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Microbial Xylanase and their applications - A review

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A B S T R A C T

β-1,4-D-xylanase have great potential for Industrial applications as they have the capacity to hydrolyse the hemi cellulose of plant cell wall. Xylanase can be used for bleaching the Kraft pulp, bread making, food additives to poultry, clarification of juices and conversion of xylan-rich lignocellulosic materials to D-xylose, which can be used further to a number of bio-products with a great aggregate value. Microbial xylanases are can be used in improving the nutritional quality of animal feed and for the bio-bleaching of Kraft pulp. The great value of xylanase a bio-bleaching agent can be evaluated as it reduces the harsh chemicals requirement in paper & pulp industry. This review presents some important applications of Xylanase.

Introduction

Enzymes are the central attraction point in metabolic processes, biochemical process, as a result of that they are widely studied not only by the biological community, but also by the process designs/engineers, chemical engineers, production experts and other scientific peoples. In olden days also peoples were using the enzymes in various processes like production of wine, bread etc.

The application of xylanase in paper and pulp industry was first reported by Viikari *et al.*, in 1986. In their study they have claimed that endoxylanses decrease chemicals needed for bleaching kraft pulp. Many researchers (Paice *et al* 1988, Clark *et al.*, 1990) have confirmed and extended this observation. Xylanase can be used as bio-bleach for pre-bleaching the Kraft pulp to reduce the use of harsh chemicals in paper and pulp Industry.

Xylanse are not only used in pulp and paper industry but also used as food additives to poultry (Bedford and Classen 1992), in wheat flour for improving dough handling and quality of baked products, for the extraction of coffee, plant oils, and starch (Wong & Saddller 1992), in the improvement of nutritional properties of agricultural silage and grain feed and in combination with peelinase and cellulase for

clarification of fruit jucies and degumming of plant fiber sciences like flex, hemp, jute and ramie (Biely 1985).

About 300 different chlorinated organic compounds have been identified in bleaching pulp mill effluents. About 200 of these have chlorinated resin acids, chlorinated phenolics and dioxin (Huynh *et al.*, 1985). These compounds have been classified as acidic, phenolic and neutral and are partly responsible for oxygen demand (BOD and (OD), effluent colour, toxicity mutagen city and carcinogenicity untreated pulp and paper mill effluents can be extremely toxic to aquatic life.

Xylan

Plant cell walls have three major polymeric constituents: cellulose (Insoluble fibers of β-1,4-glucan), hemicellulose (non-cellulosic polysaccharides including glucans, mannans and xylans) and legnin (A complex poly phenolic structure). Xylan is the major hemicellulaose in wood from angiosperms but is less abundant in wood from gymnosperms. Xylan is composed of a backbone of glycosidically β–1,4- linked xylopyranose units in terrestrial plants but in marine algae β-1,3-linked back bone are found (Dekker & Richards 1976).

Isolated β-1 4-xylans are generally polydispersed and highly branched, heteropolymer, though homoxylans that consists of exclusively of xylosyl residues have been isolated from esparto grass (Chanda *et al.*, 1980). Xylan of hardwood where it contains 10-35% of dry weight is acetyl-4-0-methyl gluouronoxlyan with a degree of polymerization of about 200 has a backbone β -1-4 linked xylopyranose units. Approximately 10% β -D-Xylopyranose backbone units are substituted at C-2 with a 1,2 linked 4-0-methyl-α -D glucoronic acid residue while 70% are acetylated C-2 or C-3 or both. The structures of oligosaccharides, isolated after the xylanase treatment of hardwood suggest that xylan has two kinds of xylose and β -1-4, xylobiose attached to main chain of 1, 4 linked β-D-xylopyranosyl residues and both of them are branched through the O-3 position of xylose residues of the main chain.

Softwood contains 10-15% xylan as arabino-4-0 methyl glucuronoxylan with Dp of >120 (Plus and Schuseil, 1993). This material, which is not acetylated, contains β-D-xylopyranose, 4-0-methyl –α -D-glucuronic acid and L-arabinose in a ratio of 1000:20:13.

Xylan is categorized as linear homoxylan, arabinoxylan, glucuronoxylan and glucuronoarabinoxylan. The O-acetyl groups present at C_2 and C_3 positions of xylosyl residues inhibit xylanase from completely degrading acetyl xylan probably by stearic hindrance. So the synergistic action of acetyl xylan esterase and Xylanase is necessary for complete hydrolysis of acetyl xylan.

The presence of small amounts of feruloyl and p-coumaroyl acids linked via L-arabinase residue has been shown in xylan structure. The presence of covalent bond between lignin and hemicellulose perhaps through xylan substituent in many cases has been documented.

Evidence for the existence of an ether linkage between arabinase and lignin and ester linkage between glucuronic acid and lignin has also been shown. Feruloyl groups may also cross link xylan and lignin. The side chains determine the solubility, physical conformation and reactivity of the xylan molecule with other hemicellulosic components and hence greatly influence the mode and extent of enzymatic cleavage.

