	G158T		Y198W													108	0.56	191
pMD127	E126N	G158T		S229P						4.9							471	4.30	110
PMD132	E126N	G158T										1.5					424	3.21	132
pMD125	E126N	Y198W		S229P					0.4		11.8	2.2					114	0.57	200
PMD122	E126N	S229P															645	4.53	142

pMD96	Mutation							Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl		Beta	Phad	B/P
	ID	1	2	3	4	5/6/7	80	85	75	80	85	80	85	80	85			
SSM359 A5		E126D														548	3.24	169
PMD128		E126N														603	4.33	139
SSM411 C10		N128E								1.7						166	1.61	103
SSM379 D4		G144E							0.5							316	1.03	307
PMD146		Y146G	G158T	Y198W	S229P	R316S				19.2		3.3	1.4	3.3	1.4	84	0.22	382
PMD147		Y146G	G158T	Y198W	S229P	A309P		9.9			12.5	7.8	5.5	7.8	5.5	77	0.28	272
PMD149		Y146G	G158T	Y198W	S229P	A309P/ R316S					7.6	5.9	3.7			87	0.26	335
PMD150		Y146G	G158T	Y198W	S229P	R353T					2.3	2.4				65	0.23	282
PMD151		Y146G	G158T	Y198W	S229P			3.4				2.8				98	0.44	223
PMD158		Y146G	G158T	Y198W	S229P	A309P/ R316S/ R353T		13.4		39.0	5.2	6.1				56	0.27	207
pMD147 bf		Y146G	G158T	Y198W	S229P	A309P										53	0.19	276
PMD153		Y146G	G158T	S229P	A309P						3.9	2.9	2.0	2.9	2.0	233	1.42	199
PMD154		Y146G	G158T	S229P							1.8	2.3				239	1.13	212
PMD156		Y146G	G158T	S229P	R316S							1.8		1.8		299	1.40	214
PMD157		Y146G	G158T	S229P	A309P	R316S					3.6	1.8		3.2	1.8	278	1.01	275
PMD153		Y146G	G158T	S229P	A309P			8.7				3.2	2.5	3.2	2.5	183	0.86	213
PMD157		Y146G	G158T	S229P	A309P	R316S		11.8				3.3	1.1	3.3	1.1	319	1.42	225
SSM381 G12		Y146G					19.2	2.6		5.3	0.8					409	1.71	239
SSM381 A3		Y146G					16.0	2.5		4.0	0.9					424	2.43	174
SSM381 B9		Y146E							2.0							308	0.91	338

pMD96	Mutation						Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl			
	ID	1	2	3	4	5/6/7	80	85	75	80	85	80	85	Beta	Phad	B/P
SSM381 D7	Y146D								0.4					267	0.61	438
SSM413 A4	N148K											0.0		406	1.78	228
SSM330 A1	D149V													511	4.22	121
SSM330 C5	D149L													405	3.23	125
SSM364 B3	D151W								0.0			0.0		151	0.25	613
SSM364 D3	D151A								0.0			0.0		163	0.18	904
SSM364 D7	D151V								0.0					168	0.18	944
PMD141	G153A	A309P								0.0				215	0.76	284
PMD161	L157M	A309P												53	0.22	241
PMD140	L157M						7.3			1.9				331	1.56	212
pMD124	G158T	Y198W	S229P				20.0	2.2	40.6	9.3	1.8	2.1		127	0.55	231
PMD144	G158T	Y198W	S229P		A309P		46.3	11.6		17.8	4.3			76	0.29	261
PMD148	G158T	Y198W	S229P		A309P			7.4				4.0	2.2	70	0.26	266
PMD152	G158T	Y198W	S229P		A309P	R316S					4.7	3.7		67	0.21	313
PMD155	G158T	S229P	A309P					6.0			1.5	1.5		235	1.09	216
PMD159	G158T	S229P	A309P		R316S	R353T				3.4		1.6		81	0.29	280
PMD131	G158T	S229P					7.2			2.9				380	2.92	130
PMD130	G158T						8.0	1.7		2.3				380	3.10	122
SSM415 G2	N164R											0.0		362	1.68	216
SSM410 E1	Q169K						7.5			1.9				260	1.74	149
SSM410 F8	Q169V						5.6			1.9				273	1.64	166
SSM410 E3	Q169R						6.5			2.2				344	2.52	136

pMD96	Mutation						Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl			
	ID	1	2	3	4	5/6/7	80	85	75	80	85	80	85	Beta	Phad	B/P
SSM410 E2	Q169G											1.5		307	1.37	225
SSM410 G5	Q169E											0.5		377	1.41	268
SSM410 H9	Q169N											0.5		356	1.46	244
SSM348 B10	R182S									1.9				576	3.18	181
SSM348 A4	R182H						6.2		5.4	1.8				502	2.98	169
SSM348 D8	R182M						5.2		5.0	1.9				687	3.92	175
SSM348 A9	R182D						5.0		4.5	2.1				593	3.65	163
SSM348 D11	R182S						5.9		5.0	1.7				584	3.40	172
SSM348 H4	R182G						6.7		5.3	1.8				519	2.68	194
SSM419 A5	F192Y									1.9	0.6			158	1.50	106
SSM419 A11	F192F									2.5				316	1.56	203
SSM419 B4	F192M											0.3		298	1.45	205
SSM420 B11	V195D											0.7		181	1.22	148
pMD129	Y198W	S229P					9.8	2.4	16.9	6.6	1.1	0.6		183	0.77	297
SSM383 E8	A199P													231	0.78	296
SSM422 G5	P200G						8.0			2.3				164	0.88	187
SSM422 B4	P200A						6.1			2.0				255	1.33	192
SSM361 A2	R202K								1.6					228	0.87	264
SSM325 F3	S229P						7.9	1.8	8.8	2.0				355	2.51	141
SSM325 F3	S229P													289	1.76	164
SSM341 A9	G303E						4.4		4.9	1.4				404	1.53	264
SSM341 G11	G303D						3.7		4.3					388	1.69	230

pMD96	Mutation							Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl				
	ID	1	2	3	4	5/6/7		80	85		75	80	85	80	85	Beta	Phad	B/P
SSM332 A11	A309T															334	1.95	171
SSM332 A6	A309E															359	2.18	165
SSM332 Q2	A309M															465	2.63	177
SSM332 Q1	A309V															465	2.29	203
SSM332 Q3	A309I															404	1.87	216
SSM332 Q4	A309P							7.5	2.5		5.3	2.1				546	2.70	202
PMD181	A309P											2.1				364	1.46	250
SSM318 B2	D312E															429	3.13	137
SSM365 C2	R316Q															372	1.66	224
SSM365 B4	R316S							7.5	2.5		4.8	1.8				330	1.52	216
SSM365 F4	R316P							7.1	2.0		4.7	1.8				362	1.79	202
SSM365 C10	R316K							11.3	5.5		5.5					342	1.22	281
SSM407 A5	T324L							5.1				1.7	0.4			399	1.95	205
SSM407 B11	T324M							5.4				1.8	0.5			304	1.40	217
SSM407 A5	T324L													0.7		349	1.91	183
SSM407 B10	T324A													0.6		345	1.83	189
SSM333 A9	H335M															54	0.50	108
SSM360 C7	R353T							5.6			4.9	1.8				327	1.32	248
SSM418 B2	R358A											1.5				145	1.38	105
SSM418 B12	R358T											1.8				153	1.46	105
SSM418 C6	R358L											1.8				155	1.48	105
SSM418 C7	R358V											2.5	0.5			155	1.66	94

pMD96		Mutation						Na-citr. pH 6.5			Na-citr. pH 6.5 + NaCl			Na-acet.+NaCl			
ID	1	2	3	4	5/6/7	80	85	75	80	85	80	85	Beta	Phad	B/P		
SSM418 E2	R358Q								1.7	0.5			156	1.57	99		
SSM418 D12	R358E								1.8	0.5			133	1.25	106		
SSM418 A2	R358N										0.6		358	1.53	234		
SSM418 B5	R358G										0.8		304	2.11	144		
SSM356 A7	S367R							5.7					43	0.23	190		
SSM356 B5	S367Q					5.0		7.3	2.0				449	2.49	180		
SSM320 G3	D390E						1.2						542	3.17	171		
SSM320 D1	D390D												362	2.30	158		
SSM323 A3	D422Q						1.2						561	3.13	179		
SSM323 A4	D422P						1.2						480	2.81	171		

pMD153		Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Na-acet.+ NaCl				
ID	1	2	3	4	85	90	85	85	80	85	Beta	Phad	B/P	
pMD153 avg					12.3	1.7	3.9	3.9	3.1	2.2	208	1.14	206	
pMD233	G70D	N145D	S225E	H272Q					5.1	1.9	541	1.01	536	

pMD153	Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl	Na-acet.+ NaCl				
	1	2	3	4	85	90	85	80	85	Beta	Phad	B/P
ID												
pMD234	G70D	N145D	S225E	H272Q				4.6	1.7	512	1.00	512
pMD212	G70D	N145D	W339E				4.7		2.8	382	0.44	876
pMD214	G70D	N145D	W339E					3.7	2.7	395	0.50	796
pMD212 bf	G70D	N145D	W339E					3.1	1.6	426	0.58	734
pMD214 bf	G70D	N145D	W339E					2.6	0.8	381	0.53	723
pMD212 bf	G70D	N145D	W339E					2.7	1.0	358	0.43	834
pMD212 bf	G70D	N145D	W339E		12.2			2.6		308	0.42	733
pMD219	G70D	N145D						2.3	2.0	238	0.55	433
pMD240	G70D	N145D						5.4		230	0.60	383
pMD220	G70D	S225E	H272Q					3.4	1.3	205	0.65	315
SAS1401 L10	G70D								2.7	254	1.01	268
SAS1401 L10 bf	G70D									271	1.02	266
pMD216	G70D							3.3	2.8	220	1.09	202
PMD173	G104R	Q169R	P200A	T324L		1.3	5.2		4.9	261	1.72	151
PMD174	G104R	Q169R	P200A				4.6		2.6	299	2.28	131
PMD177	G104R	Q169R	T324L				3.9		2.0	337	2.46	137

pMD153	Mutation					Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl		Na-acet.+ NaCl		Beta	Phad	B/P
	1	2	3	4		85	90	85		80	85			
ID														
PMD179	G104R	Q169R						4.2				320	2.40	133
pMD188	G104R	P200A									3.5	227	1.22	186
PMD175	G104R	T324L						2.9			1.4	331	1.93	171
PMD178	G104R							3.0				337	1.38	244
pMD232	C140A	C150A								2.1	0.0	168	1.22	138
SSM448 O17	D142D										4.0	378	2.05	184
SSM448 M7	D142D									3.2		240	1.86	129
pMD222	N145D	H272Q								5.2	2.8	225	0.63	357
pMD222 bf	N145D	H272Q								5.1		237	0.65	365
pMD215	N145D	W339E								2.6	2.6	288	0.53	542
SAS1387 D16	N145D										1.9	117	0.32	366
SAS1387 D16 bf	N145D											303	0.81	374
pMD213	N145D										3.7	280	0.94	297
SAS1387 D16 bf	N145D					22.3				8.7	1.9	293	0.95	309
PMD164	L157M	T158G	G303E					1.4				452	1.63	277
SAS1401C6	L157M	T158G									1.2	379	1.92	197
SAS1401 L17	L157M	T158G									1.3	315	1.16	255

