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Review

Biosynthesis, structural architecture and biotechnological potential of bacterial tannase: A molecular advancement

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HIGHLIGHTS

- Tannase production by bacteria is extensively reviewed.
- This review describe the advances in cultivation aspects and downstream processing.
- Progress on biochemical and structural information of bacterial tannase.
- Efforts in immobilization, cloning with special emphasis on future research growth.

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ABSTRACT

Tannin-rich materials are abundantly generated as wastes from several agroindustrial activities. Therefore, tannase is an interesting hydrolase, for bioconversion of tannin-rich materials into value added products by catalyzing the hydrolysis of ester and depside bonds and unlocked a new prospect in different industrial sectors like food, beverages, pharmaceuticals, etc. Microorganisms, particularly bacteria are one of the major sources of tannase. In the last decade, cloning and heterologous expression of novel tannase genes and structural study has gained momentum. In this article, we have emphasized critically on bacterial tannase that have gained worldwide research interest for their diverse properties. The present paper delineate the developments that have taken place in understanding the role of tannase action, microbial sources, various cultivation aspects, downstream processing, salient biochemical properties, structure and active sites, immobilization, efforts in cloning and overexpression and with special emphasis on recent molecular and biotechnological achievements.

1. Introduction

Enzymes are biocatalysts largely employed in various industrial processes, offering several advantages over chemical catalysts. Green biotechnology encourages the application of enzymes for the production of chemicals, fuels, secondary metabolites and others in industrial level, preferably from renewable sources. The global market has a big need for industrial enzymes that is estimated to be worth about 1.6 billion $US, split among food enzymes (29%), feed enzymes (15%) and general technical enzymes (56%) (Outtrup and Jorgensen, 2002). The majority of industrial enzymes (around 65%) are classified as "hydrolases" (Johannes and Zhao, 2006), and tannin acyl hydrolase (tannase, E.C.3.1.1.20) belongs to this class, catalyzes the hydrolysis of ester and depside bonds in varied substrate like gallo tannins, epigallocatechin-3-gallate, gallic acid esters and epicatechin gallate to release gallic acid and glucose (Lekha and Lonsane, 1997). Tannase is adaptive, intracellular/extracellular, inducible hydrolase in nature and placed into esterase superfamily (Aguilar et al., 2007; Banerjee and Mahapatra, 2012).

Tannase has been involved in the ripening of fruits by the breakdown of ester bonds of glucose with chebulinic, gallic and hexahydrophenic acids. The major commercial applications of tannase reside in food, feed, beverages, pharmaceutical and chemical industries with the production of gallic acid, instant tea, coffee flavor refreshing drinks and acron wine. Moreover, tannase is used in clarification of beer and fruit juices, improvement in the flavor of grape wine and manufacturing of animal feed (Das Mohapatra et al., 2009a; Madeira et al., 2011). Tannase is also used in analytical probe preparation for determining the structures of naturally occurring gallic acid esters, to detect cancerous cells, in treatment of olive mill and leather industry wastewater effluents containing tannins (Belmares et al., 2004; Noguchi et al., 2007; Das Mohapatra et al., 2009a).

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Gallic acid, the major hydrolytic product of tannic acid, is used in food, cosmetics, adhesives and in the synthesis of potent antioxidant, propyl gallate (Aithal and Belur, 2013). It also serves as a precursor for the commercial production of trimethoprim (an antimalarial drug) and as photosensitive resin in semiconductor production (Das Mohapatra et al., 2006). Gallic acid acts as an anti-apoptotic agent, helps to protect human cells against oxidative damage and found to show cytotoxic activity against cancer cells. It can be used in the manufacture of writing inks and dyes, as photographic developer, in the tannery industry for homogenization of tannins, for the production of pyrogallol and gallic acid (Purohit et al., 2006). Pyrogallol (metabolic end product of gallic acid) also have several industrial importance for staining of leathers, fur, coloring of hair, photographic plate developing agent, anti-lung cancer drug, anti-tumor drug, etc. (Zeida et al., 1998).

Tannase have tremendous potential in various industrial sectors and hence their commercial usage has accelerated in the recent years. Upto the year of 2001, only Juelich Chiral Solutions GmbH (Germany) in Europe, commercialized tannase in extract form (Aguilar and Gutierrez-Sanchez, 2001). Owing to its large commercial applicability tannase is currently commercialized by few companies: GmbH (Germany), Biocon (India), Sigma–Aldrich Co. (USA), ASA special enzyme, Wako Pure Chemical Industries, Ltd. (Japan), Kikkoman (Japan) and Novo Nordisk (Denmark).

Biotechnological production of tannase can be obtained from microbial, animal and vegetal sources, but microorganisms are commonly used for commercial production since they produce more stable tannases than the vegetal or animal enzymes. Constant large-scale production of tannase can be achieved by microbial fermentation process. Microorganisms are the main source for industrial enzymes due to their biochemical diversities and amenability to genetic modifications (Lekha and Lonsane, 1997; Beniwal et al., 2013). Bacteria, yeast and filamentous fungi are known as tannase producers. A foremost problem in the utilization of fungal strains for industrial applications is that degradation by fungi is relatively slow and difficult to genetic manipulation because of their genetic complexity (Beniwal et al., 2010, 2013).

