

Microbial β -Glucosidase: Sources, Production and Applications

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Abstract Cellulose is the most abundant biopolymer in biosphere and the major constituent of plant biomass. Cellulose polymer is made up of β -glucose units linked by β -glucosidic bonds. Cellulase is an enzymatic system that catalyzes the hydrolysis of cellulose polymer to glucose monomers. This enzymatic system consists of three individual enzymes namely endoglucanase, exoglucanase and β -glucosidase which act synergistically to degrade cellulose molecules into glucose. Cellulases are produced by bacteria, fungi, plants, and animals and used in many industrial applications such as textile industries, laundry and detergent industries, paper and pulp industry, animal feeds, and biofuels production. β -Glucosidase is a diverse group of enzymes with wide distribution in bacteria, fungi, plants and animals and has the potential to be utilized in various biotechnological processes such as biofuel production, isoflavone hydrolysis, flavor enhancement and alkyl/aryl β -D-glucoside and oligosaccharides synthesis. Thus, there is increased demand of β -glucosidase production from microbial sources under profitable industrial conditions. In this review, β -glucosidase classification, localization, and mechanism of action will be described. Subsequently, the various sources of β -glucosidase for industrial sector will be discussed. Moreover, Fermentation methods and various parameters affecting β -glucosidase production will be highlighted on the light of recent findings of different researchers. Finally, β -glucosidase applications in biofuel production, flavors enhancement, isoflavones hydrolysis, cassava detoxification and oligosaccharide synthesis will be described.

Keywords: cellulose, glycoside hydrolase, cellulase, β -glucosidase, biofuel, transglycosylation

Cite This Article: Amer Ahmed, Faiz ul-Hassan Nasim, Kashfa Batool, and Aasia Bibi, "Microbial β -Glucosidase: Sources, Production and Applications." *Journal of Applied & Environmental Microbiology*, vol. 5, no. 1 (2017): 31-46. doi: 10.12691/jaem-5-1-4.

1. Introduction

Cellulose is the most abundant organic biopolymer in biosphere and the major constituent of lignocellulosic material making up to 35-50% of plant biomass. Hemicellulose and lignin are the other two constituents making up to 20-35% and 10-15%, respectively. This biomass is known to be renewable with annual production of approximately 1×10^{10} tons, sustainable and cheap source of energy [1-8]. Biomass is the fourth among world energy sources after coal, fossil fuel and natural gas, providing 10-14% of the total energy [9,10]. Lignocellulosic material can be converted into numerous valuable organic compounds such as sugar, bioethanol, amino acids, organic acids and food additives. It can also be used as substrate for production of many industrially important enzymes [11,12,13,14,15]. Cellulose is a linear polymer of anhydro- β -D-glucose unit linked by β -(1-4) O-glycosidic bonds ranging from 800-10000 units forming a chain with average molecular weight of 100000 Da [4,7,16,17,18]. Cellulose chains are stabilized by intra- and intermolecular hydrogen bonds and Van Der Waals forces [19,20]. Usually cellulose polymer has two regions: crystalline region recalcitrant to enzymatic hydrolysis and amorphous region easily accessible to

enzymatic hydrolysis [21,22,23]. To be utilized in various industrial applications e.g., bioethanol production, cellulose must first be broken down to simple fermentable sugar i.e., glucose. In nature, cellulose degradation is mediated by combined action of three individual enzymes named as endoglucanase (1,4- β -D-glucan hydrolase; EC 3.2.1.4), exoglucanase (1,4- β -D-glucan glucohydrolase EC 3.2.1.74) and β -glucosidase (β -D-glucoside glucohydrolase EC3.2.1.21) [24,25,26,27]. To begin with, endoglucanase randomly attacks and hydrolyzes glucosidic bonds in the interior of the molecule especially in the amorphous regions generating oligosaccharides chains of different length. This is followed by exoglucanase/cellobiohydrolase that processively hydrolyzes these chains at their reducing and nonreducing ends releasing glucose, cellobiose, and short oligosaccharides. These two enzymes act synergistically and are usually inhibited by cellobiose. Finally, β -glucosidase breaks down cellobiose and short oligosaccharides into glucose units thus eliminating cellobiose inhibitions on endoglucanase and cellobiohydrolases [22,24,28-33]. These three enzymes are collectively referred to as cellulase enzyme and produced by bacteria, fungi, protozoa, plants, and animals [26,34,35,36]. Cellulase enzymes collectively are used in various industries such as laundry and detergents industry, textile industry, paper and pulp industry, animals feed, food industry etc. [18,28,35-40].

β -Glucosidase is an ubiquitous enzyme produced by all life domains: bacteria, fungi, plants and animals including noncellulolytic organisms such as human [24]. It hydrolyzes β -D-glucosidic bonds of various compounds comprising of alkyl- β -D-glucosides, aryl- β -D-glucosides, cyanogenic glucosides, disaccharides and short chain oligosaccharides liberating glucose from their nonreducing end, in addition, some novel β -glucosidases with β -galactosidase and β -xylosidase activity have also been reported [41,42]. Under certain circumstances, β -glucosidase also catalyzes synthetic reactions of oligosaccharides/glycosides [43,44,45]. This synthetic activity is brought about in two ways: either through reverse hydrolysis or transglycosylation. In reverse hydrolysis reaction, lowering water activity, trapping of product or high substrate concentration results in a shift of reaction equilibrium toward synthesis through "reverse hydrolysis". This reaction is under thermodynamic control. In transglycosylation reaction, donor glycoside is hydrolyzed by the enzyme resulting in enzyme-glycosyl intermediate which is in turn attacked by a nucleophile other than water such monosaccharide, disaccharide, aryl-amino, alkyl-alcohol or monoterpene alcohol to yield a new elongated product. This reaction is under the kinetic control [44,46,47].

β -Glucosidase plays fundamental roles in many physiological processes [48,49]. For instance, in plants, it is involved in defense [50,51], β -glucan chain synthesis and cell wall metabolism [52,53], lignification [54,55], phytohormone activation [56,57], secondary metabolism [58,59], and fruit ripening [60,61]. In microorganisms, it plays roles in cellulose hydrolysis, carbon recycling and cellulase gene induction [62,63,64,65]. In mammals, β -glucosidase is involved in hydrolysis of glucosyl ceramides and in humans its defect causes Gaucher's disease [66, 67].

β -Glucosidases, particularly those derived from microbial sources, have the potential to be used in many biotechnological processes such as bioethanol production [68,69], improvement of the aroma in wine and fruit juices industry through release of the aromatic compounds from flavorless glycosides [70]. They are also used to hydrolyze isoflavone glycosides thus increasing their absorption from small intestine positively affecting human health [71,72,73]. β -Glucosidases can also be utilized for detoxification of cassava [74,75,76], and deinking of waste paper [77,78]. Based on synthetic activity, β -glucosidase is utilized in biosynthesis of oligosaccharides and alkyl glycosides [79,80,81,82,83]. These compounds have wide range of uses in medical sciences as therapeutics agents, diagnostics tools, and as growth promoters for probiotics bacteria [84]. Alkyl glycosides have anionic surfactant properties and can be used as antimicrobial agents [85,86,87], and in pharmaceutical, cosmetics, detergent and foods industries [83].

β -Glucosidases are produced by microorganisms in low quantities [88], and inhibited by their end product i.e., glucose [89], resulting in accumulation of cellobiose during cellulolysis which in turn inhibits both endo-/exo-glucanase. β -Glucosidase is therefore considered to be the key enzyme in determining the cellulase efficiency and the bottle neck in bioethanol production through biomass conversions [90,91,92]. Researchers are focusing on

finding or developing microorganisms with high β -glucosidase productivity and/or β -glucosidase with high glucose tolerance, thermostability and catalytic efficiency.

In this review, we describe β -glucosidases classification, localization, and mechanism of actions. Further, the microbial sources of β -glucosidases, production methods along with parameters affecting their production will be discussed thoroughly. Finally, biotechnological applications of β -glucosidases such as bioethanol production, flavors enhancement of wine and fruit juices, among other potential applications, will also be highlighted.

1.1. β -Glucosidase Classification

β -Glucosidase cleaves β -D-glucosidic bonds from a variety of compounds releasing glucose as the end product. Thus, differing greatly in their substrate specificity particularly with regard to the aglycone moiety making their classification a challenge [44]. The two widely accepted methods for their classification are: 1) classification based on substrate specificity and 2) classification based on nucleotide sequences identity and hydrophobic cluster analysis [43]. Based on substrates specificity, β -glucosidases are categorized in three classes: 1) aryl- β -glucosidases hydrolyzing only aryl- β -glucoside linkage, 2) cellobiases hydrolyzing only cellobiose, and 3) broad substrate specificity β -glucosidase hydrolyzing wide range of substrates with different bonds such as $\beta(1\rightarrow4)$, $\beta(1\rightarrow3)$, $\beta(1\rightarrow6)$, $\alpha(1\rightarrow4)$, $\alpha(1\rightarrow3)$, and $\alpha(1\rightarrow6)$ linkage. Most of the reported microbial β -glucosidases show broad substrate specificity [46,93,94]. Based on sequence identity and hydrophobic cluster analysis, β -glucosidases are placed in Glycoside Hydrolase (GH) family 1 and family 3 as in Carbohydrate active enZyme database "CaZy" [49,95,96,97]. β -Glucosidases belonging to GH family 1 are reported from archeobacteria, plants and animals whereas β -glucosidases belonging to GH family 3 are from bacteria, fungi and yeast, although β -glucosidase can also be found in family 5, 9, 30 and 116 [43,44,46,73].

1.2. Localization of β -Glucosidases

Microbial β -glucosidases are localized as intracellular, extracellular, or cell-bound enzymes [98,99]. Generally β -glucosidases belonging to GH 3 are localized as extracellular or cell-bound enzymes whilst those belonging to GH 1 are predominately intracellular enzymes [100,101]. Some Fungal species such as *Trichoderma reesei* are known to synthesize extracellular, intracellular and cell-bound β -glucosidase [102]. Majority of the reported fungal β -glucosidases are extracellular and belong to GH 3 whereas majority of the reported bacterial β -glucosidases are intracellular and belonging to GH 1[44]. For instance, extracellular and cell-bound β -glucosidase from *Aspergillus kawachii* [92], an intracellular β -glucosidase from the bacterium *Bacillus circulans* subsp. *Alkalophilus* [103], and extracellular β -glucosidase from unidentified bacterial isolate M+, and *Bacillus subtilis* strain [104,105] have all been reported. Extracellular, intracellular and cell bound β -glucosidase in yeast have also been identified [106,107,108].

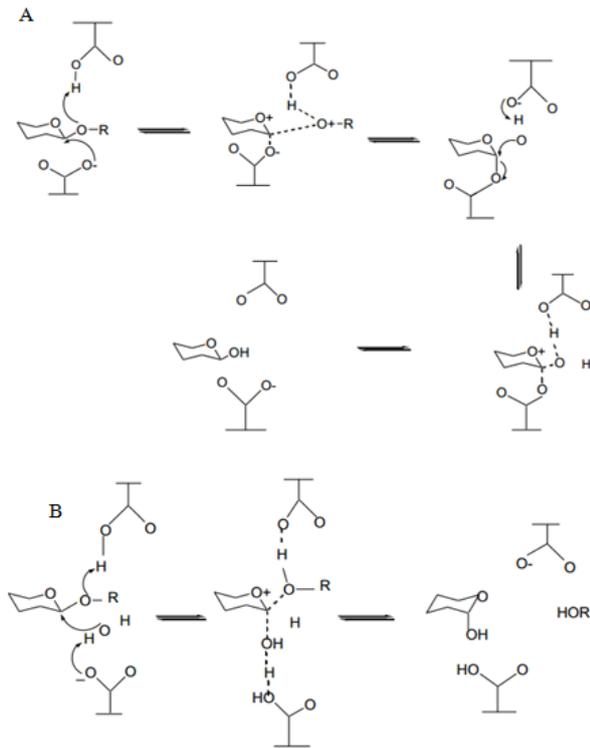


Figure 1. Mechanism of action of retaining β -glucosidase (A) and inverting β -glucosidase (B)

1.3. Mechanism of Actions of β -Glucosidase

β -Glucosidase are either retaining or inverting enzymes depending on the configuration of anomeric carbon atom of the released glucose e.g., retaining β -glucosidase cleaves β -glucosidic bond with the resulting glucose unit has β -configuration whereas in inverting β -glucosidase the resulting glucose has α -configuration. β -Glucosidase belonging to GH family 1 and 3 are retaining enzyme while those placed in GH family 9 are inverting enzymes [49]. Both inverting and retaining enzymes follow acid-base catalysis mechanism and two residues at their active site, general acid/base catalyst and nucleophile, are involved in catalysis. Retaining enzymes catalyze the hydrolysis in two steps: glycosylation and deglycosylation, or double displacement mechanisms. In glycosylation, the catalytic acid/base donates a proton to the substrate leading to formation of oxocarbenium ion, and then the nucleophile attack the anomeric carbon atom yielding enzyme-glycosyl intermediate. In the deglycosylation step, a water molecule attacks enzyme-glycosyl intermediate to displace the catalytic nucleophile from the glucose with basic assistance of the catalytic acid/base [109,110,111]. Inverting enzymes catalyze the hydrolysis of glycosidic bond in one step reaction in which a water molecule acts as nucleophile and attacks the anomeric carbon atom to displace the aglycone (Figure 1) [109]. The catalytic residues are highly conserved among glycoside hydrolase families, and clans. The nucleophile of β -glucosidase belonging to GH 3 has been identified as Asp residue which is highly conserved; while catalytic general acid/base residue appeared to be presented by different motifs in different members, although mostly it is His-Asp dyad motif in which the histidine side chain involves in catalysis [112,113,114,115]. In β -glucosidases belonging

to GH family 1, the catalysis is mediated by two glutamic acid residues one acts as nucleophile and other as general acid/base catalyst [116]. For instances, in *Streptomyces* sp, a glutamic acid at position 178 acts as general acid/base catalyst while glutamic residue at position 383 acts as nucleophile [117].

2. β -Glucosidase Sources

β -Glucosidase is a ubiquitous enzyme expressed by all life domains: bacteria, fungi, plants and animals. It has been purified and characterized from animals and plants [118,119]. For the industrial utilization, microorganisms are considered the best choice for enzyme productions. The preference of microorganisms as source of industrial enzymes is attributed to many reasons such as 1) microorganisms grow rapidly speeding up the production of enzyme, 2) microorganisms are easier to handle than animals and plants since they require less space making the processes cost effective, 3) microorganisms can easily be manipulated with help of genetic engineering, mutagenesis and direct evolution and 4) furthermore, some microorganisms produce enzymes with special characteristic such as thermostability and alkalophilicity which can be utilized in many industries requiring such harsh conditions [120,121]. β -Glucosidase is obtained from fungi and bacteria, although fungi are the preferred source of cellulase enzymes [122].