pMD153	Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl	Na-acet. + NaCl		Beta	Phad	B/P
	1	2	3	4	85	90		80	85			
SAS1398 G17	L157M	T158G					85		2.2	294	1.14	259
SAS1392 I15	L157M	T158G							2.0	251	1.00	251
SAS1396 H24	L157M	T158G							1.9	216	0.82	264
PMD162	T158G	G303E	R316K				1.6			541	1.54	351
PMD165	T158G	G303E	R316K				1.5			394	1.02	385
PMD169	T158A	G303E	R316K							348	1.08	322
PMD167	T158A	G303E					1.2			413	1.48	279
PMD172	T158G	G303E					1.9		0.6	461	1.10	421
pMD172	T158G	G303E								288	ND	ND
pMD172	T158G	G303E							1.1	232	0.53	438
pMD172	T158G	G303E								333	0.83	401
pMD172 bf	T158G	G303E			4.9			1.4	0.6	513	0.98	523
PMD170	T158G	R316K					2.0			545	1.75	312
PMD171	T158A	R316K					2.3		0.6	531	1.90	279
PMD168	T158G						2.2	2.2	0.9	512	1.92	267
pMD184	T158A								1.4	286	1.43	200
SAS1391 G13	P168L								1.7	212	0.83	256

pMD153	Mutation				Na-citr. pH 6.5		Na-citr. pH 6.5 + NaCl	Na-acet. + NaCl		Beta	Phad	B/P
	1	2	3	4	85	90		80	85			
ID	Q169R	P200A	T324L				85		2.6	291	2.29	127
PMD176	Q169R					1.1			3.3	234	1.45	162
PMD187	S225G								1.1	330	1.73	191
Hit78 D1	S225E								2.2	271	1.05	209
Hit78 B1	S225V								0.9	337	1.48	228
Hit78 G1	S225E							2.3	1.1	174	0.85	205
pMD218	S237G								1.9	174	0.94	204
Hit78 F3	W282S							2.8	2.2	220	0.79	234
Hit78 H7												
pMD221	W282S							4.2	0.0	192	0.94	204
PMD163	G303E	R316K					2.2			463	1.53	303
pMD185	G303E								1.0	262	0.67	391
SAS1402 G14	W308K							2.3	1.8	284	1.21	235
SAS1402 G14 bf	W308K							0.0		161	0.80	201
PMD166	R316K						3.0	3.6		520	2.27	229
PMD180	T324L								1.9	234	0.88	265
SAS1379 O9	W339E								1.3	235	0.73	322

pMD153	Mutation					Na-citr. pH 6.5	Na-citr. pH 6.5 + NaCl	Na-acet.+ NaCl				
	1	2	3	4	85			90	80			
ID	1	2	3	4	85	90	85	80	85	Beta	Phad	B/P
SAS1379 O13	W339A								1.2	199	0.65	301
pMD217	W339E							2.3	1.5	235	0.63	373
SSM433 C3	Y341E							0.0		161	0.65	247
SSM433 H1	Y341C							2.3		196	0.64	306

pMD153d1	Mutation				Na-acet.+ NaCl		Beta	Phad	B/P
	ID	1	2	3	80	85			
pMD153 avg					3.1	2.2	208	1.14	206
pMD205	G70D		N145D	W339E		3.1	322	1.15	280
pMD206	G70D		N145D	W339E		2.3	313	0.98	320
pMD205 bf	G70D		N145D	W339E	3.1		632	3.94	160
pMD206 bf	G70D		N145D	W339E	2.4		571	3.43	167
pMD239	G70D		N145D		5.5		159	0.94	169
pMD211	G70D		W339E			1.8	389	1.64	237
pMD208	G70D					3.1	279	1.98	141
pMD209	N145D		W339E		2.1	1.9	234	0.89	263
pMD207	N145D				3.9	4.0	284	1.46	195
pMD210	W339E					1.3	324	1.68	193

pMD172	Mutation						Na-citr. pH 6.5	Na-acet.+ NaCl		Beta	Phad	
	1	2	3	4	5	85		80	85			
ID							85	80	85	Beta	Phad	B/P
pMD172 avg							4.9	1.4	0.8			446
pMD192	N26E	L157M	Q169R	P200G	G158T			0.7	0.4	373	2.06	181
pMD203	N26E	L157M	Q169R	P200G					1.0	79	0.32	248
pMD202	N26E	L157M	P200G						0.8	94	0.25	378
pMD198	N26E	L157M	P200G							337	1.66	203
pMD189	N26E	Q169R	P200G					0.7	0.5	446	1.38	324
pMD193	N26E	Q169R	P200G					0.7	0.3	402	1.41	285
pMD204	N26E	Q169R	P200G					0.8	0.3	337	1.38	244
pMD190	N26E	P200G						0.8	0.5	485	0.95	511
pMD191	N26E								0.3	404	0.86	470
pMD200	N26E								0.7	141	0.48	294
pMD197	D142E	Q169R								117	0.41	287
pMD225	N145D	S237D	R233H					1.0	0.4	267	0.43	628
pMD228	N145D	S237G	H272Q					1.6	1.1	257	0.37	695
pMD231	N145D	S237D	H272Q					1.5	1.0	255	0.34	750
pMD224	N145D	S237G						1.9	1.2	159	0.26	612

pMD172	Mutation						Na-citr. pH 6.5	Na-acet.+ NaCl		Beta	Phad	B/P
	1	2	3	4	5	85		80	85			
ID							85		85	Beta	Phad	B/P
pMD230	N145D	H272Q							2.1	208	0.29	715
pMD230 bf	N145D	H272Q						2.2	2.3	351	0.41	849
pMD230 bf	N145D	H272Q						3.2		230	0.24	958
pMD194	Q169R	P200G							0.7	366	1.19	307
pMD201	P200G								1.0	147	0.41	358
pMD227	S237G	L110F						1.3	1.0	296	0.67	445
pMD223	S237G	H272Q						1.5	1.3	259	0.59	439
pMD226	S237D							1.5	1.3	287	0.65	442
pMD229	H272Q								2.2	243	0.52	472
pMD229 bf	H272Q							1.7	1.7	355	0.60	587
pMD229 bf	H272Q									378	0.63	600
pMD229 bf	H272Q						3.7	1.9		145	0.32	453
pMD229	H272Q									500	0.76	656

pMD212	Mutation		Na-citr. pH 6.5	Na-acet.+ NaCl					
ID	1	2	85	80	85	Betamyl	Phad	B/P	
pMD212 avg			12.2	2.8	1.79	368	0.47	794	
pMD238	G188H	Y198W		4.0	4.09	158	0.16	1018	
pMD238 bf	G188H	Y198W		6.4		98	0.10	980	
pMD235	G188T		8.5	3.3	1.26	356	0.40	894	
pMD236	G188H		16.1	3.8	1.29	415	0.52	796	
pMD237	G188S				1.76	380	0.49	774	
pMD237 bf	G188S		12.6	3.3		255	0.28	911	

pMD230	Mutation					Na-acet.+ NaCl	Beta	Phad	B/P
	1	2	3	4					
ID									
pMD230 avg.						80			841
pMD245	F121D	A161S	P309A			0.64	443	0.63	704
pMD257 bf	F121D	A161S	P309A	W339E		0.31	429	0.41	1046
pMD257 bf	F121D	A161S	P309A	W339E			753	0.53	1429
pMD243 bf	F121D	A161S	W339E			0.59	382	0.38	1014
pMD243 bf	F121D	A161S	W339E			0.56	245	0.22	1111
pMD249	F121D	A161S				1.17	472	0.66	720
pMd249	F121D	A161S				1.12	369	0.57	647
pMD247	F121D	P309A				0.59	501	0.69	727
pMD246	A161S	P309A	W339E			0.38	495	0.67	738
pMD248 bf	A161S	P309A				0.96	351	0.87	402
pMD248 bf	A161S	P309A				1.07	253	0.58	436
pMD248 bf	A161S	P309A				0.84	321	0.64	502
pMD248 bf	A161S	P309A					215	0.65	331
pMD248 bf	A161S	P309A					18	0.09	200

pMD230		Mutation				Na-acet.+ NaCl	Beta	Phad	B/P
ID	1	2	3	4		80			
pMD248 bf	A161S	P309A					0	-	-
pMD260 bf	A161S					2.78	381	0.64	596
pMD244	P309A					1.16	421	0.58	726

pMD248	Mutation		Na- acet.+ NaCl	Beta	Phad	B/P
	1	2				
ID			80	Beta	Phad	B/P
pMD248 avg			0.9			386
pMD267	A3T	G70D	1.5	256	0.49	525
pMD275	A3S	G70D	1.0	164	0.20	832
pMD265	A3T	P229S	1.1	239	0.43	555
pMD274	A3S	P229S	0.8	149	0.20	741
pMD264	A3T		1.1	205	0.42	488
pMD266	A3S		1.0	301	0.64	472
pMD268	G70D		1.3	258	0.48	536
pMD263	P229S		1.3	209	0.33	633

pMD253	Mutation					Na-acet.+ NaCl	Beta	Phad	
	1	2	3	4					
ID						80		B/P	
pMD253 avg.						0.8		441	
pMD277	A3T	G70D	P229S			0.6	343	0.40	863
pMD279	A3S	G70D	P229S	Y227C		0.6	76	0.14	543
pMD271	A3S	G70D				0.8	420	0.76	551
pMD271 bf	A3S	G70D				0.9	517	0.58	886
pMD271 bf	A3S	G70D					609	0.98	621
pMD270	A3S	P229S				0.7	304	0.60	506
pMD276	A3T	P229S				0.7	243	0.32	758
pMD272	A3T					0.8	160	0.35	461
pMD278	A3S					0.6	275	0.41	678
SSM463 A5	T67K					0.5	110	0.25	432
SSM463 E11	T67V					0.7	303	0.69	441
SSM463 B11	T67Q					0.7	314	0.84	373
SSM463 H11	T67H					0.6	292	1.16	251
SSM463 A1	T67R					0.7	266	1.22	219
SSM463 A2	T67G					0.7	199	0.69	287

pMD253	Mutation				Na-acet.+ NaCl	Beta	Phad	B/P
	1	2	3	4				
ID					80			
SSM463 C7	T67G				0.6	159	0.61	263
SSM463 A12	T67N				0.6	190	0.55	342
SSM463 A5	T67K				0.7	510	1.80	283
SSM464 A7	G69M				0.7	166	0.40	415
SSM464 D9	G69I				0.5	220	0.59	374
SSM464 C12	G69H				0.7	154	0.54	285
SSM464 A3	G69E				0.4	356	0.75	473
SSM464 D8	G69A				0.6	324	0.88	369
SSM464 C4	G69R				0.5	177	0.78	226
SSM464 C10	G69P				0.3	142	0.59	239
SSM464 C5	G69T				0.6	181	0.69	264
SSM464 A12	G69K				0.6	700	3.64	192
SSM464 D8 b	G69A				0.5	254	0.81	313
pMD273	G70D	P229S	G74S		-	41	0.06	633
pMD269	G70D	P229S			1.0	339	0.61	556
SSM465 A11	S72E				0.6	364	0.79	460
SSM465 A2 (1)	S72K				0.6	258	0.94	273
SSM465 A2 (2)	S72K				-	132	0.45	293

