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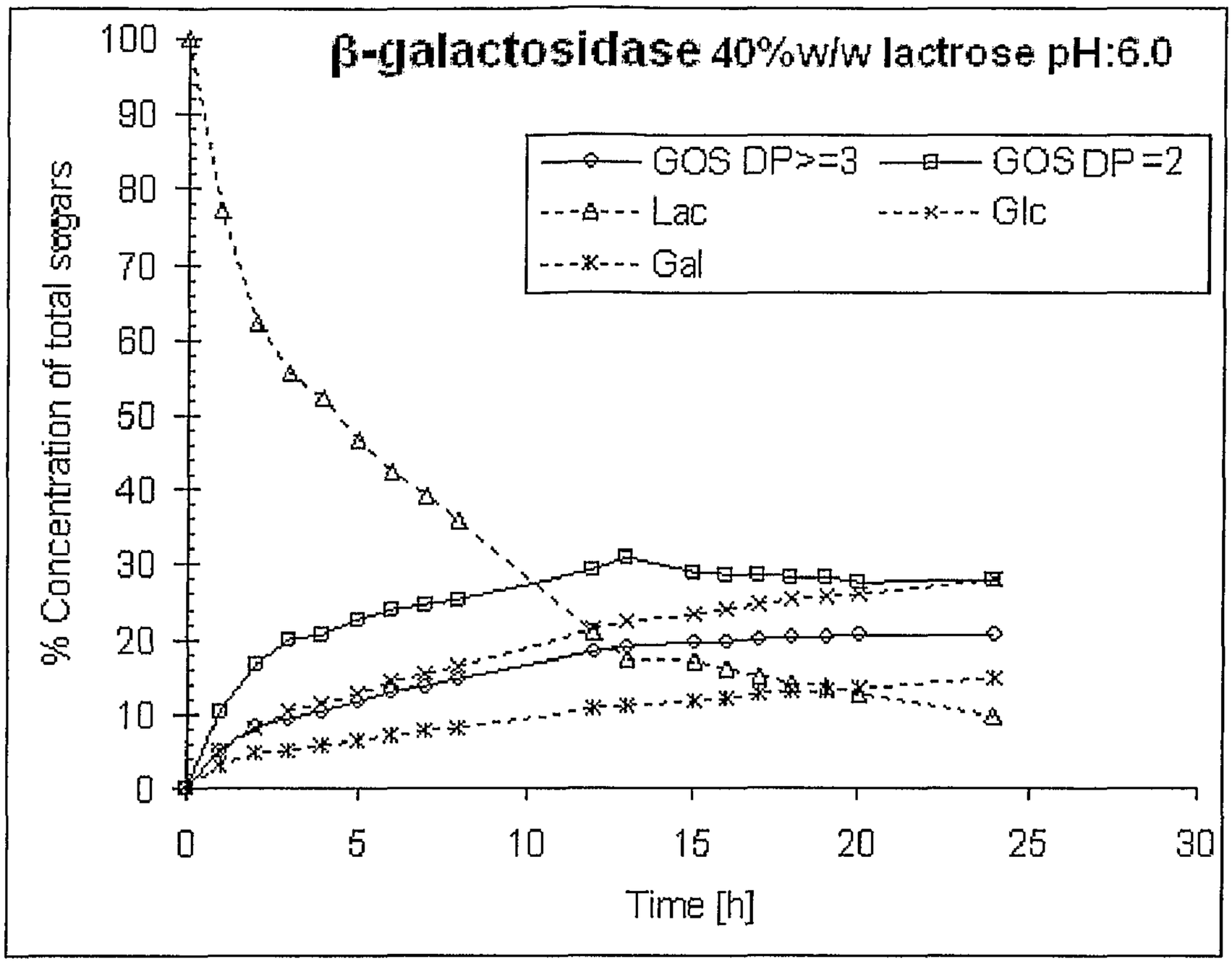

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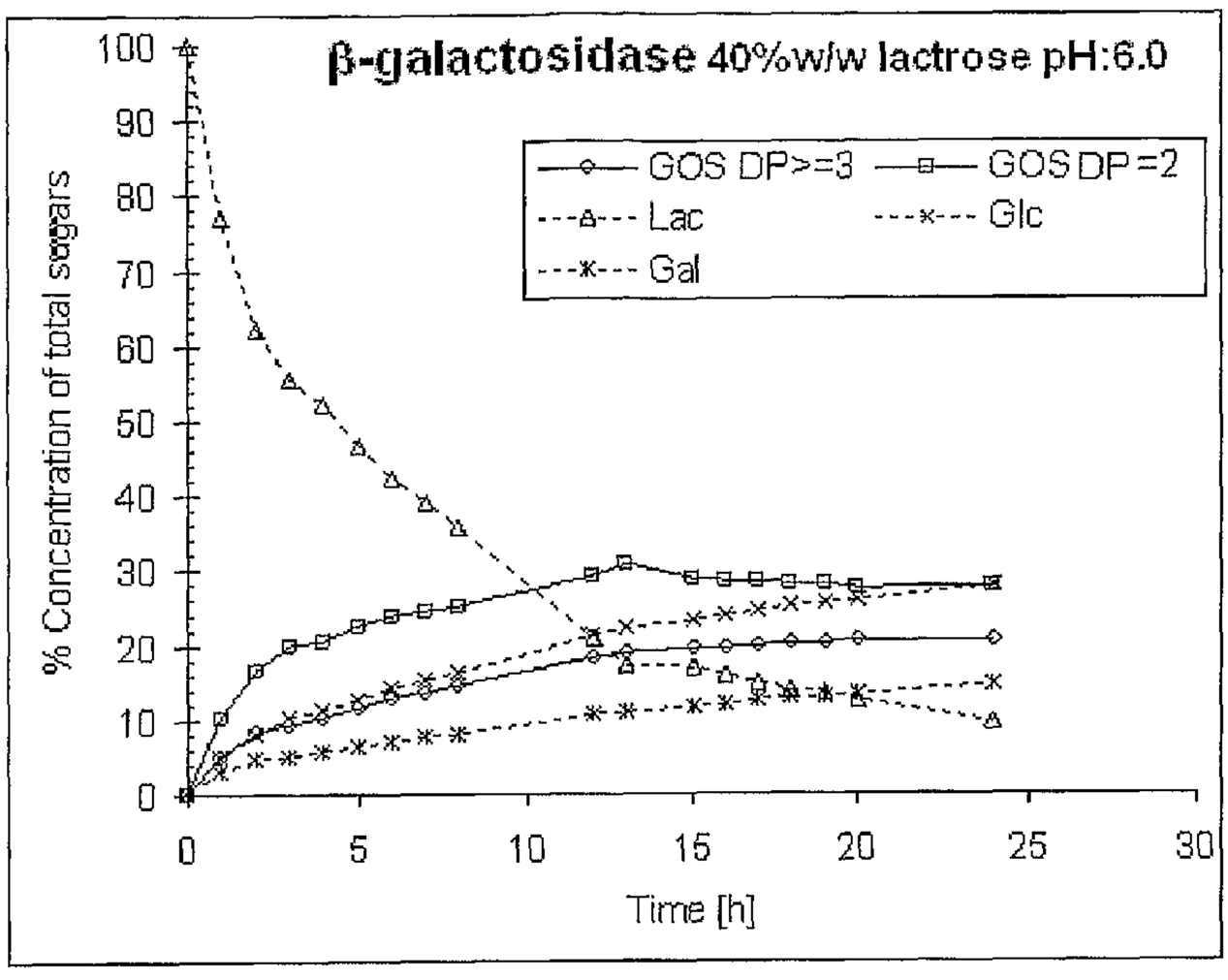