2.1. Fungal β -Glucosidase

β -Glucosidase has been produced, purified, and characterized from many fungal species majority of which are extracellular enzymes belonging to GH 3. For instance, β -glucosidase has been produced and characterized from *Trichoderma reesei* [123], the filamentous fungus *Acremonium persicinum* [124], *Aspergillus oryzae* [96], *lanuginosus*-SSBP [125], *Thermoascus aurantiacus* [126], *Chaetomium thermophilum* var. *coprophilum* [127], *Penicillium purpurogenum* [128], *Daldinia eschscholzii* [129], *Melanocarpus* sp. MTCC 3922 [130], *Neocallimastix patriciarum* W5 [131], *Monascus purpureus* [132] and brown-rot basidiomycete *Fomitopsis palustris* [133]. Moreover, β -glucosidase recently has been produced from *Penicillium purpurogenum* KJS506 [134], *Phoma* sp. KCTC11825BP [135], *Aspergillus fumigatus* Z5 [136], *Penicillium italicum* [137], *Fusarium proliferatum* NBRC109045 [33], *Aspergillus saccharolyticus* [138,139], *Aspergillus niger* A20 [140], *Fusarium solani* [141], *Flammulina velutipes* [142], *Monascus sanguineus* [143], *Sporothrix schenckii* [144], *Gongronella butleri* [145], and *Fusarium oxysporum* [146]. Although *Trichoderma reesei* is major source of industrial cellulase, it lacks sufficient amount of β -glucosidase activity for efficient cellulolysis, therefore supplementary β -glucosidase is required for efficient biomass hydrolysis. The fungal species *Aspergillus niger* is the major source of commercial β -glucosidase under the name of Novazym188 [90].

2.2. Bacterial β -Glucosidase

Although bacteria are known to secrete cellulase enzyme in lower quantities, they have been the focus of

many researchers for production of cellulases and β -glucosidase because of their high multiplication rate and robust properties exhibited by bacterial enzymes [147,148,149]. β -Glucosidase has been identified, purified and characterized from several bacterial species such as *Clostridium thermocellum* [150], *Pyrococcus furiosus* [151], *Bacillus circulans* subsp. *Alkalophilus* [103], *flavobacterium johnsoniae* [152], *Actinomycete Thermobifida fusca* [153], *Paenibacillus* sp. Strain C5 [154], *Lactobacillus brevis* [155], *Caldicellulosiruptor saccharolyticus* [156], and *Terrabacter ginsenosidimutans* sp. [157]. Recently high glucose tolerant β -glucosidase with high specific activity toward cellobiose from *Thermoanaerobacterium thermosaccharolyticum* has been characterized [158] and β -glucosidase with ability to transform ginsenoside Re to the minor ginsenoside Rg 2 from *Pseudonocardia* sp. Gsoil 1536 has also been identified [159].

2.3. Metagenomics β -Glucosidase

Microorganisms are the most diverse and enormous living organisms on Earth, representing about 60% of the total biomass. Current research estimated that soil and oceans contains about $4-5 \times 10^{30}$ and 3.6×10^{29} microbial cells, respectively [160]. Only 1% of these microorganisms are culturable by laboratory standard techniques and majority, about 99%, are unculturable under laboratory conditions, thus making them unexplored to investigation and utilization for production of many value-added products [161,162,163]. Metagenomic, a term coined by Handelsma in 1998, is culture-independent technique utilized to analyze the genetic material present in an environmental sample [164]. This approach starts with environmental DNA extraction and digestion, metagenomic DNA library construction, and screening of libraries for gene and sequences of interest [160,163,165,166]. Screening of metagenomic library can be done either by function-based screening, gene specific screening or direct sequencing [160,164,167]. Finally cloning and expression studies are carried out for the gene of interest. Metagenomic approach can be utilized for finding a novel genes encoding for novel protein e.g., enzymes with special characteristics. Numbers of β -glucosidases have been characterized using metagenomic approach from different environmental samples such *Globitermes brachycerastes* gut metagenome [168], wetland soil metagenome [169], agricultural soil metagenome [170,171,172,173], compost microbial metagenome [174], cow rumen metagenome [175], rabbit cecum metagenome [176], buffalo rumen metagenome [177], bioreactor contents metagenome [178] Kusaya gravy metagenome [179], marine metagenome library [180,181], hydrothermal hot spring metagenome [182], alkaline-polluted soil metagenome [183], amazon soil metagenome [184], cattle rumen metagenome [185], and mangrove soil metagenome [186].

3. Microbial β -Glucosidase Production

Generally microorganisms produce low amount of β -glucosidase e.g., cellulase hyperproducer species, *Trichoderma reesei*, lacks sufficient β -glucosidase activity

[187,188]. Therefore, the search for microorganisms with high β -glucosidase productivity is the concern of researchers. β -Glucosidases have been produced from number of fungi, yeast and bacteria using either solid state fermentation (SSF) or submerged fermentation (SMF) [99,189,190]. In SSF, the microorganism is grown on solid substrate such as castor bean cake, sugarcane bagasse, cassava cake, wheat bran, rice straw or corn husk solely or in combination. Substrate is used steadily and slowly therefore SSF can be carried out for long period of time. SSF is more suited for cultivation of microorganisms with less moisture content requirement. The advantages of SSF are high productivity, cheap substrate utilization, low energy requirement, minimal water output and lacking of foam up, but heat generation and lacking knowledge on automation are the limitations [191,192,193]. In SMF, free flowing liquid such as molasses and broths containing different nutrients is utilized for cultivation of microorganisms. The bioactives, enzymes, and metabolic wastes are secreted into fermentation medium and the substrates are rapidly utilized therefore continuous supplementation with nutrients is needed. This fermentation technique is best suited for microorganisms that require high moisture content such as bacteria. The main advantages of SMF are the easiness of: sterility, heat and mass transfer, process monitoring and automation, and extraction and recovery of enzymes and bioactives [46,192,194,195,196,197,198]. There are several reports on β -glucosidase production from filamentous fungi, and yeast by SSF and SMF. Table 1 summarizes production methods from different microbial sources.

Table 1. Production methods of β -glucosidase from different fungi and yeast species

Fungal species	Fermentation method	Ref#
<i>Tolyposcladium cylindrosporium</i> Syzx4	SMF	[199]
<i>Penicillium simplicissimum</i> H-11	SMF	[200]
<i>Aspergillus strain</i> SA 58	SSF	[201]
<i>Penicillium citrinum</i> YS40-5	SSF	[202]
<i>Fusarium proliferatum</i>	SMF	[33]
<i>Fusarium solani</i>	SSF	[203]
<i>Aspergillus niger</i> + <i>A. Oryzae</i>	SSF	[204]
<i>Fomitopsis palustris</i>	SMF	[133]
<i>Aspergillus niger</i> SOI017	SMF	[205]
<i>Flammulina velutipes</i>	SMF	[142]
<i>Monascus sanguineus</i>	SSF	[143]
<i>Phoma sp. KCTC11825BP</i>	SMF	[135]
<i>Aspergillus niger</i> AS 3.4309	SSF	[206]
<i>Aspergillus terreus</i> EMOO 6-4	SSF	[207]
<i>Thermomucor indicae-seudaticae</i> N31	SSF	[208]
<i>Aspergillus niger</i> HDF05	SSF	[209]
<i>Gongronella butleri</i>	SSF	[145]
<i>Penicillium miczynskii</i>	SMF	[210]
<i>Fusarium oxysporum</i>	SMF	[146]
Yeast species		
<i>Aureobasidium pullulans</i>	SMF	[211]
<i>Candida peltata</i>	SMF	[106]
<i>Kluyveromyces marxianus</i>	SMF	[212]
<i>Aureobasidium sp.</i>	SSF+SMF	[213]
<i>Saccharomyces cerevisiae</i>	SMF	[214]

3.1. Production Parameters

Optimization of fermentation conditions is very crucial step for profitable enzyme production and commercialization. There are many parameters which need to be carefully optimized during fermentation processes for enzyme production. These parameters include carbon source and concentration, nitrogen source and concentration, salts, pH, temperature, oxygen availability, fermentation period, inoculum size etc. [215,216]. The optimal conditions for fermentation vary depending on microbial species, required end product (e.g., enzymes), and production methods, among others factors.

3.1.1. Carbon Source

β -Glucosidase, among other cellulases, is an inducible enzyme synthesized by microbial cells in response to various carbon sources included in fermentation medium. These carbon sources may be complex such as cellulose, wheat bran, rice straw, rice husk, sugar cane bagasse, and pectin, or simple sugar such as glucose, lactose, cellobiose, or sophorose. Complex sugar cannot enter the cells through cell membrane, it is therefore believed that some constitutively expressed enzymes degrade them to simple sugar such as cellobiose, lactose etc. which can then be transported through the cell membrane via specific transporters to the cytosol where they induces the expression of these enzymes in poorly understood mechanism [64,101,217,218]. Synthesis of β -glucosidase, and other cellulases, is repressed by metabolizable sugar such as glucose in phenomenon known as catabolite repression [213,214]. The optimal carbon source for β -glucosidase production varies depending on the species utilized for β -glucosidase production, fermentation method, and other fermentation parameters and interaction among these factors. For instances, optimum production of extracellular and intracellular β -glucosidase from *Chaetomium thermophilum* var. *coprophilum* was achieved when sugar-cane bagasse and avicel used as carbon source, respectively [127]. *Aspergillus oryzae* optimally produces β -glucosidase with high glucose-tolerance (HGT-BGL) when quercetin was used as carbon source [96]. Under solid state fermentation, *Aspergillus* strain SA 58 expressed two extracellular β -glucosidase when pectin was used as carbon source [201]. Microbial consortium implies two or more microbial groups. Optimal production of β -glucosidase from the microbial consortium of *Aspergillus niger* and *A. oryzae* was achieved when wheat bran was used as carbon source [204]. Similarly, optimum production of β -glucosidase from *Fusarium proliferatum* NBRC109045 was achieved when it was cultured on corn stover and wheat bran containing medium [33]. *Aspergillus saccharolyticus* produced an optimal β -glucosidase activity when cultivated on media containing xylose, xylan, wheat bran, and pretreated corn stover [138]. *Flammulina velutipes* and *Penicillium Purpurogenum* achieved optimal β -glucosidase production when grown on medium containing sucrose as carbon source [128,221]. Optimal β -glucosidase production from *Monascus sanguineus* was obtained when jack fruit seed was used as carbon source among wheat bran, coconut residue, tamarind seed and jack fruit seed tested [143]. *Stereum hirsutum* produced optimum β -glucosidase when it was

grown on avicel followed by cellulose and minimum production was observed in glucose containing medium [222]. *Lichtheimia ramosa* produced optimal β -glucosidase activity under wheat bran as carbon source under SSF [223] and that from *Aspergillus niger* NRRL 3112 was produced optimally when wheat bran and glycerol were used as co-substrate [224]. More interestingly, an optimal production of extracellular β -glucosidase from *Candida peltata* was achieved when it was grown on glucose and xylose containing broth medium both of which are considered simple metabolizable sugar and a catabolite repressors for these genes [106]. *Kluyveromyces marxianus* produced optimal β -glucosidase when cultivated in medium containing cellobiose, sucrose and lactose [212] and *Aureobasidium pullulans* produced highest level of extracellular β -glucosidase when cultivated on medium containing lactose and corn bran [211]. Optimum production of extracellular β -glucosidase from *Proteus mirabilis* VIT117 was achieved in medium supplemented with sorbitol as carbon source [225].

Many filamentous fungi have been shown to express multiple isoforms of β -glucosidase when cultured on different carbon source [45,96]. For example, *Aspergillus niger* NII-08121/MTCC 7956 expressed four isoform of β -glucosidase when it was cultivated on lactose or cellulose as carbon source while only two isoforms were found when wheat bran or rice straw was used as the carbon source [226]. Similarly, *Penicillium funiculosum* NCL1 express 4 isoforms on wheat bran, 2 isoforms on sugarcane bagasse, 1 isoform on avicel containing medium under SMF whereas no isoform was induced on salicin [227]. These isoforms may result from presence of multiple genes, differential mRNA splicing, and posttranslational modifications such as glycosylation and proteolytic digestion [228,229]. The regulatory mechanism underlying the generation of these isoforms is not clear. Further investigation are needed and which may help in designing the fermentation condition for production of most suitable isoform e.g., glucose tolerant β -glucosidase.

3.1.2. Nitrogen Source

For microbes to grow, nitrogen source must be included in the fermentation medium to synthesize amino acids, proteins, nitrogenous compounds, vitamins, nucleic acids and bioactives [121,230]. Nitrogen source can be organic or inorganic. Organic nitrogen sources can be peptone, yeast extract, beef extract, tryptone, or soybean meal. Inorganic source of nitrogen can be ammonium sulphate, ammonium chloride, ammonium hydrogen phosphate etc. For optimum β -glucosidase production, different species required different nitrogen source. Most of researchers have not reported optimization of nitrogen source for β -glucosidase production. β -Glucosidase was optimally produced from *Penicillium simplicissimum* H-11 cultivated on medium containing bean cake powder as nitrogen source [190]. *Chaetomium thermophilum* var. *coprophilum* produced optimum β -glucosidase when grown on peptone and yeast extract as nitrogen source [231]. *Aspergillus* strain SA 58 produced high level of extracellular β -glucosidase when cultured on medium containing beef extract as nitrogen source while least production was observed when ammonium salts were used

as nitrogen source [201]. *Flammulina velutipes* produced highest β -glucosidase activity when L-asparagine was used as nitrogen source in comparison to other ammonium salts which produced negligible to low activity [221] whereas *Penicillium citrinum* YS40-5 was found to produce the highest level of extracellular β -glucosidase when cultivated on urea containing medium as nitrogen source under SSF [232]. *Penicillium purpurogenum* was found to produce high level of intracellular β -glucosidase when grown on medium containing NaNO_3 as nitrogen source among three salt tested NaNO_3 , KNO_3 , $(\text{NH}_4)_2\text{NO}$ tested [128]. *Stereum hirsutum* produced optimal β -glucosidase when tryptone was used as nitrogen source [222]. *Kluyveromyces marxianus* produced optimal β -glucosidase when corn steep liquor was used as nitrogen source [212]. *Aspergillus protuberus* produces optimum β -glucosidase when ammonium sulfate was used as nitrogen source under SSF [233]. Similarly, the mechanism by which these nitrogen sources influence the expression of β -glucosidase is not clear and more future investigation is required.