pMD253	Mutation					Na-acet.+ NaCl	Beta	Phad	B/P
	1	2	3	4					
SSM465 B6	S72N					0.7	240	0.61	394
SSM465 D12	S72T					0.7	252	0.65	389
SSM465 A2 (2)	S72K					0.8	320	1.08	295
SSM466 A1	G73M					0.7	96	0.31	313
SSM466 B8	G73S					0.5	69	0.22	309
SSM466 A4	G73T					0.4	76	0.26	290
SSM466 A3	G73N					0.5	97	0.26	368
SSM466 C7	G73L					-	88	0.30	289
SSM466 A8	G73E					0.6	119	0.60	197
SSM466 B5	G73D					-	24	0.21	116
SSM466 A1	G73M					0.8	419	1.49	281
SSM466 B8	G73S					0.6	336	1.03	327
SSM466 A4	G73T					0.5	229	0.73	313
SSM466 A3	G73N					0.5	331	0.89	371
SSM466 C7	G73L					0.8	211	0.70	300
SSM467 D3	G75C					0.6	100	0.19	531
SSM467 C10	G75S					0.2	332	0.78	423
SSM467 F6	G75R					0.0	258	1.16	223

pMD253	Mutation				Na-acet.+ NaCl	Beta	Phad	B/P
	1	2	3	4				
ID								
SSM467 A9	G75Y				80	269	0.87	310
SSM467 F12	G75S				0.0	260	0.62	419
SSM467 C12 (1)	G75F				0.3	235	0.59	401
SSM467 A10	G75W				0.0	275	0.76	363
SSM467 C12 (2)	G75F				0.0	221	0.64	345
SSM467 G10	G75E				0.6	299	0.51	582
SSM467 D3	G75C				0.4	379	0.91	417

pMS281	Mutation					Na-acet. + NaCl	Beta	Phad	B/P
	ID	1	2	3	4				
	pMS281 avg.					80			1045
	pMS302	A161S	Q169D	P229S		0.7	310	0.31	993
	pMS303	A161S	Q169D	P229S	Q272H	0.9	466	0.60	778
	pMS300	A161S	Q272H			1.4	120	0.08	1474
	pMS300 bf	A161S	Q272H				249	0.51	488
	pMS299	Q169D	P229S			1.1	408	0.23	1771
	pMS299 bf	Q169D	P229S			1.1	198	0.11	1840
	pMS310	P229S	Q272H			1.4	190	0.16	1194
	pMS301	P229S				1.5	123	0.22	555
	pMS301 bf	P229S					344	0.29	1196
	pMS309	Q272H				1.7	229	0.19	1182

pMS284	Mutation					Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7				
ID						80			
pMS284 avg.						1.0	363	0.74	489
pMS422	Y33N	G70D	Q272H	E303G	L307K	2.4	132	0.49	271
pMS423	N34D	G70D	Q272H	E303G	L307K	2.1	132	0.46	288
pMS363	D68C	N145D	G158T	L307K			23	0.11	209
pMS352	D68C	N145D	L307R				59	0.12	492
pMS367	D68C	N145D	L307K				58	0.14	414
pMS365	D68C	G158T	E303G	L307K			16	0.25	64
pMS351 bf	D68C	G158T	L307R				43	0.26	163
pMS360	D68C	E303G	L307K				56	0.33	170
pMS354	D68C	L307R					30	0.09	333
pMS357	D68C	L307R					41	0.10	410
pMS359	D68C	L307K					71	0.21	338
pMS362	D68C	L307K					50	0.16	313
pMS434 OS21	G70D	E76V	E223G	Q272H	E303G/ L307K	-	9	0.03	286
pMS442	G70D	F121G	A161S	E223G	Q272H/ E303G/ L307K	0.6	148	3.34	44

pMS284		Mutation					Na-acet. + NaCl			
ID	1	2	3	4	5/6/7	80	Beta	Phad	B/P	
pMS444	G70D	F121G	A161S	Q272H	E303G/ L307K	0.8	139	2.93	47	
pMS445	G70D	F121G	E223G	Q272H	E303G/ L307K	0.7	148	1.61	92	
pMS425	G70D	F121G	Q272H	E303G	L307K	0.8	108	0.70	155	
pMS421	G70D	P141A	Q272H	E303G	L307K	0.7	95	0.33	288	
pMS426	G70D	N145D	G146Y	Q272H	E303G/ L307K	0.8	124	0.41	301	
pMS402	G70D	N145D	A161T	E303G	L307H		103	0.61	169	
pMS406	G70K	N145D	A161S	L163M	E303G/ L307R	1.2	99	0.65	152	
pMS402 bf	G70D	N145D	A161T	E303G	L307H	2.9	666	4.00	166	
pMS411	G70K	D145N	A161S	E303G		1.7	126	1.52	83	
pMS412	G70K	N145D	A161S	E303G	L307H	2.0	180	1.71	105	
pMS402 bf	G70D	N145D	A161T	E303G	L307H		566	3.09	183	
pMS415	G70D	N145D	A161S	E303G	L307H	2.5	159	0.67	237	
pMS388	G70D	N145D	Y198W	E303G	L307K		24	0.09	267	
pMS393	G70D	N145D	Y198W	E303G	L307K	3.2	21	0.09	233	
pMS380	G70D	N145D	Q272H	E303G	L307K	2.7	481	2.13	226	

pMS284	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
ID	G70K	N145D	Q272H	E303G	L307K		80	407	2.66	153
pMS383	G70D	N145D	E303G	L307H			2.2	545	2.03	268
pMS375	G70K	N145D	E303G	L307K			2.1	460	2.88	160
pMS384	G70K	N145D	E303G	L307K			2.4	471	3.53	133
pMS381 bf	G70D	N145D	E303G	L307K			2.9	125	0.40	313
pMS387	G70K	N145D	E303G	L307K			3.7	112	0.63	178
pMS390	G70D	N145D	E303G	L307H			3.2	214	0.54	396
pMS396	G70K	N145D	E303G	L307K			1.7	424	2.49	170
pMS390 bf	G70K	N145D	E303G	L307K				349	2.23	157
pMS390 bf	G70K	D145N	E303G	N302K			1.7	126	1.25	101
pMS410	G70K	D145N	E303G	N302K				72	0.56	129
pMS410 (b)	G70D	N145D	E303G	L307H				963	3.11	310
pMS396 bf	G70K	N145D	E303G	L307H	1bpdel			4	0.01	440
pMS413 bf	G70D	N145D	E303G	L307H				650	1.91	340
pMS396 bf	G70D	G146Y	Q272H	E303G	L307K			68	0.66	103
pMS439	G70D	L157I	Q272H	E303G	L307K		0.9	132	0.37	357
pMS433 OS21	G70D	A161S	E223G	Q272H	E303G/L307K		1.4	116	1.62	72

pMS284	Mutation					Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7				
ID						80	Beta	Phad	B/P
pMS427	G70D	A161S	Q272H	E303G	L307K	1.8	103	0.85	121
pMS398	G70K	A161S	E303G	L307K			60	1.17	51
pMS399	G70K	A161S	E303G	L307H		1.3	140	1.61	87
pMS401	G70K	A161S	E303G	L307H		1.4	128	1.57	82
pMS401 bf	G70K	A161S	E303G	L307H		1.4	752	8.73	86
pMS428	G70D	F178L	Q272H	E303G	L307K	1.1	102	0.34	303
pMS429	G70D	T179A	Q272H	E303G	L307K	2.1	111	0.38	296
pMS395	G70D	Y198W	E303G	L307H			48	0.16	300
pMS438	G70D	E223G	Q272H	E303G	L307K		74	0.70	106
pMS446	G70D	E223G	Q272H	E303G	L307K		97	0.45	214
pMS430	G70D	P229S	Q272H	E303G	L307K	2.0	113	0.32	353
pMS437 OS21	G70D	V267I	Q272H	E303G	L307K	2.0	124	0.38	326
pMS382	G70D	Q272H	E303G	L307K		2.1	100	0.54	185
pMS382 bf	G70D	Q272H	E303G	L307K			295	1.84	160
pMS382 bf	G70D	Q272H	E303G	L307K		2.1	442	2.64	167
pMS382 bf	G70D	Q272H	E303G	L307K		2.1	421	2.84	148
pMS382 bf	G70D	Q272H	E303G	L307K			410	2.66	154
pMS382 bf	G70D	Q272H	E303G	L307K			333	1.97	169

pMS284	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
ID							80			
pMS431	G70D	Q272H	E303G	L307K	P334S		0.8	97	0.26	373
pMS432	G70D	Q272H	E303G	L307H			2.7	238	0.65	366
pMS382 bf; kontrolprøve	G70D	Q272H	E303G	L307K			2.2	470	2.28	206
pMS435 OS21	G70D	Q272H	E303G	L307K			2.0	104	0.36	290
pMS436 OS21	G70D	Q272H	E303G	P309A			1.2	221	0.60	368
pMS441	G70D	Q272H	E303G	L307K	P309A			63	0.43	147
pMS432	G70D	Q272H	E303G	L307H				231	0.91	254
pMS435	G70D	Q272H	E303G	L307K				132	0.65	203
pMS435	G70D	Q272H	E303G	L307K				110	0.59	186
pMS391 bf	G70K	E303G	L307K				1.6	321	2.43	132
pMS403	G70K	E303G	L307R				2.0	85	0.39	218
pMS418	G70D	E303G	L307H				1.7	160	1.18	136
SSM474 A02	G70K							305	0.64	477
SSM474 A03	G70G							278	0.51	545
SSM474 B01	G70E							330	0.47	702
SSM474 C05	G70S							70	0.18	384
SSM474 D04	G70G							187	0.46	407

pMS284		Mutation					Na-acet. + NaCl			
ID	1	2	3	4	5/6/7	80	Beta	Phad	B/P	
SSM474 D10	G70G						105	0.25	425	
SSM474 E06	G70Q						131	0.35	373	
SSM474 E09	G70A						125	0.32	393	
SSM474 G02	G70S						130	0.31	424	
SSM474 G11	G70V						160	0.40	401	
SSM474 H02	G70L						204	0.38	537	
SSM474 B06	G70P						106	0.25	432	
SSM474 C03	G70D						85	0.18	465	
pMS368	N145D	G158T	L307K				78	0.26	300	
pMS368 bf	N145D	G158T	L307K				288	0.94	306	
pMS368 bf	N145D	G158T	L307K			1.8	243	0.78	312	
pMS405	N145D	A161S	E303G	L307R		2.7	89	0.50	178	
pMS405 bf	N145D	A161S	E303G	L307R		3.2	525	3.27	160	
pMS409	D145N	A161S	E303G	Q305L		1.6	107	0.91	118	
pMS416	D145N	A161S	E303G			1.9	130	0.48	270	
pMS386	N145D	Y198W	G70K	E303G	L307K		19	0.18	106	
pMS372 bf	N145D	Y198W	E303G	L307K		3.2	510	2.48	206	
pMS358	N145D	E303G	L307K				134	1.71	79	