(57) Abstract: The present invention concerns a β-galactosidase with transgalactosylating activity isolated from Bifidobacterium bifidum. The β-galactosidase is capable of converting lactose to a mixture of oligosaccharides which are β-linked and unexpectedly produces the α-linked disaccharide galactobiose. The mixture may be incorporated into numerous food products or animal feeds for improving gut health by promoting the growth of bifidobacteria in the gut, and repressing the growth of the pathogenic microflora.

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GALACTOSIDASE WITH ALPHA-GALACTOSYLTRANSFERASE ACTIVITY

PRODUCT AND PROCESS

The present invention relates to a β-galactosidase with transgalactosylating activity capable of converting lactose to a mixture of oligosaccharides which are β-linked and unexpectedly produces the α-linked disaccharide α1-6 galactobiose. In particular it relates to a β -galactosidase isolated from a recently discovered strain of *Bifidobacterium bifidum*.

The invention particularly relates to DNA sequences encoding the isolated β -galactosidase enzyme, to the enzyme encoded by such a DNA sequence and to a host cell comprising the DNA sequence or a recombinant vector incorporating the DNA sequence. The invention also relates to the use of the enzyme encoded by a DNA sequence, or of the host cell containing a DNA sequence or recombinant vector, to produce oligosaccharides.

Bifidobacteria naturally colonise the lower intestinal tract, an environment which is poor in mono and disaccharides since such sugars are preferentially consumed by the host and microbes present in the upper intestinal tract. In order to survive in the lower intestinal tract bifidobacteria produce various kinds of exo- and endoglycosidases in surface bound and/or extracellular forms, by which they can utilise diverse carbohydrates.

Besides hydrolase activity, some enzymes from bifidobacteria show transferase activity. This transglycosylation activity of glycosidases is extensively used for the enzymatic synthesis of various oligosaccharides, which have proven to act as bifidobacteria growth promoting factors.

It is known that members of bifidobacteria produce β-galactosidase enzymes that are involved in the bacterial metabolism of lactose. Møller, P.L. et al in Appl & Environ. Microbial., (2001), 62, (5), 2276-2283 describe the isolation and characterisation of three β-galactosidase genes from a strain of *Bifidobacterium bifidum*. They found that all three β-galactosidases were able to catalyse the formation of beta-linked galactooligosaccharides by transgalactosylation.

Dumortier et al in Carbohydrate Research, 201, (1990), 115-123 described the formation of beta-linked oligosaccharides by a transgalactosylation reaction during lactose hydrolysis with *Bifidobacterium bifidum* DSM 20456. Their analysis of the structure of the mixture of oligosaccharides produced showed that the linkages were β-(1→3), β-(1→6) and β-(1→4)-D-galactosyl linkages. Dumortier suggested that compounds produced by *Bifidobacterium bifidum* are involved in the adherence of bacteria in the large intestine.

A strain of *Bifidobacterium bifidum* has been found that is capable of producing a galactosidase enzyme activity that converts lactose to a novel mixture of galactooligosaccharides which unexpectedly contains up to 35% of disaccharides including galabiose (Gal (α 1-6) - Gal). This disaccharide is known (see Paton, J C and Paton, A W (1998), Clin. Microbiol. Revs., 11, 450-479; Carlsson, K A (1989), Ann. Reviews Biochem., 58, 309-350) to be an antiadhesive capable of preventing the adhesion of toxins, eg Shiga toxin and pathogens such as *E. coli*, to the wall of the gut.

This strain of *B bifidum* was deposited under accession number NCIMB 41171 at the National Collection of Industrial & Marine Bacteria, Aberdeen, UK on 31 March 2003. It is also described in UK Patent No 2 412 380.

It has now been found that this strain of *B bifidum* produces several β-galactosidases, one of which unexpectedly exhibits α-galactosyltransferase activity. This enzyme produces a number of different oligosaccharides which are β-linked, but it also produces the α-linked disaccharide galabiose.

According to the invention there is provided a DNA which encodes a protein with an amino acid sequence as given in SEQ. ID NO: 2 or hybridises under stringent conditions to the DNA which encodes this protein. The sequence of the DNA is given in SEQ. ID NO: 1 or may comprise a fragment or degenerative thereof.

The phrase "degenerative" is construed to mean a DNA sequence which is at least 50% homologous to SEQ. ID NO: 1, preferably from 50 to 98% homologous, most preferably from 75 to 95% homologous.

Such a DNA sequence may comprise nucleotide substitutions, additions or deletions which result in less than 60%, preferably less than 45%, more preferably less than 25% change in the amino acid sequence shown in SEQ. ID NO: 2. Nucleotide substitutions may result in conservative amino acid substitutions.

According to a second aspect of the invention there is provided an enzyme encoded by a DNA sequence as defined above. Such an enzyme may comprise the amino acid sequence given in SEQ. ID NO: 2 or a fragment thereof.