3.1.3. Temperature

Temperature of β -Glucosidase production varies from species to species. Usually production temperature of β -glucosidase coincides with optimal temperature for microorganism growth. For instance, β -glucosidase has been produced from *Monascus purpureus* at 30°C [132], *Penicillium italicum* at 28°C [137], *Chaetomium thermophilum* var. *coprophilum* at 45°C [231], *Penicillium simplicissimum* H-11 at 30°C [190], *Daldinia eschscholzii* at 25°C [129], *Thermoascus aurantiacus* at 50°C [126], and *Aspergillus oryzae* at 28°C [96]. *Aspergillus* strain SA 58 was found to produce maximal β -glucosidase at a temperature of 35°C, although the organism grows optimally at 30°C. A temperature of 32°C was optimal for β -glucosidase production from *Penicillium purpurogenum* KJS506 which grow optimally at 28°C [134]. Optimum production of β -glucosidase from *Lichtheimia ramosa* and *A. protuberus* was obtained at 35 and 30°C when tested in a temperature range of 25–45°C and 25–40°C, respectively [223,233]. β -Glucosidase has been produced from bacterial species: *Clostridium thermocellum* at 60°C [150], archaeon *Pyrococcus furiosus* at 90°C [151], *Lactobacillus brevis* at 25°C [155], *flavobacterium Johnsonae* at 28°C [152], psychrotolerant *Shewanella* sp. G5 at 15°C [154], these temperatures are exactly the same for species growth. Most of researchers has also reported the optimization of temperature for β -glucosidase production from various species rather an arbitrary temperature usually the same for optimal growth is used.

3.1.4. pH

Different species required different initial pH for optimal production of β -glucosidase. Like in case of temperature, most researchers worked on β -glucosidase have not reported optimization of pH for β -glucosidase production rather they use an arbitrary pH at which these species grow optimally. For instance, β -Glucosidase has been produced from *Fusarium oxysporum* at pH 6 [234], *Penicillium italicum* at pH 4.5 [137], *Aspergillus oryzae* at pH 6.0 [96], *Fusarium proiferatum* NBRC109045 at pH 5.0 [33], *Candida peltata* at pH 5.0 [211], *Daldinia*

eschscholzii at pH 5.5 [129], and *Phoma* sp. KCTC11825BP at pH 4.5 [135]. *Aspergillus* strain SA 58 was found to produce optimal β -glucosidase at pH 5.0 when screened from pH 3.0–9.0 [201]. *Pichia pastoris* achieved optimal β -glucosidase production at pH 7.5 when screened from pH 4–8 [235] The microbial consortium of *A. niger* and *A. oryzae* was found to produce optimal β -glucosidase at pH 5.5 when it was screen from pH 4.5 and 7 [99].

3.1.5. Incubation Time/Fermentation Period

Fermentation period is another crucial parameters affecting enzyme production. Fermentation process has to be carried out for an optimum time which otherwise optimal production of specific value-added product e.g., enzyme cannot be achieved. Usually the production of enzyme increased with increase of incubation time till it reaches an optimal peak beyond what there is a decline in enzyme production and activity. The decline in the enzyme production may be attributed to decline in the nutrient availability, accumulation and/toxicity of waste products, and decrease in the stability of the enzyme itself. Optimal β -glucosidase production from *Aspergillus niger* and *Trichoderma* sp. was achieved after 4 and 5 days of fermentation, respectively, after which the production was decreased gradually [215]. Optimum extracellular β -glucosidase production from *Penicillium purpurogenum*, and *Chaetomium thermophilum* var. *coprophilum* was achieved after 96 and 140 h, respectively [231]. Optimum production of an extracellular β -glucosidase from *Fusarium solani*, *Lichtheimia ramosa*, and *Thermomucor indicae-seudaticae* was achieved at 72, 96 and 196 h on SSF [203,208,223].

In addition, number of other parameters affect the production of these bioactives or enzymes such β -glucosidase during fermentation processes. These parameters includes inoculum size, moisture content, fermentation methods, fermentation volume, fermenter size, substrate concentration, salts and its concentration, aeration, and additives. The exact mechanism by which fermentation parameters affect β -glucosidase production is not clear and it appears to be species specific and highly influenced by interaction between parameters. Future investigation should focus on understanding the mechanisms by these parameters influence the production of this valuable enzymes and the interaction between various parameters so that designing of cost effective processes may be initiated. Moreover, isolation of new microbes, fungi and bacteria, and optimization of fermentation conditions for β -glucosidase production under SSF and/SMF is highly encouraged.

3.2. Statistical Design Approach for Improvement of β -Glucosidase Production

Optimization of fermentation conditions for production of β -glucosidase is of the crucial importance because these parameters significantly affect the enzymes production, yield and productivity. Optimization is usually carried out using the traditional approach known as One Variable At a Time (OVAT) by changing one variable keeping all other factors constant. However, OVAT is not efficient method

for optimization because it ignores the interactions between different parameters which are actually independent, in addition, it is laborious, expensive and time consuming thus it usually fails to identify optimal fermentation conditions. Statistical methods such as Response Surface Methodology (RSM) is a new effective statistical method for optimization of fermentation conditions because it takes the interaction of multiple variables into consideration and reduces the number of experiments needed to be performed [207,236]. RSM has been used for optimization of 4 parameters (yeast extract concentration, cellobiose concentration, ammonium sulfate concentration, and pH) for β -glucosidase production from *Aspergillus niger* SOI017 and found that 0.275% yeast extract, 1.125% cellobiose, and 2.6% ammonium sulfate at a pH value of 3 are the optimal condition for β -glucosidase production [205]. Job *et al* optimized the fermentation condition for glucose tolerant β -glucosidase from *Paecilomyces* sp. using Plackett–Burman and Box–Behnken design revealing that peptone concentration of 2 g/l, inoculum concentration of 1.2×10^6 spores/ml and an incubation period of 96 h are the optimal conditions for enzyme productions [237]. El-Naggar *et al* employed two Plackett–Burman and Box–Behnken designs for optimization of β -Glucosidase production from *A. terreus* demonstrating that NaNO₃, KH₂PO₄ and Tween 80 are the variable with maximum effect on enzyme production [207]. Mahapatra *et al* found that an optimum inoculum size, pH and yeast extract of 2 %, 9 and 2 %, respectively, are the optimum for extracellular β -glucosidase production from *Proteus mirabilis* VIT117 using Plackett–Burman and RSM statistical approaches [225].

4. β -Glucosidase Applications

β -Glucosidase is a hydrolytic enzyme that acts upon β (1-4) glucosidic bonds of disaccharides, oligosaccharides and glucose-substituted molecules. Under certain circumstances, it also catalyzes synthetic reactions through reverse hydrolysis or transglycosylation. β -Glucosidase has the potential to be used in many biotechnological applications. β -Glucosidase applications can be divided into: 1) applications based on hydrolytic activity 2) applications based on synthetics activity.

4.1. Applications Based on Hydrolytic Activity

β -Glucosidase involves in the hydrolysis of β (1-4) glucosidic linkages of disaccharides e.g., cellobiose, oligosaccharides and glucose-substituted molecules, although some novel β -glucosidase can hydrolyze bonds such as β (1-3), β (1-6), β (1-2) bonds. Therefore it can be utilized in many applications in biofuel production, food technology, and biomedical sciences.

4.1.1. Biofuel Production

Production of biofuel e.g., bioethanol, from plant biomass, involves the use of many enzymes that act synergistically to degrade the lignocellulosic material to pentose and hexose sugar which in turn is fermented to

ethanol. Cellulases and xylanases are the major components' of these enzymes [238]. Cellulase enzymatic system is comprised of three enzymes, endoglucanase, cellobiohydrolase, which degrade the cellulose chain to cellobiose and short oligosaccharide and both get inhibited by cellobiose, and β -glucosidase which hydrolyze cellobiose and oligosaccharides into glucose unit eliminating cellobiose inhibition and increasing the rate of cellulolysis. Unfortunately β -glucosidase itself are inhibited by their end-product i.e., glucose thus limiting the rate of cellulose hydrolysis therefore β -glucosidase is considered as the rate-limiting step in cellulolysis pathway and the bottle neck in biofuel production [90,239,240]. Cellulase hyperproducers filamentous fungus *T. reesei* lacks sufficient amount of β -glucosidase, which is another hurdle in biomass conversion and biofuel production [241]. Therefore majority of reported β -glucosidase identified and characterized for their biochemical and kinetics properties are meant to be utilized in biomass hydrolysis and in solving these problems associated with β -glucosidase e.g., low productivity and glucose sensitivity [90,146,242,243,244].

4.1.2. Isoflavones Glycoside Hydrolysis

Phenolic compounds (flavonoid, flavonone, flavones, and isoflavone) are a class of plants secondary metabolites differing in their chemical structures and biological functions. These compounds recently have been the focus of many researchers especially in the field of health and food technology because of their biological activity as antioxidant, anticancer, antiallergic, anti-inflammatory agents, antihypertensive etc. [245,246,247]. Naturally, majority of these compounds are presents in form of glycosides which increase their water solubility and stability and limit their absorption from human GIT [248]. Usually these glycosides contain monoglucose unit conjugated to other sugar such as galactose, arabinose, or xylose. The release of aglycone moiety requires the action of specific enzymes such as arabinosidase, and β -glucosidase. The liberated aglycone can be easily absorbed thus increasing their biological potency [249]. Numbers of β -glucosidase have been reported for hydrolysis of isoflavone or flavonoid compounds. Table 2 summarizes the sources of β -glucosidase tested on isoflavones and flavonoid compounds.

4.1.3. Flavor Improvement

In last few decades, researchers revealed that most of the flavor compounds in plants and fruit tissue are presents in form of glycoconjugate rendering them flavorless and nonvolatile compounds [265]. Glycoside flavor compounds have been reported in wide range of fruit such as grape [266,267], yellow plum [268], mango [269], and strawberry [270]. These glycosides are complex and diverse in their structures particularly aglycone moiety. Glycone part usually consist of glucose unit conjugated to various glycosides such as 6-O- α -L-arabinofuranosyl- β -D-glucopyranosides, and 6-O- α -L-arabinopyranosyl- β -D-glucopyranosides. To make these flavorless compounds available to flavor content, they must be hydrolyzed to release the aglycone part. Hydrolysis can be carried out using acids or, most favorably enzymes [271,272]. The enzymatic hydrolysis is

carried out in two sequential steps, firstly, enzymes such as α -L-rhamnosidase, or α -L-arabinosidase cleaves of the terminal sugar: arabinose and rhamnose, secondly, β -glucosidase acts upon the corresponding β -D-glucoside releasing glucose and aglycone moiety such as monoterpenol [273]. Unfortunately, β -glucosidase from plants such as grapes has low activity and unstable under wine making conditions therefore adding β -glucosidase from microbes with high activity and stability is mandatory for complete hydrolysis of flavor compounds. β -Glucosidase with high hydrolytic efficiency for terpenyl glycoside has been reported from *Sporidiobolus pararoseus* [274], and *Aureobasidium pullulans* [275] suggesting their potential application for the development of wine aroma. Another β -glucosidase from *Oenococcus oeni* ATCC BAA-1163 capable of hydrolyzing glycoside present in muscat wine has been reported [276]. Another β -glucosidase from *Lactobacillus brevis*, lactic acid bacterium, with xylosidase, arabinosidase and cellobiosidase activities has been and was stimulated by ethanol and methanol up to 2-fold, and has half-life of 50 day at pH 7.0 and 4 days at pH 4.0 suggesting the possibility of its utilization in aroma enhancement of wine [155]. *Oenococcus oeni* ST81 was found to produce a β -glucosidase with high tolerance to fructose, malate, mannitol, or sorbitol and its activity was increased by ethanol up to 147% and its half-life at pH 5.0 was 50 days making it of interest in wine making [277]. An extracellular β -glucosidase from *Issatchenkia terricola* was also found to be highly active in the presence of 18%

ethanol, 10% glucose, and 6% metabisulfite with relative stability at pH 3.0. It was also immobilized on Eupergit C increasing its stability and resulting in aromatization of white Muscat wine over a 16-day experiment increasing monoterpenes and norisoprenoids content [278]. Vervoort *et al* reported a β -glucosidase from *Brettanomyces anomalus* capable of methyl salicylate, linalool, benzyl alcohol, and eugenol in comparison to that from *A. niger* and Almond glucosidase [279].

4.1.4. Cassava Detoxification

β -Glucosidase has the potential to be used in detoxification of cassava. Cassava is a carbohydrate rich plants that grow in many places of the world and represent a staple food for 500 million people in the world. However, consumption of raw cassava is harmful to human health due the presence of cyanogenic glycoside such as linamarin and lotaustralin [280]. Moreover, a correlation between human central nervous system syndrome “Konzo” and prolonged consumption of cassava products has been established. Naturally cassava is detoxified during processing and grating by endogenous β -glucosidase and linamarase present in the root. However, these enzymes are expressed insufficiently leaving part of cyanogenic glycosides in the processed food. It is therefore suggested that an exogenous linamarase and β -glucosidase from microbial sources can be utilized to enhance the hydrolysis of cyanogenic glycoside from this important food [75,280,281,282,283].

Table 2. List of microbial sources of β -glucosidase based on the ability to hydrolyze flavonoid compounds

Source of BGL	Flavonoid glycoside	Product	Biological activity	Ref
<i>L. acidophilus</i> LA-5	Delphinidin-3-glucoside Malvidin-3-glucoside	Gallic, Syringe homogentisic acid	Antioxidant	[250]
<i>Paecilomyces thermophila</i> J18	Daidzin, Genistin, Glycitin	Genistein, Daidzein, Glycitein	Anticancer, Osteoporosis Antihypercholesterolemia	[251]
<i>Thermoanaerobacter ethanolicus</i> JW200	Daidzin, Genistin	Genistein Daidzein	Anticancer Antipostmenopausal syndrome	[252]
<i>Pseudomonas</i> ZD-8	Genitin and Daidzin	Genistein Daidzein	Anticancer Osteoporosis etc.	[253]
<i>Bacillus subtilis</i> 18,	Genistin Daidzin	Genistein Daidzein	Anticancer Osteoporosis etc.	[254, 255]
<i>Gongronella</i> sp.	Daidzin Genistin,	Daidzein, Genistein,	Anticancer Osteoporosis	[256]
<i>Saccharomyces cerevisiae</i> HJ- 014	Gensin	Ginsenoside Rd, F2 Compound K (CK)	Anti-inflammatory Anti-cancer Anti-aging, Antioxidant activities	[257]
<i>Paecilomyces Bainier</i> sp. 229	Ginsenoside Rb1	Compound K	Tonic, Adaptogenic, Immunomodulatory, Anti-aging effects	[258]
<i>Mucilagibacter</i> sp	Protopanaxatriol-type ginsenoside mixture (PPTGM)	(S)-Rh1 (S)-Rg2	Antineoplastic, Antistress Antioxidant activities	[259]
<i>Paenibacillus</i> sp. KB0549	2,6-O-di(β -D-glucopyranosyl)- β -D- glucopyranosylsesaminol (STG)	Sesaminol	Antioxidants	[260]
<i>Pyrococcus furiosus</i>	Hesperidin, Neohesperidin, Naringin, Poncirin, Diosmin Neoponcirin, Rutin	Hesperetin, Hesperetin, Haringenin, Naringenin, Quercetin, Rutinose	Antiallergic, Antioxidant, Anti-inflammatory, Antihypertensive	[261]
<i>Bifidobacterium bifidum</i>	Daidzin, Genistin,	Daidzein Genistein	Anticancer, Osteoporosis Antihypercholesterolemia	[262]
<i>Bacteroides thetaiotaomicron</i> VPI-5482	Daidzin, Genistin, Glycitin	Daidzein Genistein Glycitein	Anticancer, Osteoporosis Antihypercholesterolemia	[263]
<i>Aspergillus terreus</i>	Daidzin, Genistin, Glycitin	Daidzein Genistein Glycitein	Anticancer, Osteoporosis Antihypercholesterolemia	[264]

4.1.5. Dinking of Waste Paper

Paper and pulp industry is one of the most wood consumer industries, and is expected to be expanded more due to increase in the world economy and population. Waste paper is one of the major environmental pollutants. Recycling of waste paper is attracting more attention in the current time to solve this two-dimensional problem: forest wood consumption and landfills pollution. Recycling of waste paper can be carried out by chemical or enzymatic method. The major hurdle to waste paper recycling is the removal of ink. Removal of ink from waste paper by conventional methods utilizes several chemicals which are environmentally harmful and decrease in the brightness of the paper. The enzymatic method for waste paper recycling has been reported to be efficient in solving these problems. The enzyme preparations for waste paper recycling contain cellulase, β -glucosidase and hemicellulase [77,284,285,286,287].