pMS284	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
ID							80			
pMS364	N145D	E303G	L307K					173	0.59	293
pMS364 bf	N145D	E303G	L307K				2.2	483	1.54	314
pMS364 bf	N145D	E303G	L307K				2.4	470	1.31	359
pMS364 bf	N145D	E303G	L307K				2.5	364	1.80	202
pMS376	N145D	E303G	L307H				2.1	894	3.40	263
pMS379	N145D	E303G	L307H				2.2	1064	4.42	241
pMS385	N145D	E303G	L307K				2.5	471	2.50	188
pMS389	N145D	E303G	L307K				3.6	110	0.34	324
pMS392	N145D	E303G	L307K				3.1	100	0.42	238
pMS397	N145D	E303G	L307H				1.5	204	0.61	334
pMS389 bf	N145D	E303G	L307K					410	1.43	287
pMS414	N145D	E303G	L307R				3.2	113	0.32	353
pMS389 bf	N145D	E303G	L307K					461	1.75	263
pMS389 bf	N145D	E303G	L307K					326	0.96	340
pMS407	D145N	E303G					2.1	169	0.76	222
pMS353	N145D	L307R						135	0.21	643
pMS355 bf	N145D	L307R						417	0.58	719
pMS361	N145D	L307K						146	0.26	562

pMS284	Mutation							Na-acet. + NaCl	Beta	Phad	
	1	2	3	4	5/6/7						
ID	1	2	3	4	5/6/7	Beta	Phad	B/P			
pMS408	D145N					72	0.16	450			
SSM475 A01	G158G					195	0.37	533			
SSM475 A02	G158F					131	0.34	381			
SSM475 A03	G158G					292	0.54	541			
SSM475 B01	G158P					24	0.51	46			
SSM475 B02	G158I					72	0.35	204			
SSM475 B04	G158A					58	0.13	448			
SSM475 B06	G158T					65	0.18	357			
SSM475 D04	G158V					121	0.36	335			
SSM475 E04	G158L					67	0.21	326			
SSM475 F02	G158Q					115	0.29	392			
SSM475 F03	G158C					28	0.05	520			
SSM475 G02	G158S					78	0.20	401			
pMS400	A161S	E303G	L307H			1.4	1.37	104			
pMS404	A161S	E303G	L307R			1.6	0.60	98			
pMS400 bf	A161S	E303G	L307H			1.5	8.62	91			
SSM470 A01	A161A					215	0.41	524			
SSM470 A03	A161K					92	0.86	106			

pMS284	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
ID							80			
SSM470 A04	A161P							154	0.77	201
SSM470 C06	A161G							192	0.68	283
SSM470 F03	A161R							76	0.79	96
SSM470 G11	A161H							121	1.92	63
pMS298	Q169D							213	0.36	592
pMS328	W232F							65	0.13	500
pMS329	W232G							46	0.09	512
pMS330	W232H							55	0.11	521
pMS331	W232I							52	0.10	515
pMS332	W232K							64	0.15	439
pMS333	W232L							62	0.12	521
pMS335	W232N							80	0.14	549
pMS336	W232P							1	0.01	180
pMS337	W232Q							100	0.17	597
pMS338	W232R							60	0.14	438
pMS339	W232S							107	0.19	553
pMS341	W232Y							103	0.21	492
pMS340	W232T							184	0.31	594

pMS284	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
ID							80			
pMS424	Q272H	E303G	L307K				1.9	103	0.54	188
pMS369	Q272H	L307K					1.0	374	0.92	407
pMS356 bf	E303G	L307R						442	1.83	241
pMS366	E303G	L307K						156	0.82	190
pMS366 bf	E303G	L307K					1.4	367	1.91	192
pMS366 bf	E303G	L307K						506	2.28	222
pMS356 bf	E303G	L307R					1.3	452	1.39	325
pMS366 bf	E303G	L307K					1.5	335	1.38	243
pMS366 bf	E303G	L307K					1.6	375	2.10	179
pMS394	E303G	L307H					1.4	244	0.89	274
pMS366 bf	E303G	L307K					2.1	336	2.09	161
SSM471 A01	L307L							240	0.55	439
SSM471 B10	L307R							132	0.20	660
SSM471 C04	L307K							108	0.24	456
SSM471 C07	L307G							301	0.40	747
SSM471 E02	L307P							74	0.02	3510
SSM471 E04	L307I							250	0.48	521
SSM471 E12	L307S							257	0.48	536

pMS284		Mutation					Na-acet. + NaCl			
ID	1	2	3	4	5/6/7	80	Beta	Phad	B/P	
SSM471 F01	L307R						71	0.03	2629	
SSM471 H07	L307M						266	0.50	538	
SSM471 C04	L307K						106	0.2	461	
SSM471 C04 bf	L307K						288	0.6	450	
SSM471 C04 bf	L307K						372	ND	ND	
SSM471 C04 bf	L307K						315	0.80	392	
pMS343	L307K						32	0.11	291	
pMS344	L307Q						72	0.22	327	
pMS345	L307V						70	0.21	333	
pMS346	L307W						180	0.62	290	
pMS347	L307Y						179	0.47	381	
pMS348	L307C						31	0.09	344	
pMS349	L307F						50	0.13	385	
SSM471 B10 bf	L307R					0.8	384	0.72	537	
SSM471 C04 bf	L307K					1.0	268	0.79	339	
pMS370 bf	L307H					0.5	730	1.67	437	
pMS371	L307E					0.4	288	0.61	472	
SSM472 A01	W308W						318	0.56	572	

pMS284 ID	Mutation						Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4	5/6/7					
SSM472 B06	W308N						80	60	0.15	395
SSM472 B09	W308R							62	0.10	592
SSM472 E07	W308T							97	0.17	577
SSM472 G03	W308S							119	0.19	630
SSM472 G05	W308G							168	0.15	1104
SSM472 G07	W308Q							168	0.23	725
SSM472 H12	W308A							226	0.26	884
pMS334	W323M							53	0.09	606
SSM473 A04	P334P							136	0.26	523
SSM473 A06	P334Q							105	0.19	565
SSM473 B08	P334T							74	0.15	498
SSM473 B11	P334H							72	0.11	642
SSM473 C02	P334T							85	0.16	525
SSM473 C11	P334S							116	0.26	441
SSM473 C12	P334A							134	0.24	558
SSM473 D03	P334K							61	0.12	499
SSM473 D04	P334M							79	0.14	568
SSM473 H07	P334L							65	0.15	432

pMS292	Mutation				Na-acet. + NaCl	Beta	Phad	B/P
	1	2	3	4				
ID					80	Beta	Phad	B/P
pMS292 avg.					4.1			547
pMS317	N34D	A161S	Q169D		1.5	275	0.57	482
pMS311	N34D	A161S	Q272H		2.8	266	0.89	299
pMS316	N34D	P229S	Q272H		4.3	294	0.56	525
pMS321	N34D	Q272H			3.0	311	0.44	707
pMS324	D149H				0.7	310	1.04	297
pMS304	A161S	Q169D	P229S	Q272H	1.6	443	1.23	360
pMS306	A161S	Q169D	P229S		1.6	454	0.94	485
pMS313	A161S	Q169D	P229S	Q272H	1.4	250	0.85	294
pMS305	Q169D	P229S	Q272H		1.7	534	0.78	684
pMS322	Q169D	P229S	Q272H	G276R	0.0	15	0.05	300
pMS308	Q169D	P229S			1.8	453	0.57	795
pMS319	Q169D				1.8	461	0.68	678
pMS307	P229S	Q272H			2.8	170	0.29	578
pMS318	P229S	Q272H			3.6	329	0.80	411
pMS315	P229S				3.0	230	0.52	442

pMS292						Na-acet. + NaCl				
ID		Mutation						Beta	Phad	B/P
		1	2	3	4					
pMS320		Q272H				80		467	1.34	349
						4.0				

pMS382	Mutation	Na-acet. + NaCl			
ID	1	80	Beta	Phad	B/P
pMS382 avg.		2.1			170
pMS454	E223E	2.1	181	0.9	212
pMS455	E223I	1.2	170	0.8	220
pMS456	E223L	1.4	152	0.6	238
pMS457	E223V	1.4	101	0.7	140
pMS458	E223F	1.6	197	0.6	346
pMS459	E223E	2.0	152	0.7	220
pMS460	E223C	1.6	75	0.1	682
pMS461	E223A	2.2	177	1.1	167
pMS462	E223G	1.5	109	0.7	147
pMS463	E223P	1.8	205	0.6	353
pMS464	E223T	1.5	231	0.7	325
pMS465	E223S	2.1	254	1.7	149
pMS466	E223Y	1.4	148	0.7	205
pMS467	E223W	1.6	130	0.4	361
pMS468	E223Q	1.9	204	0.9	217
pMS469	E223N	2.1	225	1.1	199
pMS470	E223D	2.3	209	1.1	192
pMS471	E223H	1.8	160	0.7	232
pMS472	E223K	1.8	142	0.3	414
pMS473	E223R	1.8	122	0.5	263
pMS474	E223M	1.7	154	0.6	269

What is Claimed Is:

1. A method of processing starch comprising liquefying a starch and/or saccharifying a starch liquefact to form a saccharide syrup by adding a *Pseudomonas saccharophila* amylase (PS4) variant, wherein the variant comprises a sequence having at least 90% sequence identity to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2, and wherein the PS4 variant has an altered thermostability, an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1-429 of SEQ ID NO: 1, or SEQ ID NO: 2.
2. The method of claim 1, wherein the PS4 variant comprises one or more following amino acid substitutions: N33Y, D34N, G70D, K71R, V113I, G121A/D/F, G134R, A141P, N145D, Y146G, I157L, G158T, S161A, L178F, A179T, Y198F, G223A/E/F, S229P, H272Q, V290I, G303E, H307K/L, A309P, S334P, W339E, and/or D343E of SEQ ID NO: 1, 2, 3, 4, 5, or 6.
3. The method of claim 1, wherein the PS4 variant comprises the amino acid sequence of SEQ ID NO: 3, 4, 5, or 6.
4. A method of processing starch comprising liquefying a starch and/or saccharifying a starch liquefact to form a saccharide syrup by adding a *Pseudomonas saccharophila* amylase (PS4) variant, wherein the variant comprises a sequence having at least 90% sequence identity to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2, and wherein the PS4 variant comprises one or more amino acid substitutions at following positions: 7, 8, 32, 38, 49, 62, 63, 64, 67, 72, 73, 74, 75, 76, 104, 106, 107, 110, 112, 116, 119, 122, 123, 124, 125, 126, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 200, 202, 208, 213, 220, 222, 225, 226, 227, 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 267, 269, 271, 276, 282, 285, 295, 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358, 367, 379, 390, of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, G9A, H13R, I46F, D68E, G69A/E/H/I/K/M/R/T, G70A/E/L/P/Q/S/V, K71M, G100A/S, G121I/P/R, A131T, G134C, A141S, N145S, Y146D/E, G153A/D,

G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, A179S, G184Q, G188A, A199P, G223C/F/H/M/N/Q/W/Y, S229N, W238E/G/K/P/Q/R, G303L, H307D/E/F/G/K/M/P/Q/R/S/W/Y, A309E/I/M/T/V, S334A/H/K/L/M/Q/R/T, and/or H335M of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more amino acid substitutions at positions of 420, 422, and/or 424 of SEQ ID NO: 1.