According to a third aspect of the invention there is provided a recombinant vector, preferably an expression vector, comprising a DNA sequence as defined above. Such a vector may be incorporated into a host cell such as a bacterial, yeast or fungal cell. Alternatively, the DNA sequence may be incorporated into such a host cell. A suitable host cell may be selected from Bifidobacterium, Lactococcus, Lactobacillus, Bacillus for example Bacillus subtilus or Bacillus circulans, Escherichia and Aspergillus for example Aspergillus niger.

Using lactose as a substrate, the enzyme encoded by a DNA sequence as defined above produces a mixture of disaccharides comprising Gal (β1-3) Glc, Gal (β1-3) Gal, Gal (β1-6) Gal and Gal (α1-6) Gal. Also present in the mixture of oligosaccharides are trisaccharides Gal (β1-6) Gal (β 1-4) Glc and Gal (β 1-3) Gal (β 1-4) Glc, tetrasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc and pentasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc.

The enzyme or the host cell as described above may be used to produce a mixture of disaccharides, including Gal (α 1-6) Gal (galabiose) which may form part of a product for improving gut health. Such a product may be selected from the group consisting of dairy products (for example liquid milk, dried milk powder such as whole milk powder, skimmed milk powder, fat filled milk powders, whey powders, baby milks, baby formula, ice cream, yoghurt, cheese, fermented dairy products), beverages such as fruit juice, infant foods, cereals, bread, biscuits, confectionery, cakes, food supplements, dietary supplements,

synbiotic comestible products, prebiotic comestible products, animal feeds, poultry feeds or indeed any other food or beverage.

Alternatively, the oligosaccharides so produced may be used for the preparation of a medicament for example in table or capsule form for preventing the adhesion of pathogens or toxins produced by pathogens to the gut wall. The medicament may be administered to a patient, for example following a course of antibiotic treatment, which often alters or even destroys the normal healthy gut flora.

According to yet a further aspect of the invention there is provided a process for producing an enzyme as defined above which comprises culturing a host cell as defined above in a suitable culture medium under conditions permitting expression of the enzyme and recovering the resulting enzyme from the culture.

The invention is also directed to a process for producing a mixture of oligosaccharides, including the disaccharide Gal (α 1-6) - Gal (galabiose), which comprises contacting the enzyme as defined above or a host cell as defined above with a lactose-containing material under conditions that lead to the formation of the oligosaccharide mixture.

Suitable lactose containing material may be selected from commercially available lactose, whole milk, semi-skimmed milk, skimmed milk, whey and fat-filled milk, whey permeate. Such milk products may be obtained from cows, buffaloes, sheep or goats. Fat-filled milk is defined as whole milk that has been skimmed to remove the dairy fat, which is subsequently replaced by the addition of vegetable fat or oil.

Brief Description of the Drawings

Figure 1 shows the nucleotide sequence (SEQ. ID NO: 1) of *Bifidobacterium bifidum* β-galactosidase of the invention; and

Figure 2 shows the amino acid sequence (SEQ. ID NO: 2) corresponding to the nucleotide sequence of Figure 1.

Figure 3 is a graph showing the time course reaction during galactooligosaccharide synthesis with the β-galactosidase and 40% (w/w) lactose in 0.1M phosphate buffer at pH 6.0 as substrate; and

Figure 4 shows a high performance anion exchange chromatogram of the galactooligosaccharide mixture synthesized by the β-galactosidase from *B.bifidum* NCIMB 41171 using 40% (w/w) lactose in 0.1M phosphate buffer at pH 6.0 as substrate. (Glc = glucose, Gal = galactose, Lac = lactose, α (1-6) galactobiose, DP = degree of polymerisation).

Genomic DNA was isolated from the *Bifidobacterium bifidum* strain (NCIMB 41171) using the method of Lawson *et al.* (1989) Fems Microbiol Letters, 65, (1-2), 41-45. The DNA was digested with restriction enzymes and fragments having a maximum size of 15 kbp were ligated with pSP72 vector which had been digested with the same restriction enzymes. *E. coli* cells were transformed with a vector containing insertions consisting of PstI, Eco RI, Bam HI, KpnI, SmaI or HindIII digested chromosomal DNA from the *B. bifidum*. Clones with β-galactosidase activity were selected on Luria Bertani agar plates containing p-nitrophenyl, X-β-Gal (5-bromo-4-chloro-3-indolyl-β-D-galactoside) and isopropyl-β-D-thiogalactoside (IPTG). Ligation mixtures with Bam HI chromosomal DNA gave rise to seven β-galactosidase positive clones, one of which is identified as pB1.

DNA sequencing of the inserted DNA fragment B1 was performed using the dideoxy chain-termination method of Sanger (Russel P., 2002 iGenetics, Pearson Education, Inc., San Francisco, 187-189) using the BigDye Terminator V.3.O cycle sequencing kit (Applied Biosystems, USA). The DNA sequence of B1 is shown in Figure 1 (SEQ. ID NO: 1).

The open reading frame (ORF) was located by using the ORF finder from NCBI (National Center of Biotechnology Information). The nucleotide sequence of Figure 1 was translated in all six possible reading frames and one open reading frame of 1052 amino acids encoding a putative β-galactosidase was identified. The translation is shown in Figure 2 (SEQ. ID NO: 2).

The present invention will be further described by way of reference to the following example.

Example 1

Materials and Methods

All chemicals and media preparations used throughout this study were obtained from Sigma (Dorset, UK), Invitrogen (Paisley, UK), Oxoid (Basingstoke, UK), Qiagen (West Sussex, UK) and Promega (Southampton, UK).

Bacterial Strains

The *Bifidobacterium bifidum* strain (NCIMB 41171) was maintained on cryogenic beads in Microbank tubes at -70°C. For later experiments, the strain was revived on Wilkinson Chalgren (WC) agar (Oxoid, UK) and TPY medium (trypticase phytone yeast extract medium) and grown anaerobically (CO_2 and N_2 composition 80% and 20% respectively) at 37°C for 48 hours. The colony morphology and the absence of contamination were tested by gram staining.

E. coli strains

Escherichia coli strain DH5a used in this study was commonly incubated under aerobic conditions at 37°C in Luria Bertani (LB) agar or broth (Sambrook J. and Russell W. D. (2001). Molecular Cloning: A Laboratory Manual. Cold Spring Harbor Laboratory Press, New York) and when necessary was supplemented with antibiotics (100µg/ml ampicillin and/or 15µg/ml chloramphenicol) and 40µl of 2% X-β-Gal, 7µl of 20% (isopropyl-β-D-thiogalactoside) IPTG which were applied on the surface of a pre-made 90mm agar plate.