4.2. Application Based on Synthetic Activity

β -Glucosidase is known to have synthetic activity other than hydrolytic activity, namely transglycosylation and reverse hydrolysis resulting in the synthesis of a variety of oligosaccharides, aryl- and alkyl- β -D-glycosides with wide range of applications. Synthesis of oligosaccharides by β -glucosidase is preferred over glycosyl transferase because of their higher regio- and stereo-selectivity. Moreover, synthesis of these compounds by β -glucosidase does not require any input energy in form of sugar nucleotides as is the case of glycosyl transferases [288]. Alkyl glycosides have a wide range of applications since they are biodegradable nonionic surfactants owning good emulsifying and antimicrobial properties imparted by their carbohydrate head group [102,289,290]. N-alkyl glucoside ester formed by reaction of phenyl butyric acid and n-alkyl butyl glucoside by β -glucosidase-lipase are used in treatment of fever [291]. On other hand, synthetic oligosaccharides can be utilized in various applications: 1) therapeutics agents such as Heparin and Acarbose, 2) carbohydrate based techniques such as antibacterial, anti-parasite and antiviral vaccines, and 3) probiotic agents since they enhance the growth of beneficial microorganisms in human gut flora [84,288].

5. Conclusion Remarks

β -Glucosidase is an important component of cellulase system produced by all life domains playing fundamental roles in many life processes. β -Glucosidase, as of cellulase system, it eliminates cellobiose inhibition on endoglucanase and cellobiohydrolase during cellulose hydrolysis facilitating biomass hydrolysis. It also hydrolyzes different β -D-glucosides compounds and, under certain circumstances, has synthetic activity through reverse hydrolysis and transglycosylation. Therefore, it has wide spectrum of applications exemplifying by biofuel production, food technology and biomedical sciences. β -Glucosidase is produced by microorganisms in low quantities, and inhibited by its end-product i.e., glucose limiting its application in biomass hydrolysis and biofuel production. Therefore, upcoming research should focus on finding novel microorganisms with high

β -glucosidase production efficiency and β -glucosidase with high catalytic efficiency, thermostability and glucose-tolerance. It is also of great importance to study the structure of these enzymes at molecular level and *in silico*, and to identify those amino acids involving in the catalysis and glucose tolerance so that protein engineering techniques may be employed to design a β -glucosidase with high catalytic activity and glucose tolerance making biomass hydrolysis cost effective and profitable.

References

- [1] Zietsman AJ, de Klerk D, van Rensburg P: Coexpression of alpha-l-arabinofuranosidase and beta-glucosidase in *Saccharomyces cerevisiae*. *FEMS Yeast Res* 2011 Feb; 11(1): 88-103.
- [2] Tumuluru JS, Sokhansanj S, Wright CT, Boardman RD, Yancey NA: A review on biomass classification and composition, co-firing issues and pretreatment methods. In: *Proceedings of the American Society of Agricultural and Biological Engineers Annual International Meeting: 2011*: Citeseer; 2011: 2053-2083.
- [3] Scheller HV, Ulvskov P: Hemicelluloses. *Annual Review of Plant Biology* 2010, 61(1): 263-289.
- [4] Saxena RC, Adhikari DK, Goyal HB: Biomass-based energy fuel through biochemical routes: a review. *Renewable and Sustainable Energy Reviews* 2009, 13(1): 167-178.
- [5] Okoye I, Ezugwu A, Udenwobele D, Eze S, Anyawu C, Chilaka F: Production and Partial Characterization of Cellulases from *Apergillus fumigatus* Using Two Distinct Parts of Corn Cob as Carbon Sources. *Nigerian Journal of Biotechnology* 2014, 26(1): 50-59.
- [6] McKendry P: Energy production from biomass (part 1): overview of biomass. *Bioresource technology* 2002, 83(1): 37-46.
- [7] Harmsen P, Huijgen W, Bermudez L, Bakker R: Literature review of physical and chemical pretreatment processes for lignocellulosic biomass. 2010.
- [8] Biswas R, Persad A, Bisaria VS: Production of Cellulolytic Enzymes. *Bioprocessing of Renewable Resources to Commodity Bioproducts* 2014: 105-132.
- [9] Pütün A, Özcan A, Gerçel H, Pütün E: Production of biocrudes from biomass in a fixed-bed tubular reactor: product yields and compositions. *Fuel* 2001, 80(10): 1371-1378.
- [10] Demirbaş A: Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Conversion and Management* 2001, 42(11): 1357-1378.
- [11] Sun Y, Cheng J: Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource Technology* 2002, 83(1): 1-11.
- [12] Lee J: Biological conversion of lignocellulosic biomass to ethanol. *Journal of Biotechnology* 1997, 56(1): 1-24.
- [13] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D: Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences* 2006, 103(30): 11206-11210.
- [14] Hahn-Hägerdal B, Galbe M, Gorwa-Grauslund MF, Lidén G, Zacchi G: Bio-ethanol – the fuel of tomorrow from the residues of today. *Trends in Biotechnology* 2006, 24(12): 549-556.
- [15] Gupta P, Samant K, Sahu A: Isolation of cellulose-degrading bacteria and determination of their cellulolytic potential. *International journal of microbiology* 2012, 2012.
- [16] Shahzadi T, Mehmood S, Irshad M, Anwar Z, Afroz A, Zeeshan N, Rashid U, Sughra K: Advances in lignocellulosic biotechnology: A brief review on lignocellulosic biomass and cellulases. *Advances in Bioscience and Biotechnology* 2014, 2014.
- [17] Maki M, Leung KT, Qin W: The prospects of cellulase-producing bacteria for the bioconversion of lignocellulosic biomass. *International Journal of Biological Sciences* 2009, 5(5): 500-516.
- [18] Lynd LR, Weimer PJ, Zyl WH, Isak S: Microbial cellulose utilization: fundamentals and biotechnology microbiology. *Mole Biol Reviews* 2002, 66.
- [19] Kamel S: Nanotechnology and its applications in lignocellulosic composites, a mini review. *Express Polymer Letters* 2007, 1(9): 546-575.

- [20] Agbor VB, Cicek N, Sparling R, Berlin A, Levin DB: Biomass pretreatment: fundamentals toward application. *Biotechnology advances* 2011, 29(6): 675-685.
- [21] Moon RJ, Martini A, Nairn J, Simonsen J, Youngblood J: Cellulose nanomaterials review: structure, properties and nanocomposites. *Chemical Society Reviews* 2011, 40(7): 3941-3994.
- [22] Kumar R, Singh S, Singh OV: Bioconversion of lignocellulosic biomass: biochemical and molecular perspectives. *Journal of industrial microbiology & biotechnology* 2008, 35(5): 377-391.
- [23] Anwar Z, Gulfranz M, Irshad M: Agro-industrial lignocellulosic biomass a key to unlock the future bio-energy: A brief review. *Journal of Radiation Research and Applied Sciences* 2014, 7(2): 163-173.
- [24] Tiwari P, Misra B, Sangwan NS: β -Glucosidases from the fungus *Trichoderma*: an efficient cellulase machinery in biotechnological applications. *BioMed research international* 2013, 2013.
- [25] Seo JK, Park TS, Kwon IH, Piao MY, Lee CH, Ha JK: Characterization of Cellulolytic and Xylanolytic Enzymes of *Bacillus licheniformis* JK7 Isolated from the Rumen of a Native Korean Goat. *Asian Australas J Anim Sci* 2013, 26(1): 50-58.
- [26] Lambertz C, Garvey M, Klinger J, Heesel D, Klose H, Fischer R, Commandeur U: Challenges and advances in the heterologous expression of cellulolytic enzymes: a review. *Biotechnology for biofuels* 2014, 7(1): 135.
- [27] Dashtban M, Maki M, Leung KT, Mao C, Qin W: Cellulase activities in biomass conversion: measurement methods and comparison. *Crit Rev Biotechnol* 2010, 30(4): 302-309.
- [28] Sukumaran RK, Singhania RR, Pandey A: Microbial cellulases-production, applications and challenges. *Journal of Scientific and Industrial Research* 2005, 64(11): 832.
- [29] Mussatto SI, Teixeira J: Lignocellulose as raw material in fermentation processes. Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology (Méndez-Vilas, A, Ed) 2010, 2: 897-907.
- [30] Kostylev M, Wilson D: Synergistic interactions in cellulose hydrolysis. *Biofuels* 2012, 3(1): 61-70.
- [31] Gaur R, Tiwari S: Isolation, production, purification and characterization of an organic-solvent-thermostable alkalophilic cellulase from *Bacillus vallismortis* RG-07. *BMC Biotechnology* 2015, 15(1): 1-12.
- [32] Aga A, Coh CC: Cellulosic ethanol production using a yeast consortium displaying a minicellulosome and β -glucosidase. *Microb Cell Fact* 2013, 12: 14.
- [33] Gao Z, Duong V, Le Thi HY, Katsuhiko A, Shuichi H, Ryuichiro K: The production of β -glucosidases by *Fusarium proliferatum* NBRC109045 isolated from Vietnamese forest. *AMB Express* 2012, 2(1): 49.
- [34] Sadhu S, Maiti TK: Cellulase production by bacteria: a review. *British Microbiology Research Journal* 2013, 3(3): 235-258.
- [35] Bhat MK, Bhat S: Cellulose degrading enzymes and their potential industrial applications. *Biotechnol Adva* 1997, 15.
- [36] Bhat MK: Cellulases and related enzymes in biotechnology. *Biotechnol Adv* 2000, 18(5): 355-383.
- [37] Zhang X-Z, Zhang Y-HP: Cellulases: Characteristics, Sources, Production, and Applications. *Bioprocessing Technologies in Biorefinery for Sustainable Production of Fuels, Chemicals, and Polymers* 2013: 131-146.
- [38] Sharada R, Venkateswarlu G, Venkateswar S, AnandRao M: APPLICATIONS OF CELLULASES-REVIEW. *International Journal of Pharmaceutical, Chemical and Biological Sciences* 2014, 4(2): 424-437.
- [39] Mojsov K: Application of enzymes in the textile industry: a review. 2011.
- [40] Kuhad RC, Gupta R, Singh A: Microbial cellulases and their industrial applications. *Enzyme research* 2011, 2011.
- [41] Zhou J, Bao L, Chang L, Liu Z, You C, Lu H: Beta-xylosidase activity of a GH3 glucosidase/xylosidase from yak rumen metagenome promotes the enzymatic degradation of hemicellulosic xylans. *Lett Appl Microbiol* 2012, 54(2): 79-87.
- [42] Yeoman CJ, Han Y, Dodd D, Schroeder CM, Mackie RI, Cann IKO: Thermostable Enzymes as Biocatalysts in the Biofuel Industry. *Advances in applied microbiology* 2010, 70: 1-55.
- [43] Krisch J, Takó M, Papp T, Vágvolgyi C: Characteristics and potential use of β -glucosidases from Zygomycetes. *Current research, technology and education topics in applied microbiology and microbial biotechnology* 2010.
- [44] Bhatia Y, Mishra S, Bisaria V: Microbial β -glucosidases: cloning, properties, and applications. *Critical reviews in biotechnology* 2002, 22(4): 375-407.
- [45] Sonia K, Chadha B, Badhan A, Saini H, Bhat M: Identification of glucose tolerant acid active β -glucosidases from thermophilic and thermotolerant fungi. *World Journal of Microbiology and Biotechnology* 2008, 24(5): 599-604.
- [46] Singhania RR, Patel AK, Sukumaran RK, Larroche C, Pandey A: Role and significance of beta-glucosidases in the hydrolysis of cellulose for bioethanol production. *Bioresource Technology* 2013, 127: 500-507.
- [47] Hays WS, VanderJagt DJ, Bose B, Serianni AS, Glew RH: Catalytic mechanism and specificity for hydrolysis and transglycosylation reactions of cytosolic β -glucosidase from guinea pig liver. *Journal of Biological Chemistry* 1998, 273(52): 34941-34948.
- [48] Veena V, Poornima P, Parvatham R, Kalaiselvi K: Isolation and characterization of β -glucosidase producing bacteria from different sources. *African Journal of Biotechnology* 2013, 10(66): 14891-14906.
- [49] Cairns JRK, Esen A: β -Glucosidases. *Cellular and Molecular Life Sciences* 2010, 67(20): 3389-3405.
- [50] Poulton JE: Cyanogenesis in plants. *Plant physiology* 1990, 94(2): 401-405.
- [51] Morant AV, Jørgensen K, Jørgensen C, Paquette SM, Sánchez-Pérez R, Møller BL, Bak S: β -Glucosidases as detonators of plant chemical defense. *Phytochemistry* 2008, 69(9): 1795-1813.
- [52] Hrmova M, MacGregor EA, Biely P, Stewart RJ, Fincher GB: Substrate binding and catalytic mechanism of a barley β -D-glucosidase/(1, 4)- β -D-glucan exohydrolase. *Journal of Biological Chemistry* 1998, 273(18): 11134-11143.
- [53] Hrmova M, Harvey AJ, Wang J, Shirley NJ, Jones GP, Stone BA, Hoj PB, Fincher GB: Barley beta-D-glucan exohydrolases with beta-D-glucosidase activity. Purification, characterization, and determination of primary structure from a cDNA clone. *J Biol Chem* 1996, 271(9): 5277-5286.
- [54] HÖSEL W, SURHOLT E, BORGSMANN E: Characterization of β -Glucosidase Isoenzymes Possibly Involved in Lignification from Chick Pea (*Cicer arietinum* L.) Cell Suspension Cultures. *European Journal of Biochemistry* 1978, 84(2): 487-492.
- [55] Dharmawardhana DP, Ellis BE, Carlson JE: A [beta]-Glucosidase from lodgepole pine xylem specific for the lignin precursor coniferin. *Plant physiology* 1995, 107(2): 331-339.
- [56] Schliemann W: Hydrolysis of Conjugated Gibberellins by β -Glucosidases from Dwarf Rice (*Oryza sativa* L. cv.«Tanginbozu»). *Journal of plant physiology* 1984, 116(2): 123-132.
- [57] Brzobohaty B, Moore I, Kristoffersen P, Bako L, Campos N, Schell J, Palme K: Release of active cytokinin by a beta-glucosidase localized to the maize root meristem. *Science* 1993, 262(5136): 1051-1054.
- [58] Stöckigt J, Zenk MH: Strictosidine (isovincoside): the key intermediate in the biosynthesis of monoterpene indole alkaloids. *Journal of the Chemical Society, Chemical Communications* 1977(18): 646-648.
- [59] Warzecha H, Gerasimenko I, Kutchan TM, Stöckigt J: Molecular cloning and functional bacterial expression of a plant glucosidase specifically involved in alkaloid biosynthesis. *Phytochemistry* 2000, 54(7): 657-666.
- [60] Ren JN, Yang ZY, Tai YN, Dong M, He MM, Fan G: Characteristics of β -glucosidase from oranges during maturation and its relationship with changes in bound volatile compounds. *Journal of the Science of Food and Agriculture* 2014.
- [61] Gerardi C, Blando F, Santino A, Zacheo G: Purification and characterisation of a β -glucosidase abundantly expressed in ripe sweet cherry (*Prunus avium* L.) fruit. *Plant Science* 2001, 160(5): 795-805.
- [62] Lyman ES, Li B, Renganathan V: Purification and Characterization of a Cellulose-Binding (beta)-Glucosidase from Cellulose-Degrading Cultures of *Phanerochaete chrysosporium*. *Applied and Environmental Microbiology* 1995, 61(8): 2976-2980.
- [63] Igarashi K, Tani T, Rie K, Masahiro S: Family 3 beta-glucosidase from cellulose-degrading culture of the white-rot fungus *Phanerochaete chrysosporium* is a glucan 1,3-beta-glucosidase. *J Biosci Bioeng* 2003, 95(6): 572-576.
- [64] Fowler T, Brown RD: The bgII gene encoding extracellular β -glucosidase from *Trichoderma reesei* is required for rapid