5. The method of either claim 4, wherein the PS4 variant comprises a sequence having at least 95% sequence identity to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

6. The method of either claim 4 or 5, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, P7S, A8N, G9A, H13R, P32S, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, D68E, G69A/E/H/I/K/M/R/T, G70A/E/L/P/Q/S/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104N/R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G184Q, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A/G, R202K, S208T, S213N, L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/G/V, E226C/D/G/W, Y227C/D/G/K/T, S229N, W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, V267I, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/E/F/G/K/M/P/Q/R/S/W/Y, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more substitutions of S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1.

7. The method of either claim 4 or 5, wherein the PS4 variant comprises one or more amino acid substitutions at following positions: 7, 32, 49, 62, 63, 64, 72, 73, 74, 75, 76, 107, 110, 112, 116, 119, 122, 123, 125, 128, 130, 137, 138, 140, 142, 143, 144, 148, 149,

150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 202, 220, 222, 226, 227, 232, 233, 234, 236, 237, 239, 253, 255, 257, 260, 264, 269, 271, 276, 282, 285, 297, 300, 302, 305, 308, 312, 323, 324, 325, 341, 358, 367, and/or 379 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, H13R, I38M, I46F, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R, G106K, G121I/P/R, D124S, E126D/N, A131T, G134C, A141S, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, G223C/F/H/M/N/Q/W/Y, S225E/G/V, W238E/G/K/P/Q/R, T295C, G303L, H307D/G/M/P/S, A309E/I/M/T/V, S334A/H/K/L/M/Q/R/T, H335M, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more amino acid substitutions S420G and/or D422N/P/Q of SEQ ID NO: 1; and/or an amino acid substitution at position 424 of SEQ ID NO: 1.

8. The method of claim 7, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, P7S, H13R, P32S, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E/S, C140A/R, A141S, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169D/E/G/K/N/R/V, I170E/K/L/M/N, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K, L220A/T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/G/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/L/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/G/M/P/S, W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324A/L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424D/S of SEQ ID NO: 1.

9. The method of either claim 4 or 5, wherein the PS4 variant comprises one or more amino acid substitutions at following positions: 49, 62, 63, 64, 72, 73, 74, 75, 76, 107, 112, 116, 119, 122, 123, 125, 128, 130, 137, 140, 143, 144, 148, 149, 150, 151, 154, 156, 163, 164, 168, 169, 182, 183, 192, 195, 196, 202, 257, 282, 285, 297, 300, 305, 308, 312, 323, and/or 325 of SEQ ID NO: 1, 2, 3, 4, 5, or 6; one or more following amino acid substitutions: A3T, P7S, H13R, I38M, I46F, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, G100A/S, G104R, G106K, L110F, G121I/P/R, D124S, E126D/N, A131T, G134C, N138D/E, D142/E/G/N, N145S, Y146D/E, G153A/D, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, G166N, I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, G188A, A199P, P200A, L220T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, T295C, N302K, G303L, H307D/G/M/P/S, A309E/I/M/T/V, T324L/M, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and one or more following amino acid substitutions: S420G, D422/N/P/Q, and/or G424S of SEQ ID NO: 1.

10. The method of claim 9, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, P7S, H13R, I38M, I46F, D49V, D62N, F63A/D/E/L/V, S64N/T, T67G/H/K/N/Q/R/V, G69A/E/H/I/K/M/R/T, G70E/L/P/Q/V, K71M, S72E/K/N/T, G73D/E/L/M/N/S/T, G74S, G75C/E/F/R/S/W/Y, E76V, G100A/S, G104R, G106K, V107M, L110F, D112E, N116D, N119E/G/S/Y, G121I/P/R, Y122A/E/Q/W, P123S, D124S, K125A/D/E/G/P/Q/W, E126D/N, N128E, P130S, A131T, G134C, R137C, N138D/E, C140A/R, D142E/G/N, P143T, G144E, N145S, Y146D/E, N148K/S, D149H/L/V, C150A, D151A/V/W, G153A/D, D154E/G/Y, F156Y, G158C/F/I/L/P/Q/V, S161G/H/K/P/R/T/V, L163M, N164R, G166N, P168L, Q169E/G/K/N/R/V, I170E/K/L/M, L178N/Q/W, A179E/N/P/R/S, R182D/G/H/M/S, S183G, G188A, F192M/Y, V195D, R196A/G/K/P/Q/S/T/V/Y, A199P, P200A, R202K, L220T, K222M/Y, G223C/F/H/M/N/Q/W/Y, S225E/V, E226C/D/G/W, Y227C/D/G/K/T, W232F/G/H/I/K/N/P/Q/R/S/T/Y, R233H, N234R, A236E, S237D/G, W238E/G/K/P/Q/R, Q239L, V253G, D255V, A257V, E260K/R, N264D, D269N/S/V, K271A/L/Q, G276R, W282S, V285A, T295C, Y297H, G300E, N302K, G303L, Q305E/L/T, H307D/G/M/P/S,

W308A/C/G/K/N/Q/R/S/T, A309E/I/M/T/V, D312E, W323M, T324L/M, S325G, S334A/H/K/L/M/Q/R/T, H335M, Y341C/E, R358A/E/G/L/N/Q/T/V, S367Q/R, S379G, and/or D390E of SEQ ID NO: 1, 2, 3, 4, 5, or 6; and/or one or more following amino acid substitutions: S420G, D422N/P/Q, and/or G424S of SEQ ID NO: 1.

11. The method of any of claims 4 to 10, wherein the PS4 variant comprises additional one or more amino acid substitutions at the following positions: N33, D34, G70, G121, G134, A141, Y146, I157, S161, L178, A179, G223, S229, H307, A309, and/or S334 of SEQ ID NO: 1 or 2.

12. The method of claim 11, wherein the PS4 variant comprises one or more following amino acid substitutions: N33Y, D34N, G70D, G121F, G134R, A141P, Y146G, I157L, S161A, L178F, A179T, G223E, S229P, H307K, A309P, and/or S334P of SEQ ID NO: 1 or 2.

13. The method of any of claims 4 to 12, wherein the PS4 variant has up to 25 amino acid deletions, additions, insertions, or substitutions compared to the amino acid sequence of SEQ ID NO: 1, 2, 3, 4, 5, or 6.

14. The method of any of claims 4 to 13, wherein the PS4 variant has an altered thermostability compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

15. The method of claim 14, wherein the PS4 variant is more thermostable than the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

16. The method of either claim 14 or 15, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, I38M, G70L, Q169K/R, R182G/H, P200G, G223N, S237D, D269V, K271A/Q, S367Q/R, S379G, and/or S420G of SEQ ID NO: 1 or 2.

17. The method of either claim 16, wherein the PS4 variant comprises additional one or more amino acid substitutions at following positions: G134, A141, I157, G223, H307, S334, and/or D343 of SEQ ID NO: 1 or 2.

18. The method of claim 17, wherein the PS4 variant comprises one or more following amino acid substitutions: G134R, A141P, I157L, G223A, H307L, S334P, and/or D343E of SEQ ID NO: 1 or 2.

19. The method of either claim 17 or 18, wherein the PS4 variant further comprises one or more amino acid substitutions at following positions: N33, D34, K71, L178, and/or A179 of SEQ ID NO: 1 or 2.

20. The method of claim 19, wherein the PS4 variant comprises one or more following amino acid substitutions: N33Y, D34N, K71R, L178F, and/or A179T of SEQ ID NO: 1 or 2.

21. The method of any of claims 4 to 20, wherein the PS4 variant has an altered endo-amylase activity, an altered exo-amylase activity, and/or an altered ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

22. The method of claim 21, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, G69K, G70E, K71M, G73D/E, G75C/E, Y122A, C140A, G144E, Y146D/E, N148K, C150A, D151A/V/W, G153A, G158I/P, S161G/H/K/P/R, Q169D/E/G/N/R, R196Q/S/T, R202K, S208T, S213N, K222M, G223C/F/H/M/Q/W/Y, E226D, Y227D/G/K/T, S229N, W232Q/S/T, T295C, Q305T, W308A/C/G/Q/R/S/T, A309I/V, W323M, T324L/M, S334A/H/M/Q, and/or R358E/L/N/Q/T/V of SEQ ID NO: 1 or 2.

23. The method of claim 21, wherein the PS4 variant has an increased endo-amylase activity or a decreased ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

24. The method of claim 23, wherein the PS4 variant comprises one or more following amino acid substitutions: G69K, G73D/E, Y122A, C140A, C150A, G153A, G158I/P, S161G/H/K/P/R, Q169R, S208T, S229N, T295C, Q305T, and/or R358E/L/Q/T/V of SEQ ID NO: 1 or 2.

25. The method of claim 21, wherein the PS4 variant has an increased exo-amylase activity or an increased ratio of exo- to endo-amylase activity compared to the amino acid sequence of SEQ ID NO: 1, residues 1 to 429 of SEQ ID NO: 1, or SEQ ID NO: 2.

26. The method of claim 25, wherein the PS4 variant comprises one or more following amino acid substitutions: A3T, G70E, K71M, G75C/E, G144E, Y146D/E, N148K, D151A/V/W, Q169D/E/G/N, R196Q/S/T, R202K, S213N, K222M, G223C/F/H/M/Q/W/Y,

E226D, Y227D/G/K/T, W232Q/S/T, W308A/C/G/Q/R/S/T, A309I/V, W323M, T324L/M, S334A/H/M/Q, and/or R358N of SEQ ID NO: 1 or 2.

27. The method of either claim 21 or 22, wherein the PS4 variant comprises additional one or more amino acid substitutions at following positions: W66, I157, E160, S161, R196, W221, K222, E226, D254, Q305, H307, and/or W308 of SEQ ID NO: 1 or 2.

28. The method of claim 27, wherein the PS4 variant comprises one or more following amino acid substitutions: W66S, E160F/G/L/P/R/S, S161A, R196H/P/V, W221A, K222T, Q305T/L, H307L, and/or W308A/L/S of SEQ ID NO: 1 or 2.

29. The method of either claim 23 or 24, wherein the PS4 variant comprises additional one or more following amino acid substitutions: W66S, R196H/P/V, W221A, K222T, H307L, and/or W308 of SEQ ID NO: 1 or 2.

30. The method of either claim 25 or 26, wherein the PS4 variant comprises additional one or more following amino acid substitutions: E160F/G/L/P/R/S, S161A, and/or Q305T/L of SEQ ID NO: 1 or 2.