E. coli DH5a strain (Invitrogen, Paisley, UK) (genotype: F^- φ80*lac*ZΔM Δ(*lac*ZYA-argF)U169 recA1 endA1 hsdR17(r_k^-, m_k^-) *pho*A *sup*E44 *thi*-1 *gyr*A96 *rel*A1λ^-) is an α-galactosidase positive strain and was used in expression experiments and for other genetic manipulations.

Genomic DNA Extraction from *Bifidobacterium bifidum*

Genomic DNA was isolated from the *Bifidobacterium bifidum* strain (NCIMB 41171) using the following method in which chromosomal DNA was prepared from cell pellet harvested from 100 ml of WC anaerobe broth. The cells were resuspended in 10 ml TES buffer (10 mM Tris-HCl, 10 mM EDTA, 10 mM NaCl, pH8) and treated with 200 µl of lysozyme/mutanolysin mixture (4:1, lysozyme 10 mg/ml mutanolysin 1 mg/ml) for 30 minutes at 37°C. The cells were then treated with 200 µl of proteinase K (at 20 mg/ml) and 200 µl of RNase (both 10 mg/ml) mixed and incubated for one hour at 65°C. Finally the cells were treated with 2 ml of 10% SDS and incubated for 15 minutes at 65°C. 12 ml of phenol/chloroform were added and the extraction was repeated until the water phase could easily be separated from the interphase. The genomic DNA was precipitated with isopropanol and resuspended in 10 mM Tris-HCl – 1 mM EDTA (pH8). The genomic DNA was then digested with restriction enzymes, ligated into pSP72 digested with the same enzymes and treated with alkaline phasphatase. Digestion of *B. bifidum* genomic DNA was performed using *EcoRI*, *PstI*, *BamHI*, *SmaI* and *KpnI*. Ligation mixtures were used to transform *E. coli* DH5a and β-galactosidase positive clones were identified as blue colonies on X-Gal-containing plates.

Vector DNA Preparation

The vector used for cloning and expression throughout this study was the pSP72 (Promega, UK) (Krieg, P.A. and Melton, D.A. (1987). In vitro RNA synthesis with SP6 RNA polymerase. *Methods in Enzymology.* **155**: 397-415).

This vector was chosen because of the lack of complementing activity of the α-fragment of β-galactosidase which is not encoded in pSP72. This vector does not carry the short segment of *E. coli* DNA containing the regulatory sequence and the coding information for the first 146 amino acids of β-galactosidase which in combination with *E. coli* strains (ie DH5a) which express the carboxy-terminal portion of this β-galactosidase is giving an active β-galactosidase (α-complementation).

The vector was digested with the following restriction enzymes: *Pst*I, *Bam*HI, *Hind*III, *Sma*I, *Kpn*I and *Eco*RI according to the manufacturer's instructions using a tenfold excess of enzyme over DNA (enzyme units :μgr DNA equal to ten units of enzyme per one μgr of plasmid DNA or ten enzyme units per 0.5 pmol of plasmid DNA). After enzyme heat inactivation (20 min at 65°C) the restriction patterns were analysed by horizontal gel electrophoresis analysis. The presence of a single fragment in the gel indicated the complete vector digestion and the single restriction digestion of it.

The sufficient digestion of the vector was tested also by transforming unligated molecules into competent *E. coli* DH5a cells. The number of formed colonies on LB agar plates supplemented with ampicillin (100μgr/ml) was an indicator of the undigested molecules and the expected background during the subsequent experiments.

The vectors were further dephosphorylated with calf intestinal alkaline phosphatase CIAP (Promega, Southampton, UK) according to the manufacturer's instructions. The efficiency of the treatment was tested by self ligation (with Bacteriophage T4 DNA ligase according to manufacturer instructions) following transformation into DH5a cells. The number of formed colonies showed the number of recirculised molecules (non cloned vector) and a subtraction of the above with the formed colonies without CIAP vector treatment shown the number of non dephosphorylated vectors.

Genomic DNA Library Construction

Genomic DNA was partially digested with six restriction enzymes that recognise frequently occurring hexa-nucleotide sequences within prokaryotic DNA. *EcoRI*, *BamHI*, *PstI*, *KpnI*, *SmaI* and *HindIII* are type II restriction endonucleases specifically recognizing the sequences 5'G/AATTC'3, 5'G/GATCC'3, 5'CTGCA/G'3 , 5'GGTAC/C3', 5'CCC/GGG3' and 5'A/AGCTT3' respectively, and make double–strand breaks within these sequences generating 5'overhangs of four nucleotides, AATT, GATC, AGCT for *EcoRI*, *BamHI* and *Hind* III respectively, and 3'overhangs, ACGT,GTAC for *PstI* and KpnI respectively and blunt ends for SmaI.

All these enzymes were active and able to cleave DNA only in the presence of divalent magnesium ions. These ions were the only required cofactor.

Restriction Digestion of DNA.

All restriction digestions of the genomic DNA samples were incubated for 2 hours at 37°C and finally heat inactivated at 65°C for 20 minutes. The reactions were then cooled at room temperature and the appropriate amount of loading buffer was added, followed by gentle mixing with a sealed glass capillary. The solutions then were loaded into wells of a 0.8% agarose gel (power supply 4-5volts/cm for 14-16 hours) and the size of the digested DNA was estimated with that of 1kbp DNA standards (Promega, UK) (Sambrook J. Molecular Cloning: A Laboratory Manual (2002)).

Purification of the fragments generated after restriction digestion.

Fragment purification from the reaction mixtures and the agarose gels was done by using the QIAEX gel extraction kit from Qiagen (West Sussex, UK). Protocols are described with details in the manufacturer's manual.

DNA Ligation and Transformation

After purification of the DNA fragments with the Qiaex gel extraction kit, they were ligated with CIAP-treated pSP72 vector. For ligation, appropriate amounts of DNA were transferred to sterile 0.5 ml microfuge tubes as shown in Table 1.

Tube	DNA
A	Vector (15 fmoles [~ 29.7 ng])
B	Vector (15 fmoles ~29.7ng DNA) plus insert (foreign 15 fmoles ~ 69.3ng)
C	pUC control (0.056 fmoles [~100 pg])
The molar ratio of plasmid DNA vector to insert DNA fragment should be ~1:1 in the ligation reaction. The final DNA concentration should be ~10ng/µl.	