- induction of the cellulase complex. *Molecular microbiology* 1992, 6(21): 3225-3235.
- [65] Doi RH, Kosugi A: Cellulosomes: plant-cell-wall-degrading enzyme complexes. *Nature Reviews Microbiology* 2004, 2(7): 541-551.
- [66] Lieberman RL, Wustman BA, Huertas P, Powe AC, Pine CW, Khanna R, Schlossmacher MG, Ringe D, Petsko GA: Structure of acid β -glucosidase with pharmacological chaperone provides insight into Gaucher disease. *Nature chemical biology* 2007, 3(2): 101-107.
- [67] Butters TD: Gaucher disease. *Current opinion in chemical biology* 2007, 11(4): 412-418.
- [68] Sternberg D, Vuayakumar P, Reese E: β -Glucosidase: microbial production and effect on enzymatic hydrolysis of cellulose. *Canadian Journal of Microbiology* 1977, 23(2): 139-147.
- [69] Coughlan MP: The properties of fungal and bacterial cellulases with comment on their production and application. *Biotechnology and genetic engineering reviews* 1985, 3(1): 39-110.
- [70] Gueguen Y, Chemardin P, Janbon G, Arnaud A, Galzy P: Investigation of the β -glucosidases potentialities of yeast strains and application to bound aromatic terpenols liberation. In: *Studies in Organic Chemistry*. Edited by K. Kieslich CPvdBJAMdB, Tweel WJJvd, vol. Volume 53: Elsevier; 1998: 149-157.
- [71] Pham TT, Shah NP: HYDROLYSIS OF ISOFLAVONE GLYCOSIDES IN SOY MILK BY β -GALACTOSIDASE AND β -GLUCOSIDASE. *Journal of food biochemistry* 2009, 33(1): 38-60.
- [72] Pandjaitan N, Hettiarachchy N, Ju Z: Enrichment of Genistein in Soy Protein Concentrate with β -glucosidase. *Journal of food science* 2000, 65(3): 403-407.
- [73] Michlmayr H, Kneifel W: β -Glucosidase activities of lactic acid bacteria: mechanisms, impact on fermented food and human health. *FEMS microbiology letters* 2014, 352(1): 1-10.
- [74] Obilie EM, Tano-Debrah K, Amoa-Awua WK: Souring and breakdown of cyanogenic glucosides during the processing of cassava into akyeke. *International journal of food microbiology* 2004, 93(1): 115-121.
- [75] Gueguen Y, Chemardin P, Labrot P, Arnaud A, Galzy P: Purification and characterization of an intracellular β -glucosidase from a new strain of *Leuconostoc mesenteroides* isolated from cassava. *Journal of Applied Microbiology* 1997, 82(4): 469-476.
- [76] Petruccioli M, Brimer L, Cicalini A, Federici F: The linamarase of *Mucor circinelloides* LU M40 and its detoxifying activity on cassava. *Journal of Applied Microbiology* 1999, 86(2): 302-310.
- [77] Elliston A, Collins SRA, Wilson DR, Roberts IN, Waldron KW: High concentrations of cellulosic ethanol achieved by fed batch semi simultaneous saccharification and fermentation of waste-paper. *Bioresource technology* 2013, 134: 117-126.
- [78] Yang JL, Ma J, Pierce JM, Eriksson K-EL: Composition for enzymatic deinking of waste paper. In: Google Patents; 2004.
- [79] Hansson T, Kaper T, van der Oost J, de Vos WM, Adlercreutz P: Improved oligosaccharide synthesis by protein engineering of beta-glucosidase CelB from hyperthermophilic *Pyrococcus furiosus*. *Biotechnology and bioengineering* 2001, 73(3): 203-210.
- [80] Ravet C, Thomas D, Legoy MD: Glucooligosaccharide synthesis by free and immobilized beta-glucosidase. *Biotechnology and bioengineering* 1993, 42(3): 303-308.
- [81] Bruins ME, Strubel M, van Lieshout JFT, Janssen AEM, Boom RM: Oligosaccharide synthesis by the hyperthermostable beta-glucosidase from *Pyrococcus furiosus*: kinetics and modelling. *Enzyme and Microbial Technology* 2003, 33(1): 3-11.
- [82] Kuptsova OS, Kliachko NL, levashov AV: [Synthesis of alkyl glycosides, catalyzed by beta-glycosidases in a reversed micelle system]. *Bioorg Khim* 2001 Nov-Dec;27(6): 429-33 2001.
- [83] Bankova E, Bakalova N, Petrova S, Kolev D: Enzymatic synthesis of oligosaccharides and alkylglycosides in water-organic media via transglycosylation of lactose. *Biotechnology & Biotechnological Equipment* 2006, 20(3): 114-119.
- [84] Seeberger PH, Werz DB: Synthesis and medical applications of oligosaccharides. *Nature* 2007, 446(7139): 1046-1051.
- [85] Lehmann R, Hachmann K, Biermann M, Schnegelberger H: Alkyl glycosides as potentiating agents in antiseptic compositions. In: Google Patents; 1990.
- [86] Maggio ET: Alkylglycoside compositions for drug administration. In: Google Patents; 2012.
- [87] Klueppel H-J, Foerg F: Alkylglycosides. In: Google Patents; 1992.
- [88] Mfombep PM, Senwo ZN, Isikhuemhen OS: Enzymatic activities and kinetic properties of β -glucosidase from selected white rot fungi. 2013.
- [89] Yang Y, Zhang X, Yin Q, Fang W, Fang Z, Wang X, Zhang X, Xiao Y: A mechanism of glucose tolerance and stimulation of GH1 β -glucosidases. *Scientific Reports* 2015, 5: 17296.
- [90] Sørensen A, Lübeck M, Lübeck PS, Ahring BK: Fungal beta-glucosidases: a bottleneck in industrial use of lignocellulosic materials. *Biomolecules* 2013, 3(3): 612-631.
- [91] Rani V, Mohanram S, Tiwari R, Nain L, Arora A: Beta-Glucosidase: Key Enzyme in Determining Efficiency of Cellulase and Biomass Hydrolysis. *J Bioprocess Biotech* 2014, 5(197): 2.
- [92] Iwashita K, Nagahara T, Kimura H, Takano M, Shimoi H, Ito K: The bglA Gene of *Aspergillus kawachii* Encodes Both Extracellular and Cell Wall-Bound β -Glucosidases. *Applied and Environmental Microbiology* 1999, 65(12): 5546-5553.
- [93] Hrmova M, De Gori R, Smith BJ, Fairweather JK, Driguez H, Varghese JN, Fincher GB: Structural Basis for Broad Substrate Specificity in Higher Plant β -d-Glucan Glucohydrolases. *The Plant Cell* 2002, 14(5): 1033-1052.
- [94] Langston J, Sheehy N, Xu F: Substrate specificity of *Aspergillus oryzae* family 3 β -glucosidase. *Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics* 2006, 1764(5): 972-978.
- [95] Henrissat B: A classification of glycosyl hydrolases based on amino acid sequence similarities. *Biochem J* 1991 Dec 1;280 (Pt 2): 309-16 1991.
- [96] Riou C, Salmon J-M, Vallier M-J, Günata Z, Barre P: Purification, characterization, and substrate specificity of a novel highly glucose-tolerant β -glucosidase from *Aspergillus oryzae*. *Applied and Environmental Microbiology* 1998, 64(10): 3607-3614.
- [97] Bohlin C, Praestgaard E, Baumann MJ, Borch K, Praestgaard J, Monrad RN, Westh P: A comparative study of hydrolysis and transglycosylation activities of fungal β -glucosidases. *Applied microbiology and biotechnology* 2013, 97(1): 159-169.
- [98] Günata Z, Vallier M-j: Production of a highly glucose-tolerant extracellular β -glucosidase by three *Aspergillus* strains. *Biotechnology letters* 1999, 21(3): 219-223.
- [99] Raza F, Raza NA, Hameed U: Solid state fermentation for the production of β -glucosidase by co-culture of *Aspergillus niger* and *A. oryzae*. *Pak J Bot* 2011, 43: 75-83.
- [100] Nijikken Y, Tsukada T, Igarashi K, Samejima M, Wakagi T, Shoun H, Fushinobu S: Crystal structure of intracellular family 1 β -glucosidase BGL1A from the basidiomycete *Phanerochaete chrysosporium*. *FEBS letters* 2007, 581(7): 1514-1520.
- [101] Zhou Q, Xu J, Kou Y, Lv X, Zhang X, Zhao G, Zhang W, Chen G, Liu W: Differential involvement of β -glucosidases from *Hypocrea jecorina* in rapid induction of cellulase genes by cellulose and cellobiose. *Eukaryotic cell* 2012, 11(11): 1371-1381.
- [102] Saloheimo M, Kuja-Panula J, Ylösmäki E, Ward M, Penttilä M: Enzymatic properties and intracellular localization of the novel *Trichoderma reesei* β -glucosidase BGLII (Cell1A). *Applied and Environmental Microbiology* 2002, 68(9): 4546-4553.
- [103] Paavilainen S, Hellman J, Korpela T: Purification, characterization, gene cloning, and sequencing of a new beta-glucosidase from *Bacillus circulans* subsp. *alkalophilus*. *Applied and Environmental Microbiology* 1993, 59(3): 927-932.
- [104] Bajaj BK, Pangotra H, Wani MA, Sharma A, Sharma P: Characterization of thermo-tolerant and acid/alkali tolerant β -glucosidase from bacterial isolate M+. *J Sci Ind Res* 2009, 68: 242-247.
- [105] Agrawal R, Satelewal A, Verma AK: Development of a β -glucosidase hyperproducing mutant by combined chemical and UV mutagenesis. *3 Biotech* 2013, 3(5): 381-388.
- [106] Saha BC, Bothast RJ: Production, purification, and characterization of a highly glucose-tolerant novel beta-glucosidase from *Candida peltata*. *Applied and Environmental Microbiology* 1996, 62(9): 3165-3170.
- [107] Rosi I, Vinella M, Domizio P: Characterization of β -glucosidase activity in yeasts of oenological origin. *Journal of Applied Bacteriology* 1994, 77(5): 519-527.
- [108] Hernández LF, Espinosa JC, Fernández-González M, Briones A: β -Glucosidase activity in a *Saccharomyces cerevisiae* wine strain. *International Journal of Food Microbiology* 2003, 80(2): 171-176.
- [109] Qi M, Jun H-S, Forsberg CW: Cel9D, an Atypical 1,4- β -d-Glucan Glucohydrolase from *Fibrobacter succinogenes*: Characteristics, Catalytic Residues, and Synergistic Interactions with Other Cellulases. *Journal of bacteriology* 2008, 190(6): 1976-1984.