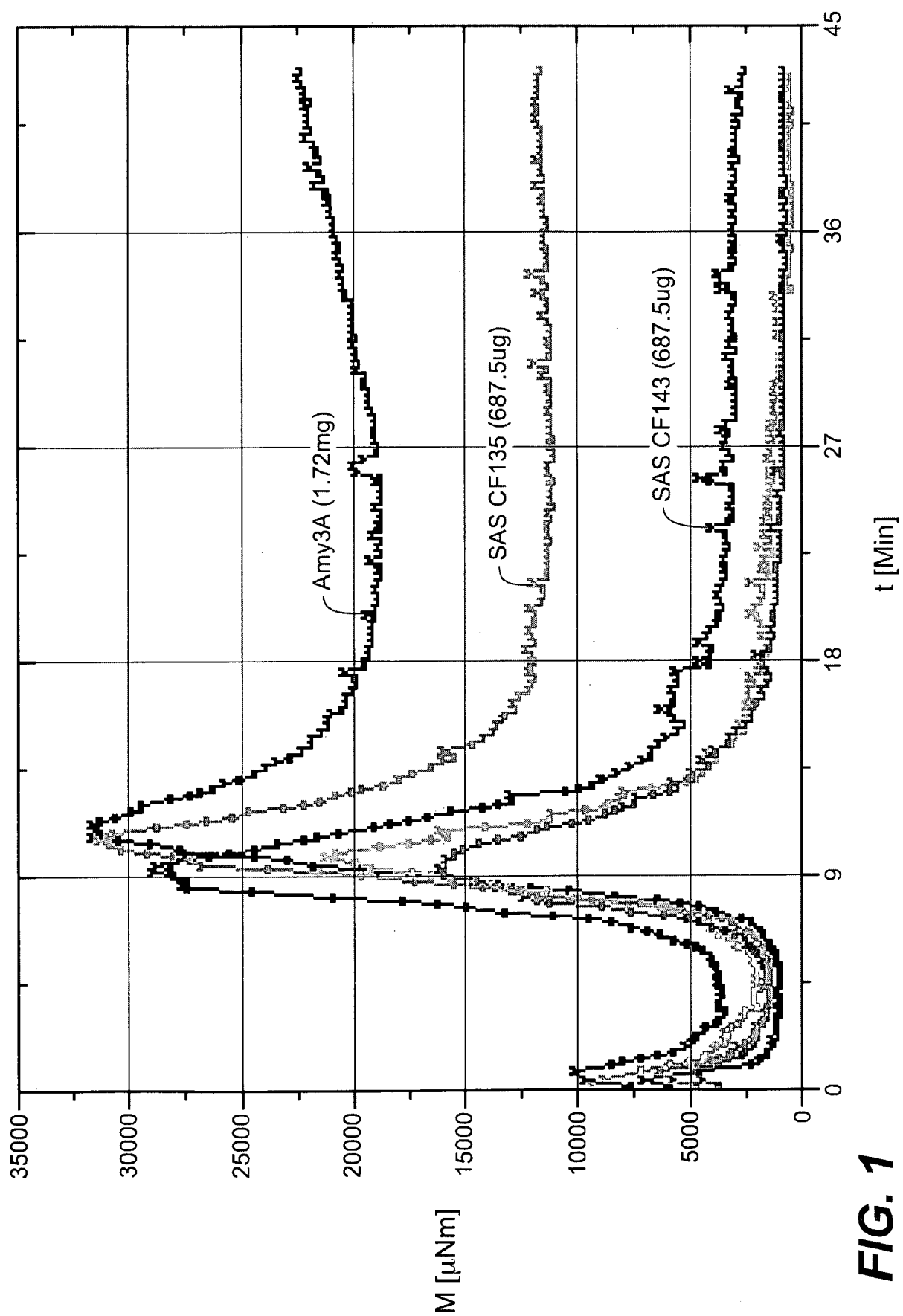
31. The method of any of claims 1 to 30 further comprising adding a debranching enzyme, an isoamylase, a pullulanase, a protease, a cellulase, a hemicellulase, a lipase, a cutinase, or any combination of said enzymes, to the starch liquefact.

32. The method of any of claims 1 to 31, wherein the starch is from corns, cobs, wheat, barley, rye, milo, sago, cassava, tapioca, sorghum, rice, peas, bean, banana, or potatoes.

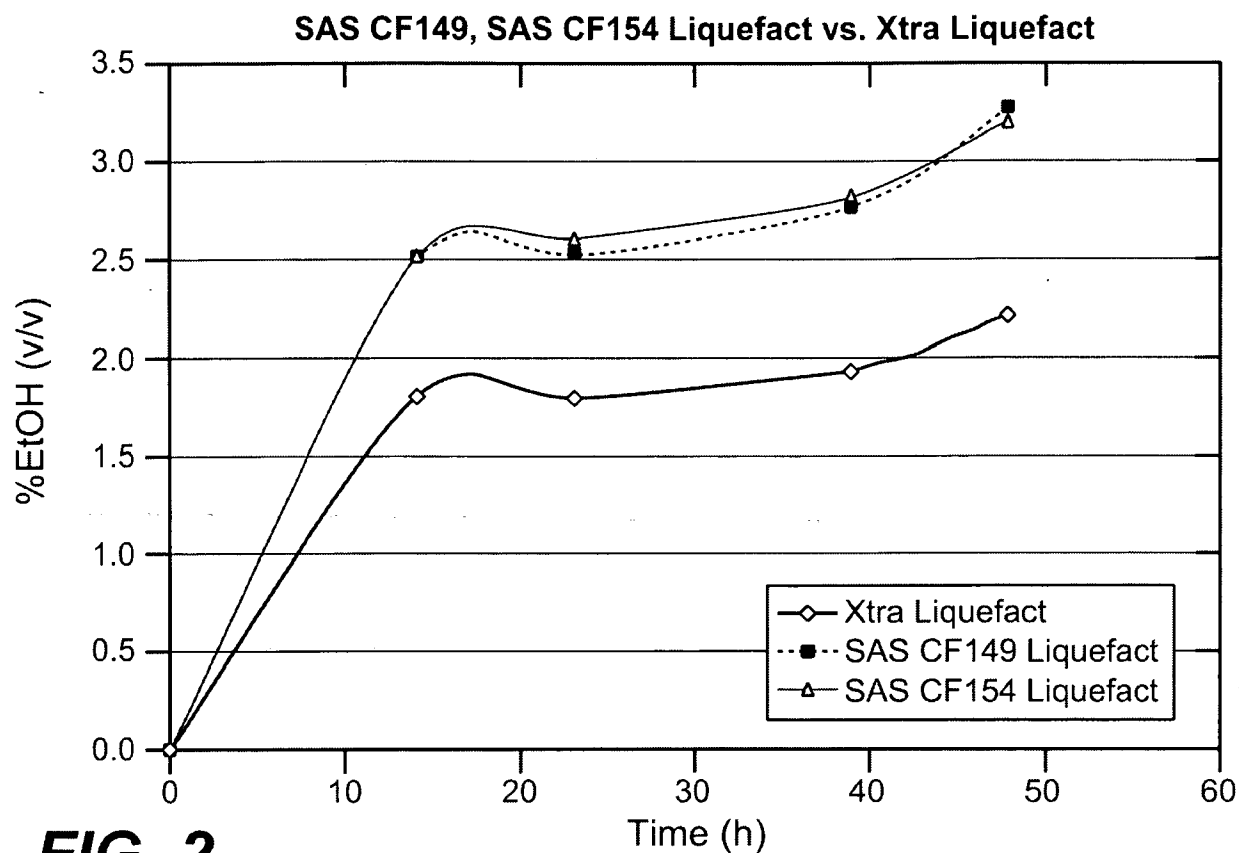
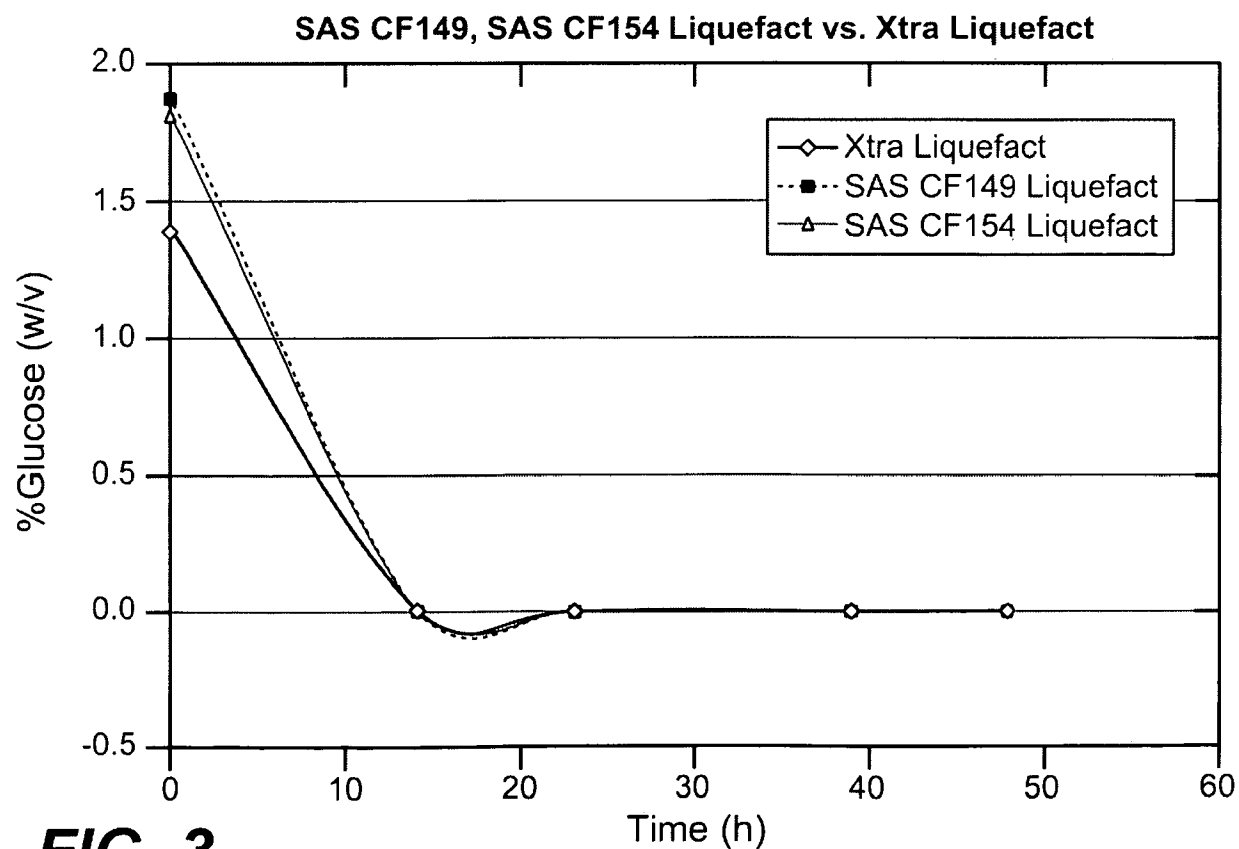
33. The method of any of claims 1 to 32 further comprising fermenting the saccharide syrup to produce ethanol.

