

Acknowledgments

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References

1. Preiss, J. and Levi, C., The Biochemistry of Plants (Preiss, J., ed.), New York, U.S.A.: Academic Press, 1980, Vol. 3, pp. 371-423.
2. Preiss, J., The Biochemistry of Plants (Preiss, J., ed.), New York, U.S.A.: Academic Press, 1988, Vol. 14, pp. 181-254.
3. Hawker, J.S., Ozbun, J.L., Ozaki, H., Greenberg, E. and Preiss, J. Interaction of spinach leaf adenosine diphosphate glucose α -1,4-glucan α -4-glucosyl transferase and α -1,4-glucan, α -1,4-glucan-6-glucosyl transferase in synthesis of branched α -glucan. *Arch. Biochem. Biophys.* **160** (1974) 530-551.
4. Dang, P.L. and Boyer, C.D. Maize leaf and kernel starch synthases and starch branching enzymes. *Phytochem.* **27** (1988) 1255-1259.
5. Boyer, C.D. and Preiss, J. Multiple forms of (1 \rightarrow 4)- α -D-glucan, (1 \rightarrow 4)- α -D-glucan-6-glycosyl transferase from developing Zea mays L. kernels. *Carbohydr. Res.* **61** (1978) 321-334.
6. Smith, A.M. Major differences in isoforms of starch-branching enzyme between developing embryos of round- and wrinkled-seeded peas (*Pisum sativum* L.). *Planta* **175** (1988) 270-279.
7. Smyth, D.A. Some properties of starch branching enzyme from indica rice endosperm (*Oryza sativa* L.). *Plant Sci.* **57** (1988) 1-8.
8. Nakamura, Y., Takeichi, T., Kawaguchi, K. and Yamanouchi, H. Purification of two forms of starch branching enzyme (Q-enzyme) from developing rice endosperm. *Physiol. Plant.* **84** (1992) 329-335.
9. Goldner, W. and Beevers, H. Starch synthase and starch branching enzyme from germinating castor bean endosperm. *Phytochem.* **28** (1989) 1809-1812.
10. Boyer, C.D. and Preiss, J. Multiple forms of starch branching enzyme of maize: evidence for independent genetic control. *Biochem.*

- Biophys. Res. Commun.* **80** (1978) 169-175.
11. Singh, B.K. and Preiss, J. Starch branching enzymes from maize. *Plant Physiol.* **79** (1985) 34-40.
 12. Baba, T., Kimura, K., Mizuno, K., Etoh, H., Ishida, Y., Shida, O. and Arai, Y. Sequence conservation of the catalytic regions of amylolytic enzymes in maize branching enzyme-I. *Biochem. Biophys. Res. Commun.* **181** (1991) 87-94.
 13. Baecker, P.A., Greenberg, E. and Preiss, J. Biosynthesis of bacterial glycogen: Primary structure of *Escherichia coli* 1,4- α -D-glucan: 1,4- α -D-glucan 6- α -D-(1,4- α -D-glucano)-transferase as deduced from the nucleotide sequence of the *glg B* gene. *J. Biol. Chem.* **261** (1986) 8738-8743.
 14. Mizuno, K., Kimura, K., Arai, Y., Kawasaki, T., Shimada, H. and Baba, T. Starch branching enzymes from immature rice seeds. *J. Biochem.* **112** (1992) 643-651.
 15. Mizuno, K., Kawasaki, T., Shimada, H., Satoh, H., Kobayashi, E., Okumura, S., Arai, Y. and Baba, T. Alteration of the structural properties of starch components by the lack of an isoform of starch branching enzyme in rice seeds. *J. Biol. Chem.* **268** (1993) 19084-19091.
 16. Boyer, C.D. and Preiss, J. Evidence for independent genetic control of the multiple forms of maize endosperm branching enzyme and starch synthases. *Plant Physiol.* **67** (1981) 1141-1145.
 17. Baba, T., Arai, Y., Ono, T., Munakata, A., Yamaguchi, H. and Itoh, T. Branching enzyme from amylo maize endosperms. *Carbohydr. Res.* **107** (1982) 215-230.
 18. Cuatrecasas, P. Protein purification by affinity chromatography: Derivatizations of agarose and polyacrylamide beads. *J. Biol. Chem.* **245** (1970) 3059-3065.