- [110] Zechel DL, Withers SG: Glycosidase Mechanisms: Anatomy of a Finely Tuned Catalyst. *Accounts of Chemical Research* 2000, 33(1): 11-18.
- [111] Withers SG, Street IP: beta-Glucosidases: mechanism and inhibition. In: *ACS Symposium series-American Chemical Society (USA): 1989*, 1989.
- [112] Li YK, Chir J, Chen FY: Catalytic mechanism of a family 3 beta-glucosidase and mutagenesis study on residue Asp-247. *Biochemical journal* 2001, 355(Pt 3): 835-840.
- [113] Thongpoo P, McKee LS, Araújo AC, Kongsaree PT, Brumer H: Identification of the acid/base catalyst of a glycoside hydrolase family 3 (GH3) β -glucosidase from *Aspergillus niger* ASKU28. *Biochimica et Biophysica Acta (BBA) - General Subjects* 2013, 1830(3): 2739-2749.
- [114] Paal K, Ito M, Withers SG: Paenibacillus sp. TS12 glucosylceramidase: kinetic studies of a novel sub-family of family 3 glycosidases and identification of the catalytic residues. *Biochemical Journal* 2004, 378(1): 141-149.
- [115] Dan S, Marton I, Dekel M, Bravdo B-A, He S, Withers SG, Shoseyov O: Cloning, Expression, Characterization, and Nucleophile Identification of Family 3, *Aspergillus niger β -Glucosidase. *Journal of Biological Chemistry* 2000, 275(7): 4973-4980.*
- [116] Wang Q, Trimbur D, Graham R, Warren R, Withers S: Identification of the Acid/Base Catalyst in *Agrobacterium faecalis*. beta.-Glucosidase by Kinetic Analysis of Mutants. *Biochemistry* 1995, 34(44): 14554-14562.
- [117] Vallmitjana M, Ferrer-Navarro M, Planell R, Abel M, Ausín C, Querol E, Planas A, Pérez-Pons J-A: Mechanism of the family 1 β -glucosidase from *Streptomyces* sp: catalytic residues and kinetic studies. *Biochemistry* 2001, 40(20): 5975-5982.
- [118] Li Y-Y, Jiang C-J, Wan X-C, Zhang Z-Z, Li D-X: Purification and partial characterization of β -glucosidase from fresh leaves of tea plants (*Camellia sinensis* (L.) O. Kuntze). *Acta biochimica et biophysica Sinica* 2005, 37(6): 363-370.
- [119] Pontoh J, Low N: Purification and characterization of β -glucosidase from honey bees (*Apis mellifera*). *Insect biochemistry and molecular biology* 2002, 32(6): 679-690.
- [120] Nigam PS: Microbial enzymes with special characteristics for biotechnological applications. *Biomolecules* 2013, 3(3): 597-611.
- [121] Sundarram A, Murthy TPK: α -amylase production and applications: A review. *Journal of Applied & Environmental Microbiology* 2014, 2(4): 166-175.
- [122] Amore A, Giacobbe S, Faraco V: Regulation of cellulase and hemicellulase gene expression in fungi. *Current genomics* 2013, 14(4): 230-249.
- [123] Chen H, Hayn M, Esterbauer H: Purification and characterization of two extracellular β -glucosidases from *Trichoderma reesei*. *Biochimica et Biophysica Acta (BBA)-Protein Structure and Molecular Enzymology* 1992, 1121(1-2): 54-60.
- [124] Pitson SM, Seviour RJ, McDougall BM: Purification and characterization of an extracellular β -glucosidase from the filamentous fungus *Acremonium persicinum* and its probable role in β -glucan degradation. *Enzyme and Microbial Technology* 1997, 21(3): 182-190.
- [125] Lin J, Pillay B, Singh S: Purification and biochemical characteristics of β -D-glucosidase from a thermophilic fungus, *Thermomyces lanuginosus*-SSBP. *Biotechnology and applied biochemistry* 1999, 30(1): 81-87.
- [126] PARRY NJ, BEEVER DE, Emyr O, VANDENBERGHE I, Van Beeumen J: Biochemical characterization and mechanism of action of a thermostable β -glucosidase purified from *Thermoascus aurantiacus*. *Biochemical journal* 2001, 353(1): 117-127.
- [127] Venturi LL, de Lourdes Polizeli M, Terenzi HF, dos Prazeres Melo Furriel R, Jorge JA: Extracellular β -D-glucosidase from *Chaetomium thermophilum* var. *coprophilum*: production, purification and some biochemical properties. *Journal of basic microbiology* 2002, 42(1): 55.
- [128] Dhake A, Patil M: Production of β -Glucosidase by *Penicillium purpurogenum*. *Brazilian Journal of Microbiology* 2005, 36(2): 170-176.
- [129] Karmchanat A, Petsom A, Sangvanich P, Piaphukiew J, Whalley AJ, Reynolds CD, Sihanonth P: Purification and biochemical characterization of an extracellular β -glucosidase from the wood-decaying fungus *Daldinia eschscholzii* (Ehrenb.: Fr.) Rehm. *FEMS Microbiology Letters* 2007, 270(1): 162-170.
- [130] Kaur J, Chadha BS, Kumar BA, Kaur G, Saini HS: Purification and characterization of β -glucosidase from *Melanocarpus* sp. MTCC 3922. *Electronic Journal of Biotechnology* 2007, 10(2): 260-270.
- [131] Chen H-L, Chen Y-C, Lu M-YJ, Chang J-J, Wang H-TC, Ke H-M, Wang T-Y, Ruan S-K, Wang T-Y, Hung K-Y *et al*: A highly efficient β -glucosidase from the buffalo rumen fungus *Neocallimastix patriciarum* W5. *Biotechnology for Biofuels* 2012, 5(1): 24.
- [132] Daroit DJ, Simonetti A, Hertz PF, Brandelli A: Purification and characterization of an extracellular beta-glucosidase from *Monascus purpureus*. *Journal of Microbiology and Biotechnology* 2008, 18(5): 933-941.
- [133] Yoon J-J, Kim K-Y, Cha C-J: Purification and characterization of thermostable β -glucosidase from the brown-rot basidiomycete *Fomitopsis palustris* grown on microcrystalline cellulose. *The Journal of Microbiology* 2008, 46(1): 51-55.
- [134] Jeya M, Joo A-R, Lee K-M, Tiwari MK, Lee K-M, Kim S-H, Lee J-K: Characterization of β -glucosidase from a strain of *Penicillium purpurogenum* KJS506. *Applied microbiology and biotechnology* 2010, 86(5): 1473-1484.
- [135] Choi J-Y, Park A-R, Kim YJ, Kim J-J, Cha C-J, Yoon J-J: Purification and characterization of an extracellular beta-glucosidase produced by *Phoma* sp. KCTC11825BP isolated from rotten mandarin peel. *Journal of microbiology and biotechnology* 2011, 21(5): 503-508.
- [136] Liu D, Zhang R, Yang X, Zhang Z, Song S, Miao Y, Shen Q: Characterization of a thermostable β -glucosidase from *Aspergillus fumigatus* Z5, and its functional expression in *Pichia pastoris* X33. *Microbial cell factories* 2012, 11(1): 1.
- [137] Park A-R, Hong JH, Kim J-J, Yoon J-J: Biochemical characterization of an extracellular β -glucosidase from the fungus, *Penicillium italicum*, isolated from rotten citrus peel. *Mycobiology* 2012, 40(3): 173-180.
- [138] Sørensen A, Andersen JJ, Ahring BK, Teller PJ, Lübeck M: Screening of carbon sources for beta-glucosidase production by *Aspergillus saccharolyticus*. *International Biodeterioration & Biodegradation* 2014, 93: 78-83.
- [139] Sørensen A, Ahring BK, Lübeck M, Ubhayasekera W, Bruno KS, Culley DE, Lübeck PS: Identifying and characterizing the most significant β -glucosidase of the novel species *Aspergillus saccharolyticus*. *Canadian journal of microbiology* 2012, 58(9): 1035-1046.
- [140] Abdel-Naby MA, Osman MY, Abdel-Fattah AF: Purification and properties of three cellobiases from *Aspergillus niger* A20. *Applied biochemistry and biotechnology* 1999, 76(1): 33-44.
- [141] Bhatti HN, Batool S, Afzal N: Production and Characterization of a Novel β -Glucosidase from *Fusarium solani*. *International Journal of Agriculture & Biology* 2013, 15(1).
- [142] Mallerman J, Papinutti L, Levin L: Characterization of β -Glucosidase Produced by the White Rot Fungus *Flammulina velutipes*. *J Microbiol Biotechnol* 2015, 25(1): 57-65.
- [143] Dikshit R, Tallapragada P: Partial Purification and Characterization of β -glucosidase from *Monascus sanguineus*. *Brazilian Archives of Biology and Technology* 2015, 58(2): 185-191.
- [144] Hernández-Guzmán A, Flores-Martínez A, Ponce-Noyola P, Villagómez-Castro JC: Purification and characterization of an extracellular β -glucosidase from *Sporothrix schenckii*. *FEBS Open Bio* 2016, 6(11): 1067-1077.
- [145] Santos F, Garcia NFL, da Paz MF, Fonseca GG, Leite RSR: Production and characterization of β -glucosidase from *Gongronella butleri* by solid-state fermentation. *African Journal of Biotechnology* 2016, 15(16): 633-641.
- [146] Olajuyigbe FM, Nlekerem CM, Ogunyewo OA: Production and Characterization of Highly Thermostable β -Glucosidase during the Biodegradation of Methyl Cellulose by *Fusarium oxysporum*. *Biochemistry research international* 2016, 2016.
- [147] Sethi S, Datta A, Gupta BL, Gupta S: Optimization of cellulase production from bacteria isolated from soil. *ISRN biotechnology* 2013, 2013.
- [148] Lynd LR, Weimer PJ, van Zyl WH, Pretorius IS: Microbial Cellulose Utilization: Fundamentals and Biotechnology. *Microbiology and Molecular Biology Reviews* 2002, 66(3): 506-577.
- [149] Ariffin H, Abdullah N, Umi Kalsom M, Shirai Y, Hassan M: Production and characterization of cellulase by *Bacillus pumilus* EB3. *Int J Eng Technol* 2006, 3(1): 47-53.

- [150] Ait N, Creuzet N, Cattaneo J: Properties of β -glucosidase purified from *Clostridium thermocellum*. *Microbiology* 1982, 128(3): 569-577.
- [151] Kengen SW, Luesink EJ, STAMS AJ, ZEHNDER AJ: Purification and characterization of an extremely thermostable β -glucosidase from the hyperthermophilic archaeon *Pyrococcus furiosus*. *European Journal of Biochemistry* 1993, 213(1): 305-312.
- [152] Okamoto K, Nakano H, Yatake T, Kiso T, Kitahata S: Purification and some properties of a β -glucosidase from *Flavobacterium johnsonae*. *Bioscience, biotechnology, and biochemistry* 2000, 64(2): 333-340.
- [153] Spiridonov NA, Wilson DB: Cloning and biochemical characterization of BglC, a β -glucosidase from the cellulolytic actinomycete *Thermobifida fusca*. *Current microbiology* 2001, 42(4): 295-301.
- [154] Cristóbal HA, Schmidt A, Kothe E, Breccia J, Abate CM: Characterization of inducible cold-active β -glucosidases from the psychrotolerant bacterium *Shewanella* sp. G5 isolated from a sub-Antarctic ecosystem. *Enzyme and microbial technology* 2009, 45(6): 498-506.
- [155] Michlmayr H, Schümann C, Barreira Braz Da Silva N, Kulbe K, Del Hierro A: Isolation and basic characterization of a β -glucosidase from a strain of *Lactobacillus brevis* isolated from a malolactic starter culture. *Journal of applied microbiology* 2010, 108(2): 550-559.
- [156] Hong M-R, Kim Y-S, Park C-S, Lee J-K, Kim Y-S, Oh D-K: Characterization of a recombinant β -glucosidase from the thermophilic bacterium *Caldicellulosiruptor saccharolyticus*. *Journal of bioscience and bioengineering* 2009, 108(1): 36-40.
- [157] An D-S, Cui C-H, Lee H-G, Wang L, Kim SC, Lee S-T, Jin F, Yu H, Chin Y-W, Lee H-K: Identification and characterization of a novel *Terrabacter ginsenosidimutans* sp. nov. β -glucosidase that transforms ginsenoside Rb1 into the rare gypenosides XVII and LXXV. *Applied and Environmental Microbiology* 2010, 76(17): 5827-5836.
- [158] Pei J, Pang Q, Zhao L, Fan S, Shi H: *Thermoanaerobacterium thermosaccharolyticum* β -glucosidase: a glucose-tolerant enzyme with high specific activity for cellobiose. *Biotechnology for Biofuels* 2012, 5(1): 1.
- [159] Du J, Cui C-H, Park SC, Kim J-K, Yu H-S, Jin F-X, Sun C, Kim S-C, Im W-T: Identification and Characterization of a Ginsenoside-Transforming β -Glucosidase from *Pseudonocardia* sp. Gsoil 1536 and Its Application for Enhanced Production of Minor Ginsenoside Rg 2 (S). *PLoS one* 2014, 9(6): e96914.
- [160] Singh BK: Exploring microbial diversity for biotechnology: the way forward. *Trends in Biotechnology* 2010, 28(3): 111-116.
- [161] Ferrer M, Belouqui A, Timmis KN, Golyshin PN: Metagenomics for mining new genetic resources of microbial communities. *Journal of molecular microbiology and biotechnology* 2009, 16(1-2): 109-123.
- [162] Simon C, Daniel R: Metagenomic Analyses: Past and Future Trends. *Applied and environmental microbiology* 2011, 77(4): 1153-1161.
- [163] Singh J, Behal A, Singla N, Joshi A, Birbian N, Singh S, Bali V, Batra N: Metagenomics: Concept, methodology, ecological inference and recent advances. *Biotechnology Journal* 2009, 4(4): 480-494.
- [164] Handelsman J: Metagenomics: application of genomics to uncultured microorganisms. *Microbiology and molecular biology reviews* 2004, 68(4): 669-685.
- [165] Rooks DJ, McDonald JE, McCarthy AJ: Metagenomic approaches to the discovery of cellulases. *Methods Enzymol* 2012, 510: 375-394.
- [166] Thomas T, Gilbert J, Meyer F: Metagenomics—a guide from sampling to data analysis. *Microb Inform Exp* 2012, 2(3): 1-12.
- [167] Uchiyama T, Miyazaki K: Functional metagenomics for enzyme discovery: challenges to efficient screening. *Current Opinion in Biotechnology* 2009, 20(6): 616-622.
- [168] Wang Q, Qian C, Zhang X-Z, Liu N, Yan X, Zhou Z: Characterization of a novel thermostable β -glucosidase from a metagenomic library of termite gut. *Enzyme and microbial technology* 2012, 51(6): 319-324.
- [169] Kim S-J, Lee C-M, Kim M-Y, Yeo Y-S, Yoon S-H, Kang H-C, Koo B-S: Screening and characterization of an enzyme with beta-glucosidase activity from environmental DNA. *Journal of microbiology and biotechnology* 2007, 17(6): 905-912.
- [170] Li G, Jiang Y, Fan X-j, Liu Y-h: Molecular cloning and characterization of a novel β -glucosidase with high hydrolyzing ability for soybean isoflavone glycosides and glucose-tolerance from soil metagenomic library. *Bioresource technology* 2012, 123: 15-22.
- [171] Biver S, Stroobants A, Portetelle D, Vandenberg M: Two promising alkaline β -glucosidases isolated by functional metagenomics from agricultural soil, including one showing high tolerance towards harsh detergents, oxidants and glucose. *Journal of industrial microbiology & biotechnology* 2014, 41(3): 479-488.
- [172] Lu J, Du L, Wei Y, Hu Y, Huang R: Expression and characterization of a novel highly glucose-tolerant β -glucosidase from a soil metagenome. *Acta biochimica et biophysica Sinica* 2013: gmt061.
- [173] Gomes-Pepe ES, Machado Sierra EG, Pereira MR, Castellane TCL, Lemos EGdM: Bg10: A Novel Metagenomics Alcohol-Tolerant and Glucose-Stimulated GH1 β -Glucosidase Suitable for Lactose-Free Milk Preparation. *PLoS one* 2016, 11(12): e0167932.
- [174] Uchiyama T, Miyazaki K, Yaoi K: Characterization of a novel β -glucosidase from a compost microbial metagenome with strong transglycosylation activity. *Journal of Biological Chemistry* 2013, 288(25): 18325-18334.
- [175] Del Pozo MV, Fernández-Arrojo L, Gil-Martínez J, Montesinos A, Chernikova TN, Nechitaylo TY, Waliszek A, Tortajada M, Rojas A, Huws SA: Microbial β -glucosidases from cow rumen metagenome enhance the saccharification of lignocellulose in combination with commercial cellulase cocktail. *Biotechnology for Biofuels* 2012, 5(1): 1.
- [176] Feng Y, Duan C-J, Liu L, Tang J-L, Feng J-X: Properties of a metagenome-derived β -glucosidase from the contents of rabbit cecum. *Bioscience, biotechnology, and biochemistry* 2009, 73(7): 1470-1473.
- [177] Guo H, Feng Y, Mo X, Duan C, Tang J, Feng J: Cloning and expression of a beta-glucosidase gene umcel3G from metagenome of buffalo rumen and characterization of the translated product. *Sheng wu gong cheng xue bao= Chinese journal of biotechnology* 2008, 24(2): 232-238.
- [178] Jiang C, Hao Z-Y, Jin K, Li S-X, Che Z-Q, Ma G-F, Wu B: Identification of a metagenome-derived β -glucosidase from bioreactor contents. *Journal of Molecular Catalysis B: Enzymatic* 2010, 63(1): 11-16.
- [179] Uchiyama T, Yaoi K, Miyazaki K: Glucose-tolerant β -glucosidase retrieved from a Kusaya gravy metagenome. *Frontiers in Microbiology* 2015, 6: 548.
- [180] Fang Z, Fang W, Liu J, Hong Y, Peng H, Zhang X, Sun B, Xiao Y: Cloning and characterization of a β -glucosidase from marine microbial metagenome with excellent glucose tolerance. *J Microbiol Biotechnol* 2010, 20(9): 1351-1358.
- [181] Wierzbicka-Woś A, Bartasun P, Cieśliński H, Kur J: Cloning and characterization of a novel cold-active glycoside hydrolase family 1 enzyme with β -glucosidase, β -fucosidase and β -galactosidase activities. *BMC Biotechnology* 2013, 13(1): 1.
- [182] Schröder C, Elleuche S, Blank S, Antranikian G: Characterization of a heat-active archaeal β -glucosidase from a hydrothermal spring metagenome. *Enzyme and microbial technology* 2014, 57: 48-54.
- [183] Jiang C, Li S-X, Luo F-F, Jin K, Wang Q, Hao Z-Y, Wu L-L, Zhao G-C, Ma G-F, Shen P-H: Biochemical characterization of two novel β -glucosidase genes by metagenome expression cloning. *Bioresource technology* 2011, 102(3): 3272-3278.
- [184] Bergmann JC, Costa OYA, Gladden JM, Singer S, Heins R, D'Haeseleer P, Simmons BA, Quirino BF: Discovery of two novel β -glucosidases from an Amazon soil metagenomic library. *FEMS Microbiology Letters* 2014, 351(2): 147-155.
- [185] Li Y, Liu N, Yang H, Zhao F, Yu Y, Tian Y, Lu X: Cloning and characterization of a new β -Glucosidase from a metagenomic library of Rumen of cattle feeding with *Miscanthus sinensis*. *BMC Biotechnology* 2014, 14(1): 1.
- [186] Mai Z, Su H, Zhang S: Characterization of a Metagenome-Derived β -Glucosidase and Its Application in Conversion of Polydatin to Resveratrol. *Catalysts* 2016, 6(3): 35.
- [187] Martínez D, Berka RM, Henriessat B, Saloheimo M, Arvas M, Baker SE, Chapman J, Chertkov O, Coutinho PM, Cullen D *et al*: Genome sequencing and analysis of the biomass-degrading fungus *Trichoderma reesei* (syn. *Hypocrea jecorina*). *Nat Biotech* 2008, 26(5): 553-560.
- [188] Stutzenberger F: Thermostable fungal β -glucosidases. *Letters in applied microbiology* 1990, 11(4): 173-178.
- [189] Baraldo Junior A, Borges DG, Tardioli PW, Farinas CS: Characterization of β -Glucosidase Produced by *Aspergillus niger*