34. The method of claim 33 further comprising recovering the ethanol.

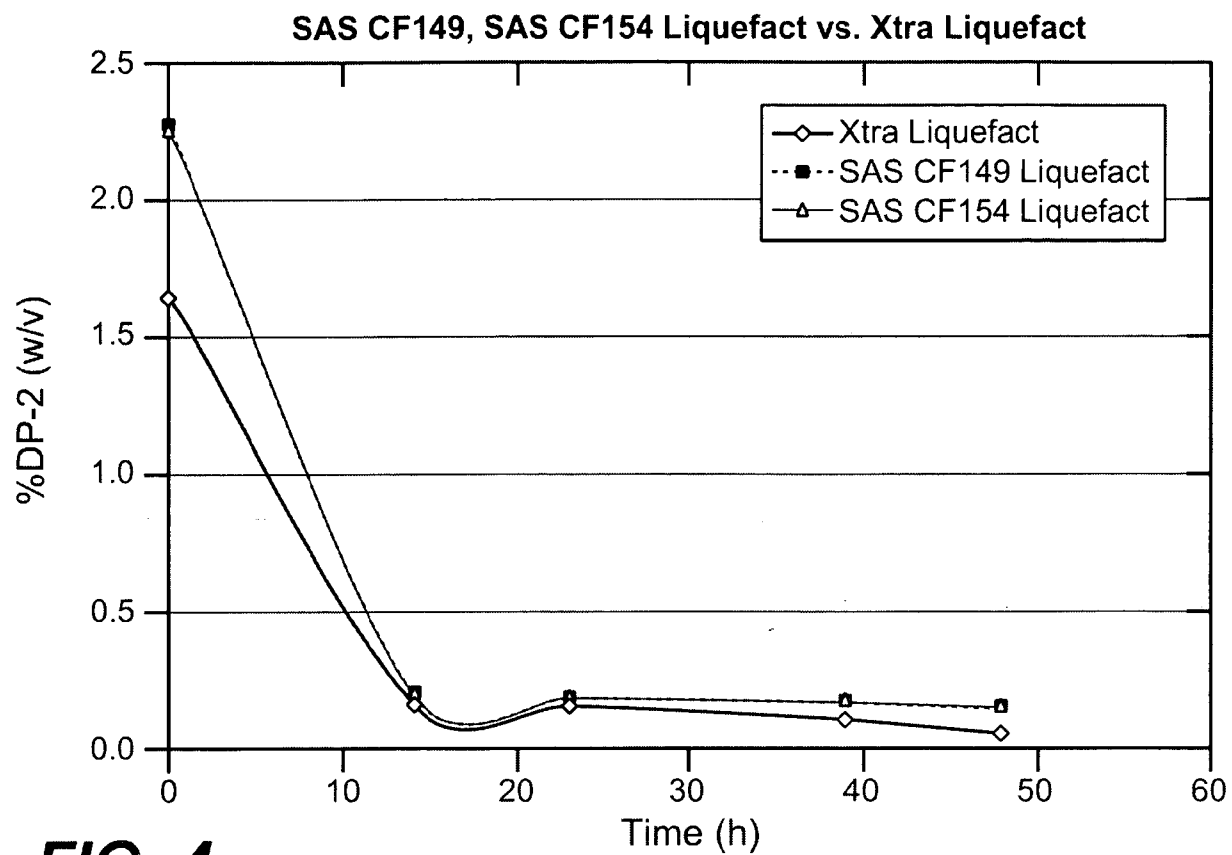
35. The method of claim 34 further comprising distilling the starch to obtain the ethanol, wherein the fermenting and the distilling are carried out simultaneously, separately, or sequentially.

**FIG. 1**

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**FIG. 2****FIG. 3**

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**FIG. 4**

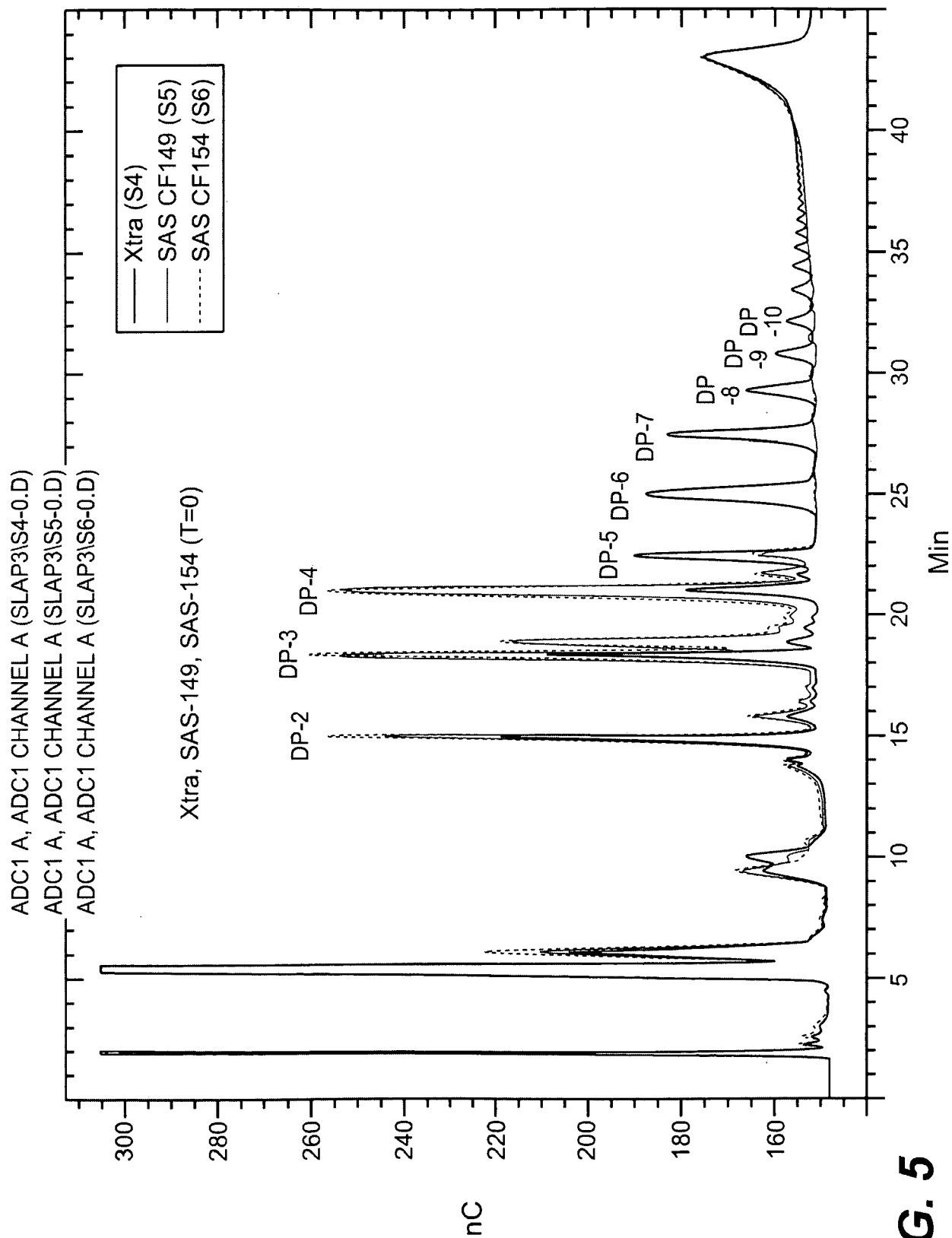


FIG. 5

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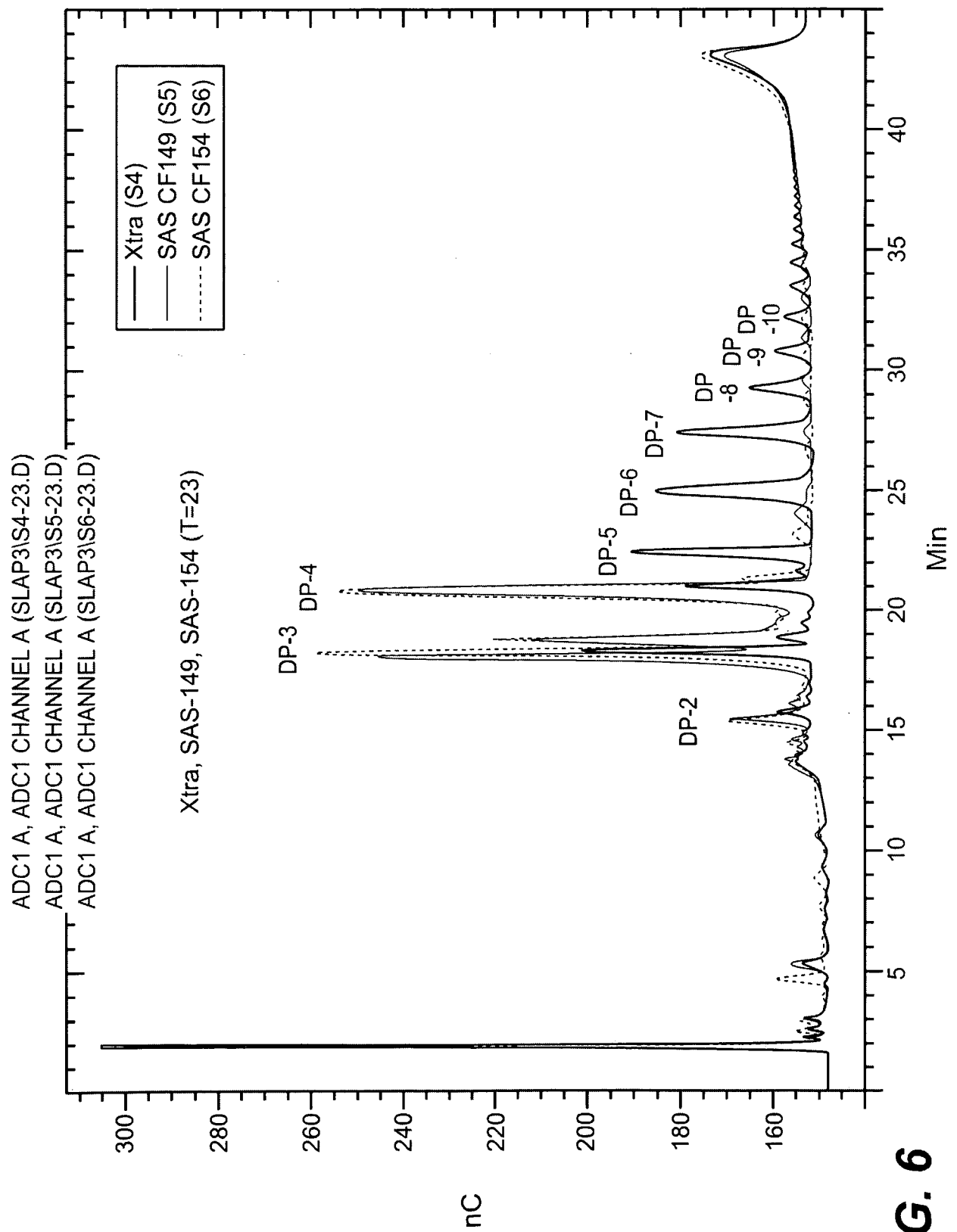