Table 1: Ligation mixtures. Tube A shows the number of self-ligated vector DNA which must be subtracted from the total number of transformants after transformation. Tube B shows the ligation of the vector with the DNA fragments and tube C shows the control in order that the transformation efficiency to be calculated.

Before each ligation the DNA fragments were warmed at 45°C for 5 minutes to melt any cohesive termini that reannealed during fragment preparation. A molar ratio of vector:insert DNA of 1:1 was chosen for all ligation reactions and the reaction assembly was done according to Promega's instructions.

To tubes A and B 1.0 µl of 10x ligation buffer and 0.5 Weiss units of T4 DNA ligase (Promega, UK) were added and the ligation volume was adjusted to 10 µl with molecular biology grade water. To tubes C 1.0 µl of 10x ligation buffer were added and the ligation volume was adjusted to 10 µl with molecular biology grade water.

DNA fragments were added to the tubes together with the water and then warmed to 45°C for 5 minutes to melt any cohesive termini that were reannealed during preparation. The DNA was chilled to 0°C before the remainder of the ligation reagents were added and the reaction mixtures were incubated overnight at 16°C (Sambrook and Russell, 2001).

After ethanol precipitation and purification of the ligated fragments (in order to remove the ligation mixture which cause reduction of the transformation efficiency) transformations were performed according to Hanahan instructions. ~50ng of ligated DNA in 5µl solution was added to 100µl of competent E.Coli DH5a cells. After heat treatment and expression of the ampicillin resistance gene the cells were spreaded over the surface of LB plates containing ampicillin (100µgr/ml), X-β-Gal (40µl of 2% X-β-Gal) and IPTG (7µl of 20%IPTG).

The number of transformants from each ligation reaction was measured. The number of transformants commonly obtained from tube C was $2x10^5$-$1x10^6$cfu/µg whereas from tube A was 500-600 cfu/µg. The number of transformants in tube A was an indication of the efficient treatment of the vector DNA. The number of transformants in tube B was in a range from 2-$4x10^4$cfu/µg.

Number of Transformants

Ligation mixtures with *Pst*I chromosomal DNA gave rise to 13 β-galactosidase positive clones out of ~2500 screened transformants whereas with *Bam*HI gave rise to 7 positive clones (~1500 scr. transformants), *Eco*RI gave rise to 3 positive clones (~1300 scr. transformants), *Kpn*I gave rise to 7 positive clones (~2000 scr. transformants), *Sma*I gave rise to 3 positive clones (~1600 scr. transformants) and *Hind*III gave rise to 2 positive clones (~1200 scr. transformants).

Positive Clone Digestion

In order to identify the different β-galactosidase genes, the plasmids isolated from the positive clones were digested according to the following table.

	Samples	Enzymes
1st Digestion	pB1, pB2, pB3, pB4, pB5, pB6, pB7	*Bam*HI
2nd Digestion	pP1, pP2, pP3, pP4, pP5, pP6, pP7, pP8, pP9, pP10, pP11	*Pst*I
3rd Digestion	pP12, pP13, pP14	*Pst*I
4th Digestion	pE1, pE2, pE3	*Eco*RI
5th Digestion	pP1, pP12, pB1, pP2, pE1, pE2, pE3……	*Pst*I and *Eco*RI
6th Digestion	pS1, pS2, pS3	*Sma*I
7th Digestion	pP1, pP12, pB1, pP2, pS1, pS2, pS3	*Pst*I and *Sma*I
8th Digestion	pK1, pK2, pK3, pK4, pK5, pK6, pK7	*Kpn*I
9th Digestion	pP1, pP12, pB1, pP2, pK1, pK2, pK3, pK4, pK5, pK6, pK7	*Pst*I and *Kpn*I
The first letter (p) indicates plasmid and the insert gene whereas the second letter (P,B,E,S,K) indicates the restriction enzyme that was used for isolation of the respective clone from the genomic DNA.		

Gel electrophoresis analysis of the generated fragments after digestion was shown that plasmids pB1, pP1, pP2 and pP11 each have an insert which encodes a different β-galactosidase . The clones containing pB1 was used for further analysis.

DNA Sequencing

DNA sequencing was performed with the dideoxy chain-termination method of Sanger by using the BigDye Terminator v.3.0 cycle sequencing kit (Applied Biosystems,

USA) and analysed with the ABI Prism 3100, a fluorescence-based DNA analysis system incorporating capillary electrophoresis.

The 5'- and 3'- ends of the inserted DNA fragments were sequenced with vector specific primers. The inserts were further sequenced by using the Genome Priming System (GPS-1) (New England Biolabs, UK). GPS-1 is a TN7 transposon-based in vitro system which uses TnsABC Transposase to insert Transposon randomly into the DNA target. The donor: target DNA mass ratio of 1:4 was used according to the manufacturer instructions. The number of isolated plasmids for sequencing after insertion of the Transprimer into the target plasmid was 25. This number was calculated according to the manufacturer instructions and it assumes a 5-fold depth of coverage.

For plasmid pB1 insertion of a ≅1699bp's transposon-insert at position 973bp downstream of the multiple- cloning site of the vector used completely eliminated the β-galactosidase activity indicating that the start codon was positioned between the vector MCS (multiple cloning site) and the transposon site, whereas insertion of the insert at position 841bp downstream of the MCS led to the formation of an active β-galactosidase indicating that the start codon exists between 841bp and 973bp downstream of the MCS. The enzyme activity was eliminated completely with insertion of the insert at a position 3565bp downstream of the MCS indicating that the stop codon is downstream of this position. Moreover insertions at positions 1239bp, 1549bp, 1683bp, 1832bp, 2108bp, 2189bp, 2270bp, 2340bp, 2414bp, 2574bp, 2648bp, 2734bp, 2807bp and 3410bp completely eliminate the enzymatic activity.

The sequencing reaction mix contained approximately 400-600ng plasmid DNA, 3.2pmol of primer solution and 4μl of BigDye Terminator solution.

Open Reading Frame Identification

The open reading frame (ORF) of B1 was located by using the ORF finder from NCBI. The bacterial genetic code was used and the frame length was determined to be 100bp. The nucleotide sequence was translated in all six possible frames and an open

reading frame of 1052 amino acids encoding a putative β-galactosidase was identified (The translation is shown in Figure 2).