- under Solid-State Fermentation and Partially Purified Using MANAE-Agarose. *Biotechnology research international* 2014, 2014.
- [190] Pandey A, Selvakumar P, Soccol CR, Nigam P: Solid state fermentation for the production of industrial enzymes. *Current science* 1999, 77(1): 149-162.
- [191] Coradi GV, Da Visitação VL, De Lima EA, Saito LYT, Palmieri DA, Takita MA, de Oliva Neto P, De Lima VMG: Comparing submerged and solid-state fermentation of agro-industrial residues for the production and characterization of lipase by *Trichoderma harzianum*. *Annals of Microbiology* 2013, 63(2): 533-540.
- [192] Brijwani K, Vadlani PV: Cellulolytic enzymes production via solid-state fermentation: effect of pretreatment methods on physicochemical characteristics of substrate. *Enzyme research* 2011, 2011.
- [193] Kovács K, Megyeri L, Szakacs G, Kubicek CP, Galbe M, Zacchi G: *Trichoderma atroviride* mutants with enhanced production of cellulase and β -glucosidase on pretreated willow. *Enzyme and Microbial Technology* 2008, 43(1): 48-55.
- [194] Hölker U, Lenz J: Solid-state fermentation—are there any biotechnological advantages? *Current Opinion in Microbiology* 2005, 8(3): 301-306.
- [195] Vinięgra-González G, Favela-Torres E, Aguilar CN, de Jesus Romero-Gomez S, Diaz-Godínez G, Augur C: Advantages of fungal enzyme production in solid state over liquid fermentation systems. *Biochemical Engineering Journal* 2003, 13(2): 157-167.
- [196] Subramaniyam R, Vimala R: Solid state and submerged fermentation for the production of bioactive substances: A comparative study. *Int J Sci Nat* 2012, 3: 480-486.
- [197] Acuña-Argüelles M, Gutiérrez-Rojas M, Vinięgra-González G, Favela-Torres E: Production and properties of three pectinolytic activities produced by *Aspergillus niger* in submerged and solid-state fermentation. *Applied microbiology and biotechnology* 1995, 43(5): 808-814.
- [198] Zhang Y, Yuan L, Chen Z, Fu L, Lu J, Meng Q, He H, Yu X, Lin F, Teng L: Purification and characterization of beta-glucosidase from a newly isolated strain *Tolypocladium cylindrosporum* Sxyz4. *Chem Res Chin Univ* 2011, 27: 557-561.
- [199] Bai H, Wang H, Sun J, Irfan M, Han M, Huang Y, Han X, Yang Q: Production, purification and characterization of novel beta glucosidase from newly isolated *Penicillium simplicissimum* H-11 in submerged fermentation. *EXCLI journal* 2013, 12: 528.
- [200] Elyas K, Mathew A, Sukumaran RK, Ali PM, Sapna K, Kumar SR, Mol KR: Production optimization and properties of beta glucosidases from a marine fungus *Aspergillus*-SA 58. *New biotechnology* 2010, 27(4): 347-351.
- [201] Ng IS, Li C-W, Chan S-P, Chir J-L, Chen PT, Tong C-G, Yu S-M, Ho T-HD: High-level production of a thermoacidophilic β -glucosidase from *Penicillium citrinum* YS40-5 by solid-state fermentation with rice bran. *Bioresource technology* 2010, 101(4): 1310-1317.
- [202] Bhatti HN, Batool S, Afzal N: Production and characterization of a novel β -glucosidase from *Fusarium solani*. *International Journal of Agriculture and Biology* 2013, 15(1): 140-144.
- [203] Raza F, Raza NA, Hameed U, Haq I, Maryam I: Solid state fermentation for the production of β -glucosidase by co-culture of *Aspergillus niger* and *A. oryzae*. *Pak J Bot* 2011, 43: 75-83.
- [204] Vaithanomsat P, Songpim M, Malapant T, Kosugi A, Thanapase W, Mori Y: Production of β -glucosidase from a newly isolated *aspergillus* species using response surface methodology. *International journal of microbiology* 2011, 2011.
- [205] Qian L-C, Fu S-J, Zhou H-M, Sun J-Y, Weng X-Y: Optimization of fermentation parameters for β -glucosidase production by *Aspergillus niger*. *J Anim Vet Adv* 2012, 11: 583-591.
- [206] El-Naggar NE-A, Haroun S, Owis E, Sherief A: Optimization of β -Glucosidase Production by *Aspergillus terreus* Strain EMOO 6-4 Using Response Surface Methodology Under Solid-State Fermentation. *Preparative Biochemistry and Biotechnology* 2015, 45(6): 568-587.
- [207] De Cassia Pereira J, Leite RSR, do Prado HFA, Bocchini Martins DA, Gomes E, da Silva R: Production and Characterization of β -glucosidase Obtained by the Solid-State Cultivation of the Thermophilic Fungus *Thermomucor indicae-seudaticae* N31. *Applied biochemistry and biotechnology* 2015, 175(2): 723-732.
- [208] Ling H, Ge J, Ping W, Xu X: [Fermentation optimization by response surface methodology for enhanced production of beta-glucosidase of *Aspergillus niger* HDF05]. *Sheng wu gong cheng xue bao= Chinese journal of biotechnology* 2011, 27(3): 419-426.
- [209] Beitel SM, Knob A: *Penicillium miczynskii* β -glucosidase: a glucose-tolerant enzyme produced using pineapple peel as substrate. *Industrial Biotechnology* 2013, 9(5): 293-300.
- [210] Saha BC, Freer SN, Bothast RJ: Production, purification, and properties of a thermostable β -glucosidase from a color variant strain of *Aureobasidium pullulans*. *Applied and Environmental Microbiology* 1994, 60(10): 3774-3780.
- [211] Rajoka M, Khan S, Latif F, Shahid R: Influence of carbon and nitrogen sources and temperature on hyperproduction of a thermotolerant β -glucosidase from synthetic medium by *Kluyveromyces marxianus*. *Applied biochemistry and biotechnology* 2004, 117(2): 75-92.
- [212] Iembo T, Da Silva R, Pagnocca F, Gomes E: Production, Characterization, and Properties of β -Glucosidase and β -Xylosidase from a Strain of *Aureobasidium* sp. *Applied Biochemistry and Microbiology* 2002, 38(6): 549-552.
- [213] Sirilun S, Chaiyasut C, Pengkumsri N, Peerajan S, Chaiyasut K, Suwannaler P, Sivamaruthi BS: Screening and characterization of β -glucosidase production by *Saccharomyces cerevisiae*. 2016.
- [214] Gautam S, Bundela P, Pandey A, Khan J, Awasthi M, Sarsaiya S: Optimization for the production of cellulase enzyme from municipal solid waste residue by two novel cellulolytic fungi. *Biotechnology research international* 2011, 2011.
- [215] Melikoglu M, Lin CSK, Webb C: Stepwise optimisation of enzyme production in solid state fermentation of waste bread pieces. *Food and Bioprocess Processing* 2013, 91(4): 638-646.
- [216] Herr D: Secretion of cellulase and β -glucosidase by *Trichoderma viride* ITCC-1433 in submerged culture on different substrates. *Biotechnology and bioengineering* 1979, 21(8): 1361-1371.
- [217] Karaffa L, Fekete E, Gamauf C, Szentirmai A, Kubicek CP, Seiboth B: D-Galactose induces cellulase gene expression in *Hypocrea corynea* at low growth rates. *Microbiology* 2006, 152(5): 1507-1514.
- [218] Roy SK, Raha SK, Dey SK, Chakrabarty S: Induction and catabolite repression of β -glucosidase synthesis in *Myceliophthora thermophila* D-14 (= ATCC 48104). *Applied and Environmental Microbiology* 1988, 54(8): 2152-2153.
- [219] Suto M, Tomita F: Induction and catabolite repression mechanisms of cellulase in fungi. *Journal of bioscience and bioengineering* 2001, 92(4): 305-311.
- [220] Mallerman J, Levin L: Characterization of β -Glucosidase Produced by the White Rot Fungus *Flammulina velutipes*. *Journal of Microbiology and Biotechnology* 2015, 25(1): 57-65.
- [221] Jeya M, Lee J-K: Optimization of β -glucosidase production by a strain of *Stereum hirsutum* and its application in enzymatic saccharification. *J Microbiol Biotechnol* 2013, 23(3): 351-356.
- [222] Garcia NFL, da Silva Santos FR, Gonçalves FA, da Paz MF, Fonseca GG, Leite RSR: Production of β -glucosidase on solid-state fermentation by *Lichtheimia ramosa* in agroindustrial residues: Characterization and catalytic properties of the enzymatic extract. *Electronic Journal of Biotechnology* 2015, 18(4): 314-319.
- [223] Abdella A, Mazeed TE-S, El-Baz AF, Yang S-T: Production of β -glucosidase from wheat bran and glycerol by *Aspergillus niger* in stirred tank and rotating fibrous bed bioreactors. *Process Biochemistry* 2016, 51(10): 1331-1337.
- [224] Mahapatra S, Vickram AS, Sridharan TB, Parameswari R, Pathy MR: Screening, production, optimization and characterization of β -glucosidase using microbes from shellfish waste. *3 Biotech* 2016, 6(2): 213.
- [225] Singhania RR, Sukumaran RK, Rajasree KP, Mathew A, Gottumukkala L, Pandey A: Properties of a major β -glucosidase-BGL1 from *Aspergillus niger* NII-08121 expressed differentially in response to carbon sources. *Process Biochemistry* 2011, 46(7): 1521-1524.
- [227] Ramani G, Meera B, Vanitha C, Rao M, Gunasekaran P: Production, purification, and characterization of a β -glucosidase of *Penicillium funiculosum* NCL1. *Applied biochemistry and biotechnology* 2012, 167(5): 959-972.
- [228] Singhania RR: Beta-Glucosidase from *Aspergillus niger* NII 08121-Molecular characterization and applications in Bioethanol production. *Cochin University of Science and Technology, Cochin, India* 2012.
- [229] Collins T, Gerday C, Feller G: Xylanases, xylanase families and extremophilic xylanases. *FEMS microbiology reviews* 2005, 29(1): 3-23.