19. Laemmli, U.K. Cleavage of structural proteins during assembly of the head of bacteriophage T4. *Nature* **272** (1970) 680-685.
20. Towbin, H., Staehelin, T. and Gordon, J. Electrophoretic transfer of proteins from polyacrylamide gels to nitrocellulose sheets: Procedure and some applications. *Proc. Natl. Acad. Sci. USA* **76** (1979) 4350-4354.
21. Benton, W.D. and Davis, R.W. Screening lambda^{gt} recombinant clones by hybridization to single plaques in situ. *Science* **196** (1977) 180-182.
22. Feinberg, A.P. and Vogelstein, B.A. A technique radiolabeling DNA restriction endonuclease fragments to high specific activity. *Anal. Biochem.* **132** (1983) 6-13.
- 23 Selden, R.F., Current Protocols in Molecular Biology (Ausubel, F.M., Brent, R., Kingston, R.E., Moore, D.D., Seidman, J.G., Smith, J.A., and Struhl, K., eds.), New York, U.S.A.: John Wiley and Sons, 1987 pp.4.9.1-4.9.8
24. Hartree, E.F. Determination of protein: A modification of the Lowry method that gives a linear photometric response. *Anal. Biochem.* **48** (1972) 422-427.
25. Bradford, M.M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.* **72** (1976) 248-254.
26. Sanger, F., Nicklen, S. and Coulston, A.R. DNA sequencing with chain-terminating inhibitors. *Proc. Natl. Acad. Sci. USA* **74** (1977) 5463-5467.
27. Kozak, M. Possible role of flanking nucleotides in recognition of the AUG initiator codon by eukaryotic ribosomes. *Nucleic Acids Res.* **9** (1981) 5233-5252.
28. Schneider, E.M., Becker, J.U. and Volkmann, D. Biochemical

- properties of potato phosphorylase change with its intracellular localization as revealed by immunological methods. *Planta* **151** (1981) 124-134.
29. Nakano, K., Mori, H. and Fukui, T. Molecular cloning of cDNA encoding potato amyloplast α -glucan phosphorylase and the structure of its transit peptide. *J. Biochem.* **106** (1989) 691-695.
 30. Anderson, J.M., Hnilo, J., Larson, R., Okita, T.W., Morell, M. and Preiss, J. The encoded primary sequence of a rice seed ADP-glucose pyrophosphorylase subunit and its homology to the bacterial enzyme. *J. Biol. Chem.* **264** (1989) 12238-12242.
 31. Wang, Z., Wu, Z., Xing, Y., Zheng, F., Guo, X., Zhang, W. and Hang, M. Nucleotide sequence of rice waxy gene. *Nucleic Acids Res.* **18** (1990) 5898.
 32. Borovsky, D., Smith, E.E. and Whelan, W.J. Purification and properties of potato 1,4- α -D-glucan : 1,4- α -D-glucan 6- α -(1,4- α -glucano)-transferase. *Eur. J. Biochem.* **59** (1975) 615-625.
 33. Buisson, G., Duee, E., Haser, R. and Payan, F. Three dimensional structure of porcine pancreatic α -amylase at 2.9 Å resolution. Role of calcium in structure and activity. *EMBO J.* **6** (1987) 3909-3916.
 34. Matsuura, Y., Kusunoki, M., Harada, W. and Kakudo, M. Structure and possible catalytic residues of Taka-amylase A. *J. Biochem.* **95** (1984) 697-702.
 35. Koßmann, J., Visser, R.G.F., Müller-Röber, B., Willmitzer, L. and Sonnewald, U. Cloning and expression analysis of a potato cDNA that encodes branching enzyme: Evidence for co-expression of starch biosynthetic genes. *Mol. Gen. Genet.* **230** (1991) 39-44.
 36. Poulsen, P. and Kreiberg, J.D. Starch branching enzyme cDNA from *Solanum tuberosum*. *Plant Physiol.* **102** (1993) 1053-1054.
 37. French, D. The schardinger dextrins. *Adv. Carbohydr. Chem.* **12**