Example 2

Synthesis with the β-galactosidase cloned enzyme isolated from *Bifidobacterium bifidum* NCIMB 41171 in *E. coli* host (strainDH5a)

The following described synthesis, unless otherwise stated, was performed with the whole *E. coli* DH5a host cells after treatment of the E.coli biomass (collected by centrifugation at 10,000 g) with toluene at a concentration of 2000 ppm in order to increase cell permeability and also to render the cells non-viable by destroying their cytoplasmic membrane. The E-coli biomass was prepared as described in Example 1 under "E coli strains".

Synthesis with cloned enzyme

Synthesis with β-galactosidase was performed at a substrate concentration of 40% (w/w) initial lactose concentration. The synthesis solution was prepared in 0.1 M phosphate buffer at pH 6.8 (or 0.1M citrate buffer pH 6.2 or potassium phosphate buffer pH 6.8)). Synthesis was performed at 40°C in shaking waterbath at 150 rpm. The pH optimum for the specific enzyme was chosen based on activity measurements (using o-nitrophenyl-β-D-galactopyranoside as substrate) of a specific enzymatic preparation at varying pH values.

For galactooligosaccharide synthesis 5 ml of an *E. coli* DH5a cell suspension (with an activity of 2.2 U/ml) were centrifuged (at 10,000 g) to collect the biomass and the supernatant was discarded. This biomass was re-suspended with 10 g of 40% (w/w) substrate solution in order to perform the synthesis.

The concentrations of the different sugars present in the mixture during synthesis are shown in Figure3. High performance anion exchange chromatography coupled with pulsed amperometric detection (HPAEC-PAD) chromatograms of galactooligosaccharide mixtures synthesized by the β-galactosidase cloned from *B. bifidum* NCIMB 41171 are

shown in Figure4. The galactooligosaccharide mixture sugar concentrations at the optimum synthesis time point are shown in table 1.

Table 1. Carbohydrate composition of galactooligosaccharide synthesis at 40 % (w/w) initial lactose concentration at the time point where maximum oligosaccharide concentration was observed.

Synthesis Init. Subst.	GOS DP≥3	GOS DP=2	Lac	Glc	Gal
% (w/w)	Concentration (% of total sugars)				
40	20.45	27.64	12.73	25.90	13.28

Lac: Lactose, Glc: glucose, Gal: galactose, DP: degree of polymerisation

WHAT IS CLAIMED IS:

1. A DNA encoding a protein with an amino acid sequence as given in SEQ. ID. NO: 2.

2. The DNA according to Claim 1, wherein the sequence of the DNA is as defined in SEQ. ID. NO: 1.

3. An enzyme encoded by the DNA sequence of Claim 1 or Claim 2.

4. An enzyme comprising an amino acid sequence according to SEQ. ID. NO: 2.

5. A β-galactosidase enzyme consisting of the sequence as defined in SEQ. ID. NO: 2.

6. A recombinant vector comprising the DNA of Claim 1 or Claim 2.

7. The vector according to Claim 6, wherein said vector is an expression vector.

8. A host cell into which the DNA of Claim 1 or Claim 2 has been incorporated.

9. A host cell comprising the vector of Claim 6 or Claim 7.

10. The host cell according to Claim 8 or Claim 9, wherein said cell is a bacterial cell, a yeast cell or a fungal cell.

11. The host cell according to Claim 10, wherein said cell is selected from the group consisting of Bifidobacterium, Lactococcus, Lactobacillus, Escherichia, Bacillus and Aspergillus.

12. The host cell according to Claim 11, wherein the cell is selected from the group consisting of Bifidobacterium bifidum, Bacillus subtilis, Bacillus circulans and Aspergillus niger.

13. A use of an enzyme with an amino acid sequence as given in SEQ. ID. NO: 2 for producing a mixture of oligosaccharides comprising β-linked galactooligosaccharides and α-linked galactooligosaccharide Gal (α 1-6) Gal.

14. The use according to Claim 13 wherein the β-linked galactooligosaccharides are disaccharides Gal (β 1-3) Glc, Gal (β 1-3) Gal, and Gal (β 1-6) Gal, trisaccharides Gal (β 1-6) Gal (β 1-4) Glc, and Gal (β 1-3) Gal (β 1-4) Glc, tetrasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc and pentasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc.

15. The use according to Claim 13 or Claim 14, wherein the mixture comprises trisaccharides Gal (β 1-6) Gal (β 1-4) Glc and Gal (β 1-3) Gal (β 1-4) Glc, tetrasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc, and pentasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc.

16. A use of the enzyme of any one of Claims 3 to 5, or the cell of any one of Claims 8 to 12, for producing a mixture of oligosaccharides to be part of a product selected from the group consisting of dairy products, beverages, infant foods, cereals, bread, biscuits, confectionary, cakes, food supplements, dietary supplements, probiotic comestible products, prebiotic comestible products, animal feeds, poultry feeds and medicaments.

17. The use according to Claim 16, wherein the mixture comprises disaccharides Gal (β 1-3) Glc, Gal (β 1-3) Gal, Gal (β 1-6) Gal and Gal (α 1-6) Gal, trisaccharides Gal (β 1-6) Gal (β 1-4) Glc and Gal (β 1-3) Gal (β 1-4) Glc, tetrasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc, and pentasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc.

18. A use of the host cell of any one of Claims 8 to 12, for producing a product selected from the group consisting of dairy products, beverages, infant foods, cereals, bread, biscuits, confectionary, cakes, food supplements, dietary supplement, probiotic comestible product, prebiotic comestible product, animal feeds, poultry feeds and medicaments.

19. The use according to Claim 16 or Claim 18 wherein the dairy product is liquid milk, dried milk powder, baby milk, baby formula, ice cream, yoghurt, cheese or fermented dairy product.

20. The use according to Claim 16 or Claim 18 wherein the beverage is fruit juice.

21. A process for producing the enzyme of any one of Claims 3 to 5 comprising culturing the host cell of any one of Claims 8 to 12 in a suitable culture medium under conditions permitting expression of said enzyme and recovering the resulting enzyme from the culture.