FIG. 6

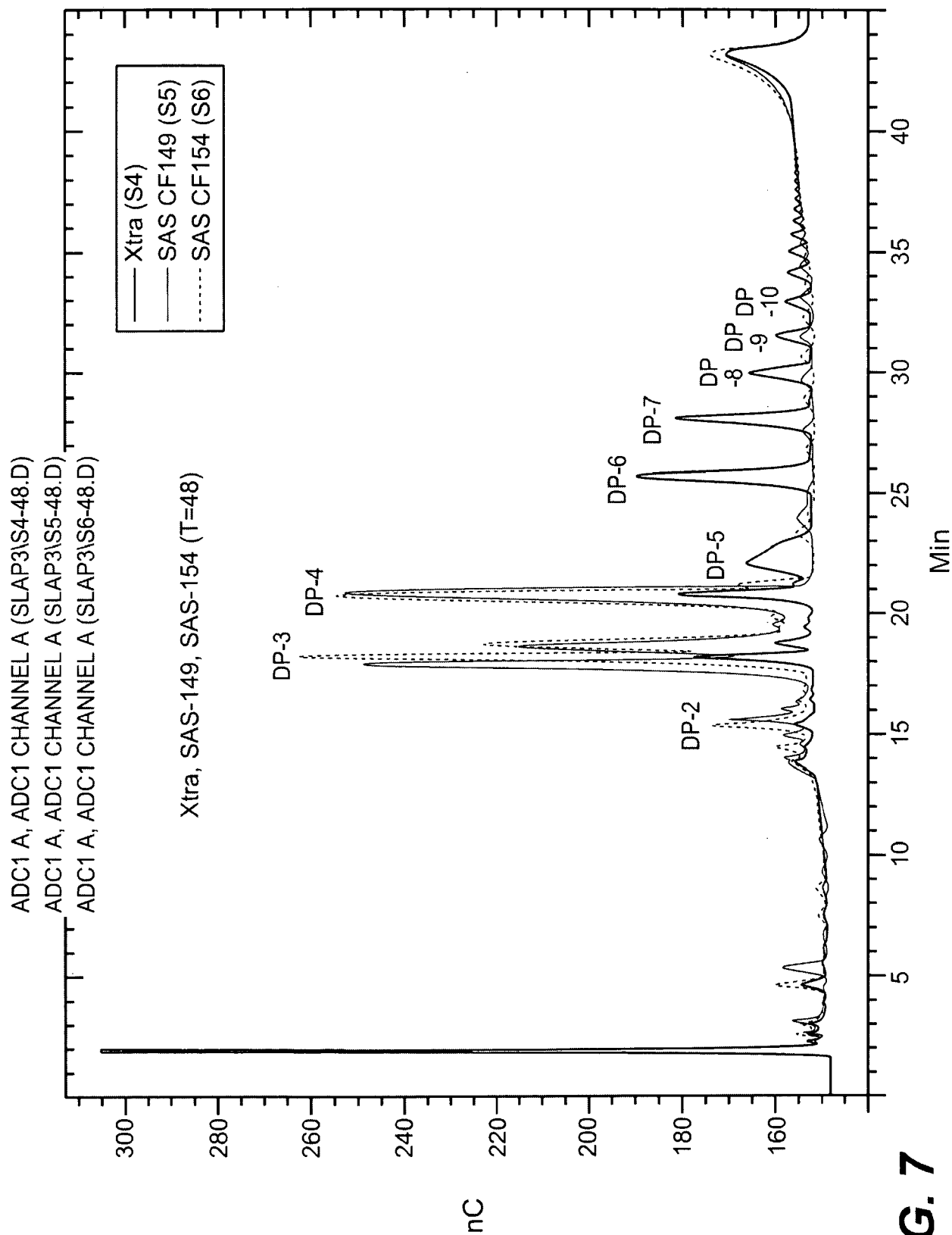


FIG. 7

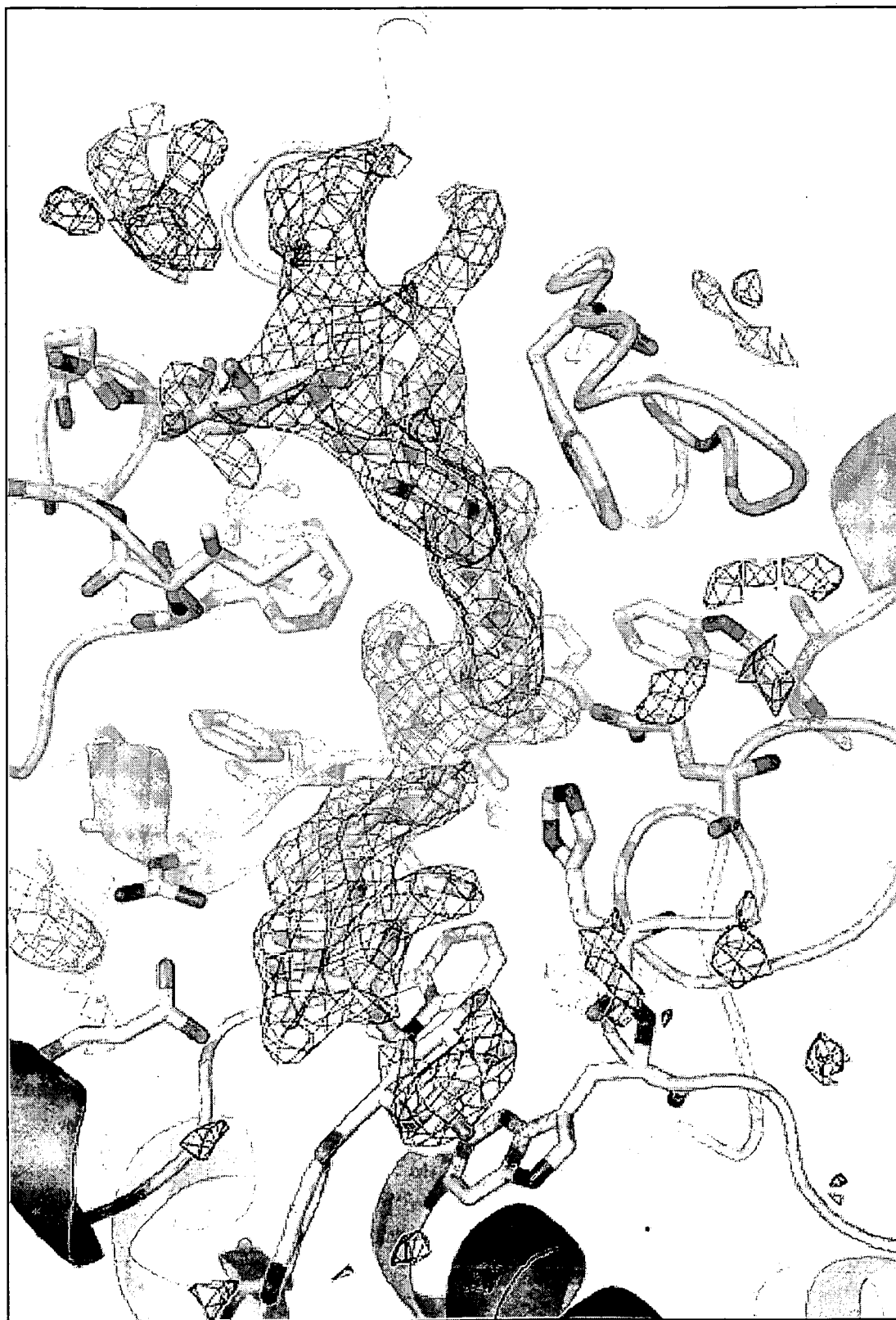
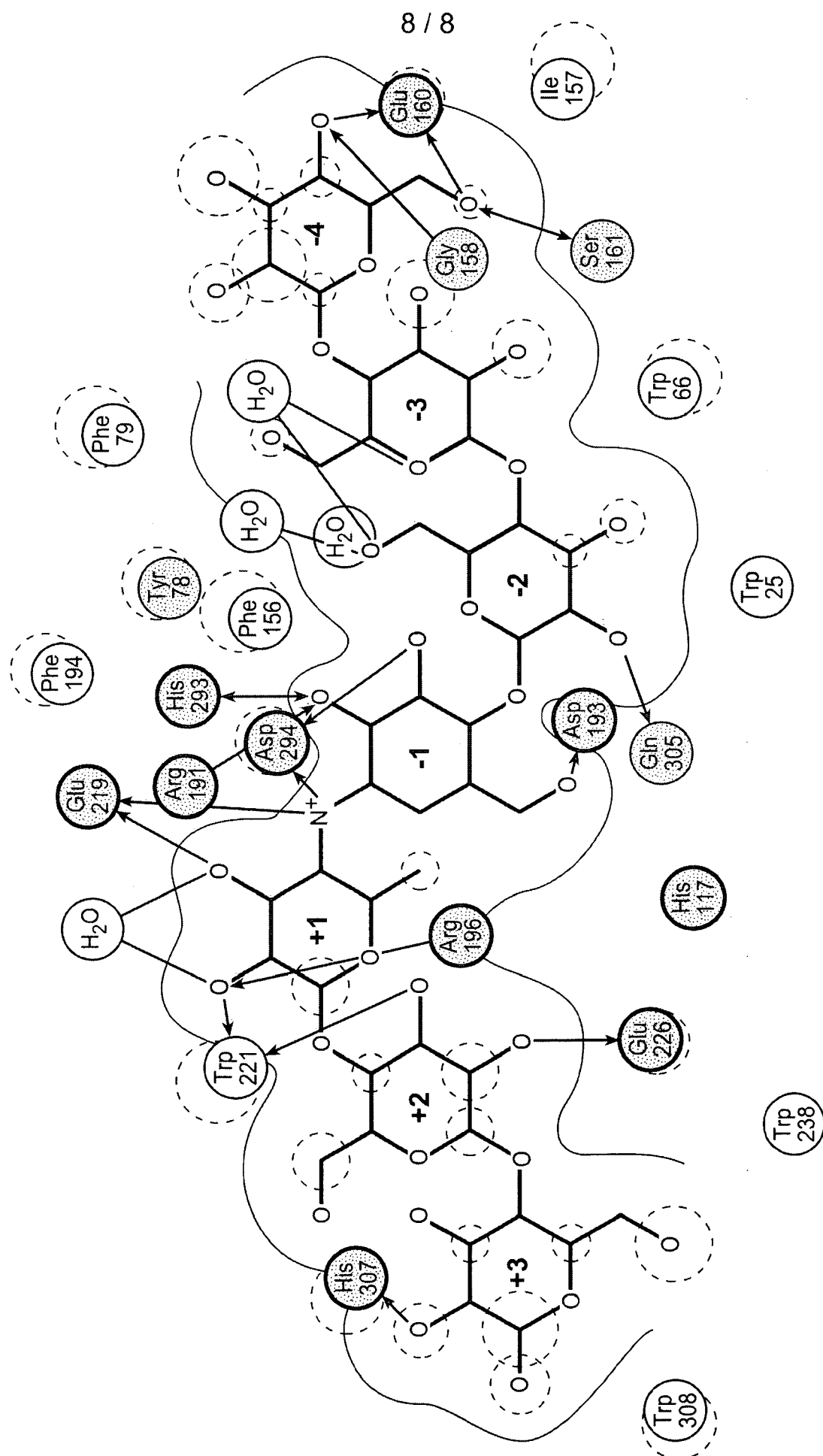


FIG. 8

**FIG. 9**