- [230] Kun LY: Microbial biotechnology: principles and applications: World Scientific; 2003.
- [231] Venturi LL, de Lourdes Polizeli M, Terenzi HF, dos Prazeres Melo Furriel R, Jorge JA: Extracellular β -D-glucosidase from *Chaetomium thermophilum* var. *coprophilum*: production, purification and some biochemical properties. *Journal of basic microbiology* 2002, 42(1): 55-66.
- [232] Ng I-S, Li C-W, Chan S-P, Chir J-L, Chen PT, Tong C-G, Yu S-M, Ho T-HD: High-level production of a thermoacidophilic β -glucosidase from *Penicillium citrinum* YS40-5 by solid-state fermentation with rice bran. *Bioresource technology* 2010, 101(4): 1310-1317.
- [233] Yadav PS, Shruthi K, Prasad BS, Chandra MS: Enhanced Production of β -glucosidase by New Strain *Aspergillus protuberus* on Solid State Fermentation in Rice Husk. *Int J Curr Microbiol App Sci* 2016, 5(12): 551-564.
- [234] Christakopoulos P, Goodenough PW, Kekos D, Macris BJ, Claeysens M, Bhat MK: Purification and Characterisation of an Extracellular β -Glucosidase with Transglycosylation and Exo-glucosidase Activities from *Fusarium oxysporum*. *European Journal of Biochemistry* 1994, 224(2): 379-385.
- [235] Batra J, Beri D, Mishra S: Response Surface Methodology Based Optimization of β -Glucosidase Production from *Pichia pastoris*. *Applied biochemistry and biotechnology* 2014, 172(1): 380-393.
- [236] Levin L, Herrmann C, Papinutti VL: Optimization of lignocellulolytic enzyme production by the white-rot fungus *Trametes trogii* in solid-state fermentation using response surface methodology. *Biochemical Engineering Journal* 2008, 39(1): 207-214.
- [237] Job J, Sukumaran RK, Jayachandran K: Production of a highly glucose tolerant β -glucosidase by *Paecilomyces variotii* MG3: optimization of fermentation conditions using Plackett-Burman and Box-Behnken experimental designs. *World Journal of Microbiology and Biotechnology* 2010, 26(8): 1385-1391.
- [238] Hu J, Arantes V, Saddler JN: The enhancement of enzymatic hydrolysis of lignocellulosic substrates by the addition of accessory enzymes such as xylanase: is it an additive or synergistic effect? *Biotechnology for biofuels* 2011, 4(1): 1-14.
- [239] Rani V, Mohanram S, Tiwari R, Nain L, Arora A: Beta-glucosidase: Key enzyme in determining efficiency of cellulase and biomass hydrolysis. *Journal of Bioprocessing & Biotechniques* 2015, 2015.
- [240] Balan V: Current challenges in commercially producing biofuels from lignocellulosic biomass. *ISRN biotechnology* 2014, 2014.
- [241] Treebupachatsakul T, Nakazawa H, Shinbo H, Fujikawa H, Nagaiwa A, Ochiai N, Kawaguchi T, Nikaido M, Totani K, Shioya K: Heterologously expressed *Aspergillus aculeatus* β -glucosidase in *Saccharomyces cerevisiae* is a cost-effective alternative to commercial supplementation of β -glucosidase in industrial ethanol production using *Trichoderma reesei* cellulases. *Journal of bioscience and bioengineering* 2016, 121(1): 27-35.
- [242] Dashtban M, Qin W: Overexpression of an exotic thermotolerant beta-glucosidase in *trichoderma reesei* and its significant increase in cellulolytic activity and saccharification of barley straw. *Microb Cell Fact* 2012, 11: 63.
- [243] Nakazawa H, Kawai T, Ida N, Shida Y, Kobayashi Y, Okada H, Tani S, Sumitani Ji, Kawaguchi T, Morikawa Y: Construction of a recombinant *Trichoderma reesei* strain expressing *Aspergillus aculeatus* β -glucosidase 1 for efficient biomass conversion. *Biotechnology and bioengineering* 2012, 109(1): 92-99.
- [244] Pei J, Pang Q, Zhao L, Fan S, Shi H: Thermoanaerobacterium thermosaccharolyticum β -glucosidase: a glucose-tolerant enzyme with high specific activity for cellobiose. *Biotechnol Biofuels* 2012, 5(31): 1-10.
- [245] Kabera JN, Semana E, Mussa AR, He X: Plant Secondary Metabolites: Biosynthesis, Classification, Function and Pharmacological Properties. *Journal of Pharmacy and Pharmacology* 2014, 2: 377-392.
- [246] Karimi E, Oskoueian E, Hendra R, Oskoueian A, Jaafar HZ: Phenolic compounds characterization and biological activities of *Citrus aurantium* bloom. *Molecules* 2012, 17(2): 1203-1218.
- [247] Servili M, Sordini B, Esposito S, Urbani S, Veneziani G, Di Maio I, Selvaggini R, Taticchi A: Biological activities of phenolic compounds of extra virgin olive oil. *Antioxidants* 2013, 3(1): 1-23.
- [248] Setchell KD, Brown NM, Zimmer-Nechemias L, Brashear WT, Wolfe BE, Kirschner AS, Heubi JE: Evidence for lack of absorption of soy isoflavone glycosides in humans, supporting the crucial role of intestinal metabolism for bioavailability. *The American Journal of Clinical Nutrition* 2002, 76(2): 447-453.
- [249] Day AJ, DuPont MS, Ridley S, Rhodes M, Rhodes MJ, Morgan MR, Williamson G: Deglycosylation of flavonoid and isoflavonoid glycosides by human small intestine and liver β -glucosidase activity. *FEBS letters* 1998, 436(1): 71-75.
- [250] Ávila M, Hidalgo M, Sánchez-Moreno C, Pelaez C, Requena T, de Pascual-Teresa S: Bioconversion of anthocyanin glycosides by *Bifidobacteria* and *Lactobacillus*. *Food research international* 2009, 42(10): 1453-1461.
- [251] Yang S, Wang L, Yan Q, Jiang Z, Li L: Hydrolysis of soybean isoflavone glycosides by a thermostable β -glucosidase from *Paecilomyces thermophila*. *Food Chemistry* 2009, 115(4): 1247-1252.
- [252] Song X, Xue Y, Wang Q, Wu X: Comparison of three thermostable β -glucosidases for application in the hydrolysis of soybean isoflavone glycosides. *Journal of agricultural and food chemistry* 2011, 59(5): 1954-1961.
- [253] Yang L, Ning ZS, Shi CZ, Chang ZY, Huan LY: Purification and characterization of an isoflavone-conjugates-hydrolyzing β -glucosidase from endophytic bacterium. *Journal of agricultural and food chemistry* 2004, 52(7): 1940-1944.
- [254] Kuo L-C, Cheng W-Y, Wu R-Y, Huang C-J, Lee K-T: Hydrolysis of black soybean isoflavone glycosides by *Bacillus subtilis* natto. *Applied microbiology and biotechnology* 2006, 73(2): 314-320.
- [255] Kuo L-C, Lee K-T: Cloning, expression, and characterization of two β -glucosidases from isoflavone glycoside-hydrolyzing *Bacillus subtilis* natto. *Journal of agricultural and food chemistry* 2007, 56(1): 119-125.
- [256] Fang W, Song R, Zhang X, Zhang X, Wang X, Fang Z, Xiao Y: Characterization of a novel β -glucosidase from *Gongronella* sp. W5 and its application in the hydrolysis of soybean isoflavone glycosides. *Journal of agricultural and food chemistry* 2014, 62(48): 11688-11695.
- [257] Choi HJ, Kim EA, Kim DH, Shin K-S: The Bioconversion of Red Ginseng Ethanol Extract into Compound K by *Saccharomyces cerevisiae* HJ-014. *Mycobiology* 2014, 42(3): 256-261.
- [258] Yan Q, Zhou X-W, Zhou W, Li X-W, Feng M-Q, Zhou P: Purification and properties of a novel beta-glucosidase, hydrolyzing ginsenoside Rb1 to CK, from *Paecilomyces Bainier*. *Journal of microbiology and biotechnology* 2008, 18(6): 1081-1089.
- [259] Cui C-H, Liu Q-M, Kim J-K, Sung B-H, Kim S-G, Kim S-C, Im W-T: Identification and characterization of a *Mucilaginibacter* sp. strain QM49 β -glucosidase and its use in the production of the pharmaceutically active minor ginsenosides (S)-Rh1 and (S)-Rg2. *Applied and environmental microbiology* 2013, 79(19): 5788-5798.
- [260] Nair A, Kuwahara A, Nagase A, Yamaguchi H, Yamazaki T, Hosoya M, Omura A, Kiyomoto K, Yamaguchi M-a, Shimoyama T: Purification, gene cloning, and biochemical characterization of a β -glucosidase capable of hydrolyzing sesaminol triglucoside from *Paenibacillus* sp. KB0549. *PLoS one* 2013, 8(4).
- [261] Shin K-C, Nam H-K, Oh D-K: Hydrolysis of flavanone glycosides by β -glucosidase from *Pyrococcus furiosus* and its application to the production of flavanone aglycones from citrus extracts. *Journal of agricultural and food chemistry* 2013, 61(47): 11532-11540.
- [262] You HJ, Ahn HJ, Kim JY, Wu QQ, Ji GE: High expression of β -glucosidase in *Bifidobacterium bifidum* BGN4 and application in conversion of isoflavone glucosides during fermentation of soy milk. *J Microbiol Biotechnol* 2015, 25(4): 469-478.
- [263] Byun DH, Choi HJ, Lee HW, Jeon HY, Choung WJ, Shim JH: Properties and applications of β -glucosidase from *Bacteroides thetaiotaomicron* that specifically hydrolyses isoflavone glycosides. *International Journal of Food Science & Technology* 2015, 50(6): 1405-1412.
- [264] Yan F-y, Xia W, Zhang X-x, Chen S, Nie X-z, Qian L-c: Characterization of β -glucosidase from *Aspergillus terreus* and its application in the hydrolysis of soybean isoflavones. *Journal of Zhejiang University Science B* 2016, 17(6): 455-464.
- [265] Maicas S, Mateo JJ: Hydrolysis of terpenyl glycosides in grape juice and other fruit juices: a review. *Applied microbiology and biotechnology* 2005, 67(3): 322-335.
- [266] Gunata YZ, Bayonove CL, Baumes RL, Cordonnier RE: The aroma of grapes I. Extraction and determination of free and glycosidically bound fractions of some grape aroma components. *Journal of Chromatography A* 1985, 331: 83-90.

- [267] Williams PJ, Strauss CR, Wilson B, Massy-Westropp RA: Use of C18 reversed-phase liquid chromatography for the isolation of monoterpene glycosides and nor-isoprenoid precursors from grape juice and wines. *Journal of Chromatography A* 1982, 235(2): 471-480.
- [268] Krammer G, Winterhalter P, Schwab M, Schreier P: Glycosidically bound aroma compounds in the fruits of Prunus species: apricot (*P. armeniaca*, L.), peach (*P. persica*, L.), yellow plum (*P. domestica*, L. ssp. *syriaca*). *Journal of Agricultural and Food Chemistry* 1991, 39(4): 778-781.
- [269] Sakho M, Chassagne D, Crouzet J: African Mango Glycosidically Bound Volatile Compounds. *Journal of Agricultural and Food Chemistry* 1997, 45(3): 883-888.
- [270] Roscher R, Herderich M, Steffen J-P, Schreier P, Schwab W: 2,5-Dimethyl-4-hydroxy-3[2H]-furanone 6'O-malonyl-β-d-glucopyranoside in strawberry fruits. *Phytochemistry* 1996, 43(1): 155-159.
- [271] Whitaker JR, Voragen AG, Wong DW: Handbook of food enzymology: Marcel Dekker; 2003.
- [272] Mateo J, Jiménez M: Monoterpenes in grape juice and wines. *Journal of Chromatography A* 2000, 881(1): 557-567.
- [273] Gunata Z, Bitteur S, Brillouet J-M, Bayonove C, Cordonnier R: Sequential enzymic hydrolysis of potentially aromatic glycosides from grape. *Carbohydrate Research* 1988, 184: 139-149.
- [274] Baffi M, Martin N, Tobal T, Ferrarezi A, Lago J, Boscolo M, Gomes E, Da-Silva R: Purification and Characterization of an Ethanol-Tolerant β-Glucosidase from *Sporidiobolus pararoseus* and Its Potential for Hydrolysis of Wine Aroma Precursors. *Applied biochemistry and biotechnology* 2013, 171(7): 1681-1691.
- [275] Baffi MA, Tobal T, Lago JHG, Boscolo M, Gomes E, Da-Silva R: Wine aroma improvement using a β-glucosidase preparation from *Aureobasidium pullulans*. *Applied biochemistry and biotechnology* 2013, 169(2): 493-501.
- [276] Michlmayr H, Schumann C, Wurbs P, Da Silva NMBB, Rogl V, Kulbe KD, Andrés M: A β-glucosidase from *Oenococcus oeni* ATCC BAA-1163 with potential for aroma release in wine: cloning and expression in *E. coli*. *World Journal of Microbiology and Biotechnology* 2010, 26(7): 1281-1289.
- [277] Mesas JM, Rodriguez MC, Alegre MT: Basic characterization and partial purification of beta-glucosidase from cell-free extracts of *Oenococcus oeni* ST81. *Lett Appl Microbiol* 2012, 55(3): 247-255.
- [278] González-Pombo P, Fariña L, Carrau F, Batista-Viera F, Brena BM: A novel extracellular β-glucosidase from *Issatchenkia terricola*: Isolation, immobilization and application for aroma enhancement of white Muscat wine. *Process Biochemistry* 2011, 46(1): 385-389.
- [279] Vervoort Y, Herrera-Malaver B, Mertens S, Guadalupe Medina V, Duitama J, Michiels L, Derdelinckx G, Voordeckers K, Verstrepen KJ: Characterization of the recombinant *Brettanomyces anomalus* β-glucosidase and its potential for bioflavouring. *Journal of applied microbiology* 2016, 121(3): 721-733.
- [280] Vasconcelos A, Twiddy D, Westby A, Reilly P: Detoxification of cassava during gari preparation. *International Journal of Food Science & Technology* 1990, 25(2): 198-203.
- [281] Maduagwu EN: Differential effects on the cyanogenic glycoside content of fermenting cassava root pulp by β-glucosidase and microbial activities. *Toxicology Letters* 1983, 15(4): 335-339.
- [282] Ugwuanyi JO, Harvey LM, McNeil B: Linamarase activities in *Bacillus* spp. responsible for thermophilic aerobic digestion of agricultural wastes for animal nutrition. *Waste Manag* 2007, 27(11): 1501-1508.
- [283] Etsuyankpa M, Gimba C, Agbaji E, Omoniyi K, Ndamitso M, Mathew J: Assessment of the Effects of Microbial Fermentation on Selected Anti-Nutrients in the Products of Four Local Cassava Varieties from Niger State, Nigeria. *American Journal of Food Science and Technology* 2015, 3(3): 89-96.
- [284] Prasad DY, Heitmann JA, Joyce TW: Enzyme deinking of black and white letterpress printed newsprint waste. *Progress in Paper Recycling* 1992, 1(3): 21-30.
- [285] Pathak P, Bhardwaj NK, Singh AK: Optimization of chemical and enzymatic deinking of photocopier waste paper. *BioResources* 2011, 6(1): 447-463.
- [286] Lee CK, Ibrahim D, Omar IC: Enzymatic deinking of various types of waste paper: Efficiency and characteristics. *Process Biochemistry* 2013, 48(2): 299-305.
- [287] Elliston A, Collins SRA, Faulds CB, Roberts IN, Waldron KW: Biorefining of Waste Paper Biomass: Increasing the Concentration of Glucose by Optimising Enzymatic Hydrolysis. *Applied biochemistry and biotechnology* 2014, 172(7): 3621-3634.
- [288] Bruins ME, Strubel M, van Lieshout JFT, Janssen AEM, Boom RM: Oligosaccharide synthesis by the hyperthermostable β-glucosidase from *Pyrococcus furiosus*: kinetics and modelling. *Enzyme and Microbial Technology* 2003, 33(1): 3-11.
- [289] Kawai R, Igarashi K, Kitaoka M, Ishii T, Samejima M: Kinetics of substrate transglycosylation by glycoside hydrolase family 3 glucan (1→3)-β-glucosidase from the white-rot fungus *Phanerochaete chrysosporium*. *Carbohydrate Research* 2004, 339(18): 2851-2857.
- [290] Rather M, Mishra S: β-Glycosidases: An alternative enzyme based method for synthesis of alkylglycosides. *sustain chem process* 2013, 1(1): 1-15.
- [291] Otto RT, Bornscheuer UT, Syldatk C, Schmid RD: Synthesis of aromatic n-alkyl-glucoside esters in a coupled β-glucosidase and lipase reaction. *Biotechnology letters* 1998, 20(4): 437-440.