22. A process for producing a mixture of oligosaccharides comprising disaccharides Gal (β 1-3) Glc, Gal (β 1-3) Gal, Gal (β 1-6) Gal and Gal (α 1-6) Gal, trisaccharides Gal (β 1-6) Gal (β 1-4) Glc and Gal (β 1-3) Gal (β 1-4) Glc, tetrasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc, and pentasaccharide Gal (β 1-6) Gal (β 1-6) Gal (β 1-6) Gal (β 1-4) Glc, said process comprising contacting the enzyme of any one of Claims 3 to 5 or the host cell of any one of Claims 8 to 12 with a lactose-containing material.

Figure 1

1 ggatccggtg aacgcgccga gcgcggtgta cgtgctgcgc tcgtgcgagt cggaggagat
61 cgcggggatc atgccccagt aggagatgtc gcgcagcgag tagatcacgt cgagcaggat
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Figure 2


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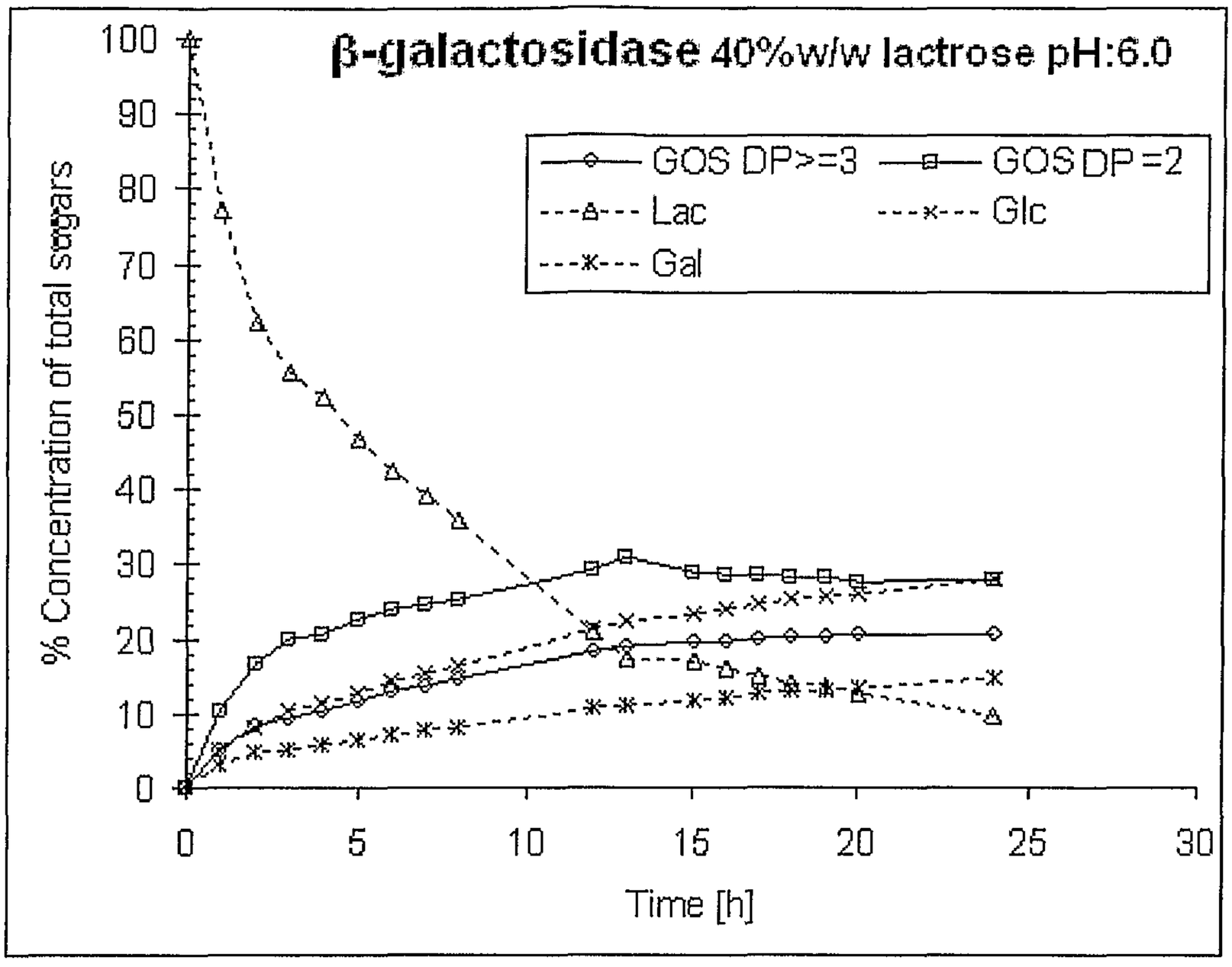
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GOS DP>=3
GOS DP =2
Lac
Glc
Gal
% Concentration of total sugars
Time [h]
0
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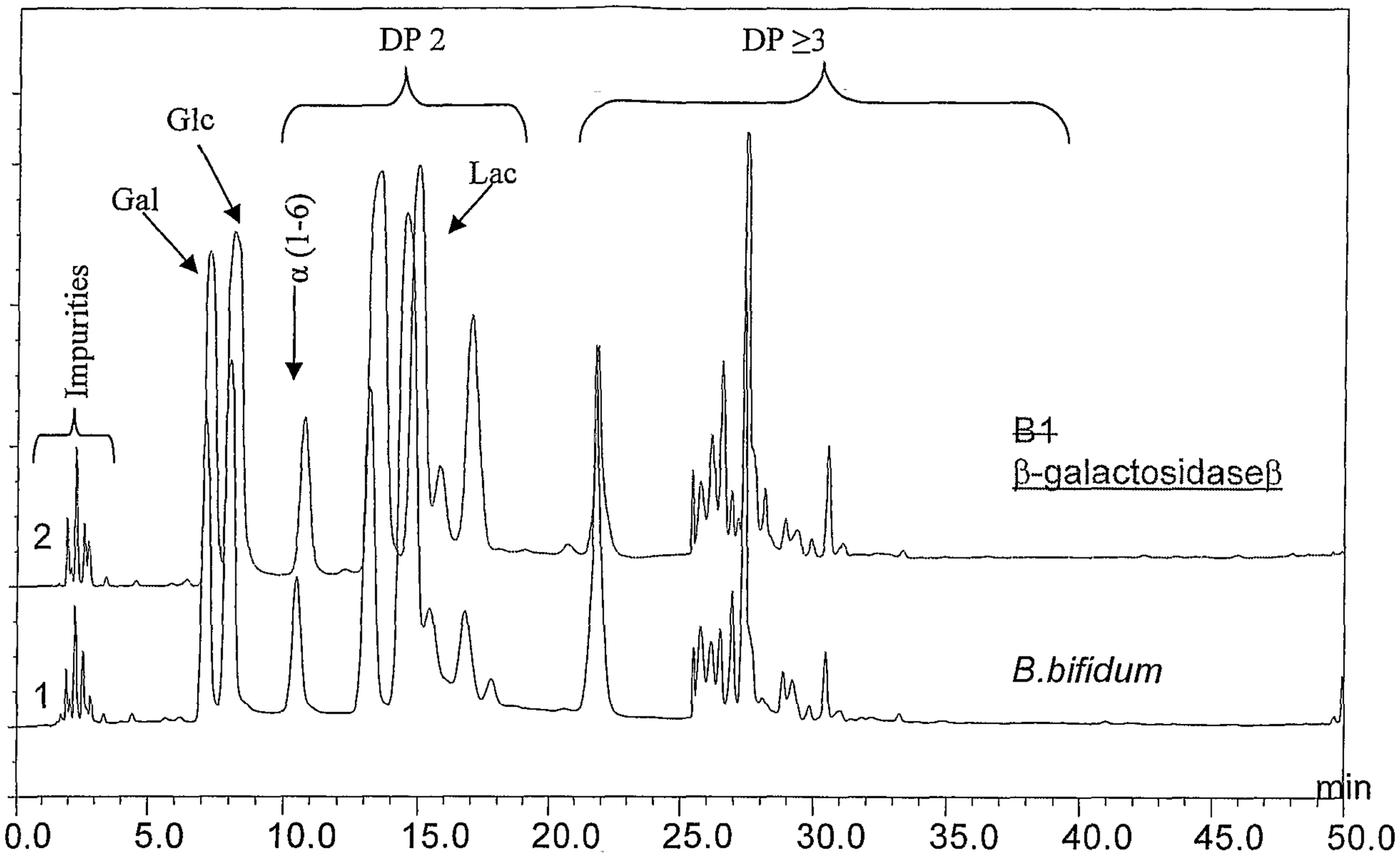
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