- (1957) 189-260.
38. Takano, T., Fukuda, M., Monma, M., Kobayashi, S., Kainuma, K. and Yamane, K. Molecular cloning, DNA nucleotide sequencing, and expression in *Bacillus macerans* cyclodextrin glucanotransferase gene. *J. Bacteriol.* **166** (1986) 1118-1122.
 39. Binder, F., Huber, O. and Bock, A. Cyclodextrin-glycosyltransferase from *Klebsiella pneumoniae* M5a1: cloning, nucleotide sequence and expression. *Gene* **47** (1986) 269-277.
 40. Kubota, M., Matsuura, Y., Sasaki, S. and Katsube, Y. Molecular structure of *B.stearotherophilus* cyclodextrin glucanotransferase and analysis of substrate binding site. *Denpun Kagaku* **38** (1991) 141-146.
 41. Katsuragi, N., Takizawa, N. and Murooka, Y. Entire nucleotide sequence of the pullulanase gene of *Klebsiella aerogenes* W70. *J. Bacteriol.* **169** (1987) 2301-2306.
 42. Jespersen, H., MacGregor, E.A., Sierks, M.R. and Svensson, B. Comparison of the domain-level organization of starch hydrolases and related enzymes. *Biochem. J.* **280** (1991) 51-55.
 43. Banks, W., Greenwood, C.T., Starch and Its Components (Banks, W., Greenwood, C.T., eds.), Edinburgh, United Kingdom: Edinburgh University Press, 1975, pp. 5-66.
 44. Banks, W., Greenwood, C.T. and Muir, D.D. Biosynthesis of starch granules. 9.: starch granules from wrinkled-seeded peas. *Staerke* **26** (1974) 289-328.
 45. Charbonniere, R., Mercier, C., Tollier, M.T. and Guilbot, A. X-ray diffraction studies of cornstarches with different amylose contents. *Staerke* **20** (1968) 75-78.
 46. Ikawa, Y. and Fuwa, H. Changes in some properties of starch granules of maize having *amylose-extender* gene by amylase attack.

- Staerke* **32** (1980) 145-149.
47. Baba, T., Kim, S. and Arai, Y. Treatment of amylo maize starch granules with urea: comparison with normal maize starch. *Carbohydr. Res.* **124** (1983) 344-348.
 48. Mercier, C. Fine structure of corn starches of various amylose percentage. Waxy, normal and amylo maize. *Staerke* **25** (1973) 78-83.
 49. Baba, T., Arai, Y., Yamamoto, T. and Itho, T. Some structural features of amylo maize starch. *Phytochemistry* **21** (1982) 2291-2296.
 50. Baba, T. and Arai, Y. Structural characterization of amylopectin and intermediate material in amylo maize starch granules. *Agric. Biol. Chem.* **48** (1984) 1763-1775.
 51. Colonna, P. and Mercier, C. Macromolecular structure of wrinkled- and smooth- pea starch components. *Carbohydr. Res.* **126** (1984) 233-247.
 52. Baba, T., Uemura, R., Hiroto, M. and Arai, Y. Structural features of amylo maize starch: components of Amylon 50 starch. *J. Jpn. Soc. Starch Sci.* **34** (1987) 196-202.
 53. Baba, T., Uemura, R., Hiroto, M. and Arai, Y. Structural features of amylo maize starch: components of Amylon 70 starch. *J. Jpn. Soc. Starch Sci.* **34** (1987) 213-217.
 54. Satoh, H. and Omura, T. New endosperm mutations induced by chemical mutagens in rice, *Oryza sativa* L. *Jpn. J. Breed.* **31** (1981) 316-326.
 55. Yano, M., Okuno, K., Kawakami, J., Satoh, H. and Omura, T. High amylose mutants of rice, *Oryza sativa* L. *Theor. Appl. Genet.* **69** (1985) 253-257.
 56. Hedman, K.D. and Boyer, C.D. Gene dosage at the *amylose-extender* locus of maize: effects on the levels of starch branching enzymes. *Biochem. Genet.* **20** (1982) 483-492.