Report on tannase from bacterial origin is scanty in literature before 1980's. For the first time, Deschamps et al. (1980, 1983) reported bacterial strains can also utilize tannic acid as the sole carbon source. In last 33 years, significant reports were published on bacterial tannase and about 60 new tannase positive bacteria have been isolated (Table 1). From the nineties onwards, there has been a strong focus on the production of tannase by bacterial strains (Mondal and Pati, 2000; Ayed and Hamdi, 2002; Selwal et al., 2010). Hence, there is an urgent need to assimilate all available information regarding bacterial tannase for future research direction.

Till date, most of the published reviews on tannase having focuses on tannin, biodegradation, screening, production aspect, regulation, immobilization, upstream and downstream processing with the strong emphasis on industrial applications and related patents. But, in comparison to fungal tannase, bacterial tannase is less focused in previous reviews. Taking into account the present communication is an attempt to focus current and last 33 years of achievement in the field of bacterial tannase. Present study describes the bacterial tannase sources, cultivation aspects, downstream processing, salient biochemical and structural characteristics, immobilization, recombinant production and future prospects.

2. The occurrence, structure and chemical composition of tannin

Tannins are naturally occurring plant polyphenolic compounds with varying molecular weight depending on the bond possessed with protein, polysaccharides (cellulose and pectin) and gelatin. Tannins are the second most abundant group of phenols (after lignin) in the nature and considered as plants' secondary metabolic product. It generally accumulated in considerable amounts in barks, roots, wood, leaves and fruits of higher plants and can be easily differenciate from others by protein precipitation, complexation with minerals and other macromolecules. Current classification of tannin distributes its in four groups: (i) hydrolysable tannin (gallotannin) (ii) ellagitannin (iii) complex tannin (iv) condensed tannin (proanthocyanidins). Gallotannin involves several molecules of organic acids such as gallic, digallic and chebulinic acids esterified to a molecule of glucose. However it easily hydrolysed under mild acid or alkaline conditions, either in hot water or enzymatically. Ellagitannins have building blocks of ellagic acid units linked to glucosides. Complex tannins can be generated through reactions between gallic or ellagic acids with catechins and glucosides. Condensed tannin is the polymer (>50 unit) of flavonoid building block.

Tannins have several important biological activities, such as a mechanism of defense against diseases caused by fungi, bacteria, and viruses. Bitter taste of tannin helps to protect plant tissues from the attack of insects and herbivores. The active principles of medicinal plants are often found to be the involvement of polyphenolic compounds. From the ancient time tannin rich plant extracts (tea) have been used as traditional medicine in China and Japan, to prevent diarrhea, diuretics, inflammation, septic, hemorrhage and cancer (Chowdhury et al., 2004). Tannin phenolics are also efficient chelators for metal ions, that's why they can be used in the treatment of poisoning caused by heavy metals. Due to their strong ability to bind with proteins; they have been used from thousands of years for tanning (Aguilar et al., 2007). Tannin and flavonoid compounds are found to be most effective inhibitors of HIV-1 (Das Mohapatra et al., 2013).

Increased amounts of tannic acid in soil have several detrimental effects like plant vegetation, cropping systems and low production yield. Side by side, tannin also causes various nutritional and processing problems like protein indigestibility, inhibition of enzymatic reactions and essential microbial processes such as those necessary for beer brewing. Thus high concentrations of tannin depress voluntary feed intake, digestive efficiency and animal productivity (Joseph and Abolaji, 1997). Nip and Burns (1969), reported low tannin concentration in feed resulting in an increase in nitrogen assimilation in ruminants, rendering higher growth rates and milk production. In addition, dietary tannins have been implicated in the development of some forms of cancer (Korpassy, 1961).

3. Isolation and screening of tanninolytic bacteria

Although tannase can be produced by several microorganisms, it remains a challenging task to obtain a strain with commercially acceptable yields. Selection of a suitable strain is the most significant factor in enzyme production process. Over the years, culturable, tannase-producing bacteria have been isolated from a wide variety of sources such as soil, waste water, compost, forest litter, decaying bark, feces, beverages, pickle, etc. (Table 1). Moreover, efficient screening techniques are a prerequisite for isolation of novel strains. Osawa and Walsh (1993) and Kumar et al. (2010) reported the techniques for isolation and screening of tannase producing bacteria. According to visual reading method of Osawa and Walsh (1993), the cell free fermented broth was alkalinized followed by incubation at 23 °C for 1 h. Changes of color from green to brown and absorption above 0.500 (λ_{440}) was considered as tannase positive culture. Kumar et al. (2010) used a combination of nutrient agar and tannic acid (% w/v: beef extract, 0.3; peptone,