Figure 3


DP 2
DP ≥3
Glc
Gal
Lac
α (1-6)
Impurities
2
1
B1
β-galactosidaseβ
B.bifidum
min
0.0
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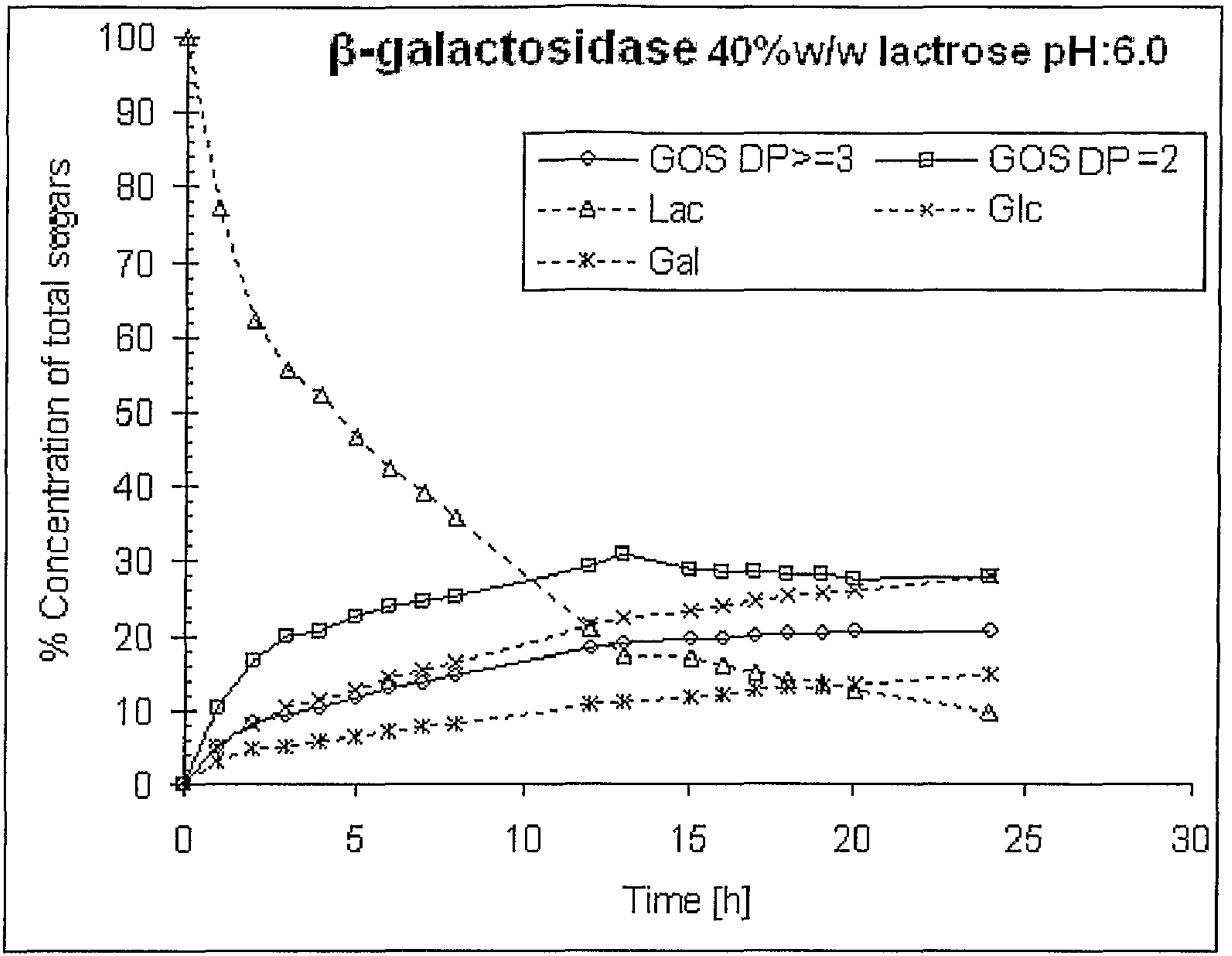
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0

Figure 4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GOS DP>=3
GOS DP=2
Lac
Glc
Gal
% Concentration of total sugars
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time [h]