57. Kawasaki, T., Mizuno, K., Baba, T. and Shimada, H. Molecular analysis of the gene encoding a rice starch branching enzyme. *Mol. Gen. Genet.* **237** (1993) 10-16.
58. Fuller, S.A., Takahashi, M., and Hurrell, J.G.K., Current Protocols in Molecular Biology (Ausubel, F.M., Brent, P., Kingston, R.E., Moore, D.D., Seidman, J.G., Smith, J.A., and Struhl, K., eds.), New York, U.S.A.: Greene Publishing Associates and Wiley-Interscience, 1991, pp. 11.11.1-11.11.5.
59. Shure, M., Wessler, S., and Fedoroff, N. Molecular identification and isolation of the *Waxy* locus in maize. *Cell* **35** (1983) 225-233
60. Hirano, H.-Y. and Sano, Y. Molecular characterization of the waxy locus of rice (*Oryza sativa*). *Plant Cell Physiol.* **32** (1991) 989-997.
61. Stark, D.M., Timmerman, K.P., Barry, G.F., Preiss, J. and Kishore, G.M. Regulation of the amount of starch in plant tissues by ADP-glucose pyrophosphorylase. *Science* **258** (1992) 287-292.
62. Schmidt, G.W. and Mishkind, M.L. The transport of proteins into chloroplasts. *Annu. Rev. Biochem.* **55** (1986) 879-912.
63. Hartl, F., Pfanner, N., Nicholson, D.W. and Neupert, W. Mitochondrial protein import. *Biochim. Biophys. Acta* **988** (1989) 1-45.
64. Garnier, J., Osguthone, D.J. and Robson, B. Analysis of the accuracy and implications of simple methods for predicting the secondary structure of globular proteins. *J. Mol. Biol.* **120** (1978) 97-120.
65. Thon, V.J., Vigneron-Lesens, C., Marianne-Pepin, T., Montreuil, J., Decq, A., Rachez, C., Ball, S.G. and Cannon, J.F. Coordinate regulation of glycogen metabolism in the yeast *Saccharomyces cerevisiae*: induction of glycogen branching enzyme. *J. Biol. Chem.* **267** (1992) 15224-15228.

66. Bhattacharyya, M.K., Smith, A.M., Ellis, T.H.N., Hedley, C. and Martin, C. The wrinkled-seed character of pea described by Mendel is caused by a transposon-like insertion in a gene encoding starch-branching enzyme. *Cell* **60** (1990) 115-122.
67. Drummond, G.S., Smith, E.E. and Whelan, W.J. Purification and properties of potato α -1,4-glucan α -1,4-glucan 6-glycosyltransferase (Q-enzyme). *Eur. J. Biochem.* **26** (1972) 168-176.
68. Borovsky, D., Smith, E.E. and Whelan, W.J. On the mechanism of amylose branching by potato Q-enzyme. *Eur. J. Biochem.* **62** (1976) 307-312.
69. Svensson, B. Protein engineering in the α -amylase family: catalytic mechanism, substrate specificity, and stability. *Plant Mol. Biol.* **25** (1994) 141-157.
70. Takeda, Y., Guan, H.-P. and Preiss, J. Branching of amylose by the branching isoenzymes of maize endosperm. *Carbohydr. Res.* **240** (1993) 253-263.
71. Kunkel, T., Roberts, J.D. and Zakour, R.A. *Methods Enzymol.* **154** (1987) 367-382.
72. Krisman, C.R. A method for the colorimetric estimation of glycogen with iodine. *Anal. Biochem.* **4** (1962) 17-23.
73. Dubols, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A. and Smith, F. Colorimetric method for determination of sugars and related substances. *Anal. Chem.* **28** (1956) 350-356.
74. Nelson, N. A photometric adaptation of the Somogyi method for the determination of glucose. *J. Biol. Chem.* **153** (1944) 375-380.
75. Guan, H.P., Baba, T. and Preiss, J. Expression of branching enzyme I of maize endosperm in *Escherichia coli*. *Plant Physiol* **104** (1994) 1449-1453.
76. Guan, H.P., Baba, T. and Preiss, J. Expression of branching

- enzyme II of maize endosperm in *Escherichia coli*. *Cell Mol. Biol.* **40** (1994) 981-985.
77. Fisher, D.K., Boyer, C.D. and Hannah, L.C. Starch branching enzyme II from maize endosperm. *Plant Physiol.* **102** (1993) 1045-1046.
78. Nakajima, R., Imanaka, T. and Aiba, S. Comparison of amino acid sequence of eleven different α -amylases. *Appl. Microbiol. Biotechnol.* **23** (1986) 355-360.
79. MacGregor, E.A. and Svensson, B. A super-secondary structure predicted to be common to several α -1,4-D-glucan-cleaving enzymes. *Biochem. J.* **259** (1989) 145-152.
80. Jespersen, H.M., MacGregor, E.A., Henrissat, B., Sierks, M.R. and Svensson, B. Starch- and glycogen-debranching and branching enzymes: prediction of structural features of the catalytic $(\beta/\alpha)_8$ -barrel domain and evolutionary relationship to other amylolytic enzymes. *J. Prot. Chem.* **12** (1993) 791-805.

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