Xylan degrading enzymes

The main enzymes responsible for the hydrolysis of xylan backbone are endo- β -xylanses, β-xylosidases and exo- β -xylanases. Besides the main chain cleaving enzymes some side chain cleaving enzymes also play an important role in xylan hydrolysis. Side chain cleaving enzymes include acetyl esterase, α -L-arabino-furanosidase and α -D glucuronidase and it has been reported that many of these enzymes act synergestically for xylan hydrolysis (Lee and Forsberg 1987).

Xylanse classification

As suggested by Wong *et al.,* (1988) xylanses may be classified mainly by 3 ways-

1. **Based on molecular weight and PI-** According to this type the xylanses are either high or low molecular wt or pI. The most attractive part of this classification is the availability of class information during purification and initial characterization of enzyme.

2. **Based on crystal structure-** Structurally Xylanses can be classified in to family F or family 10 and family G or family 11. Family 10 Xylanases generally have a high molecular weight and family 11, xylanases have low molecular weight.

3. **Based on Enzyme Kinetics-** The third type classification is based on kinetic properties and substrate specificity of the enzyme.

Microbial sources of xylanases

The multifunctional xylanolytic enzyme system is wide spread among Fungi (Belancic *et al.,* 1995, Biely *et al.,* 1985), *Actinomycetes* (Flegir *et al.,* 1995) and bacteria (Dey *et al.,* 1992). Table 1 summarizes the biochemical properties of some acidic, alkaline, and thermo stable xylanses reported in literature.

For obtaining industrially important xylanases alkaliphilic organism and thermophilic organism have been preferred. Alkaline xylanases are important due to their applications in pulp and kraft bleaching. Horikoshi and Atsukawa in 1973 reported first time alkaliphilic bacteria for xylanase production. The purified enzyme of Bacillus sp C-59-2 exhibited a broad pH optimum ranging from 6-8, May of the Xylanses produced by alkaliphilic organisms such as *Bacillus sp*. (Okazaki *et al.,* 1984) and *Aeromonas* sp 212 (Ohkoshi *et al.,* 1985) with optimum growth at pH 10 showed remarkable stability of pH 9-10. The enzymes from Bacillus sp. TAR-1, C-125 (Nakamura *et al.,* 1994, Honda *et al.,* 1985) and alkaliphilic Bacillus sp (NCL-86-6-10) (Balakrishna *et al*., 1992) were optimally active at pH 9-10. The Xylanase from *Cephalosporium* was the only one reported from an alkaliphilic fungus having activity at broad pH range of 6.5-9 (Bansod *et al.,* 1993).The Xylanase from thermophilic bacteria such as *Thermomono spora fusca* (Mc Carthy *et al.,* 1985). *B. stearothermophilius* (Khasin *et al*., 1993) have optimum temperature range 65-80^{o}C. Xylanse produced by *Aspergillus* strain (Gilbert *et al.,* 1993) grows at 37^{o}C. Thermophilic anaerobe *Clostridium steriorarium* has temperature optimum of 70^{o}C and half-life of 90 min. at 80^{o}C whereas *Thermatoga* sp. xylanase has temperature optimum at 105^{o}C with half-life of 90 min at 95^{o}C (Simpson *et al.,* 1991). However, fungal source of enzyme also shows higher thermal stability and it was reported that *Thermoaseus auranticus* has

been reported to be stable at 70°C for 24 hrs and half life of 54 min. at 80°C (Yu *et al.*, 1987). Other sources of thermophilic fungal xylanse are from *Paccilomyces variata* (Krishnamurthy and Withayathil 1989) and *T. byssochlamycloides* (Yoshika *et al.*, 1981) and having enzyme optimum temp. of 65-75°C at pH 5-6.5. Recently endo-xylanases from thermophilic actinomycete *Microtetraspora flexuosa* S 11X found to have optimum temperature of 80°C at pH 6 (Berens *et al.*, 1996).

Xylanase production

Xylanase production depends on media composition and inducing substrate. Filamentous fungi produce more Xylanase than the yeast and bacteria but fungal Xylanases are generally associated with cellulose activity (Steiner *et al.*, 1987). Trichoderma & Aspergillus species produces xylanase by using pure Xylan as substrate for enzyme production. These strains produces both cellulase and xylanase on using cellulose as a substrate, which may be due to the presence of traces of hemi cellulose in the cellulosic substrates (Biely 1993), The process that controls the extra cellular enzyme-production according to the carbon sources of medium are influenced by the availability of precursors for protein synthesis. Lower nitrogen/carbon ratio in the medium may be one of the strategies for cellulase free xylanase production (Biely 1991), cellulosic substrates in the medium were also found to be essential for the maximum xylanase production by *Clostridium scleroarium* (Berenger *et al.*, 1985). *Thermomono spora curvata* (Stutzarberger and Bodine 1992) and *Neurospore crassa* (Deshpande *et al.*, 1986). Agro waste substrates like corncob, rice straw, wheat straw, wheat bran corn stalk and bagasse can be used as a substrate for xylanase production by certain micro organisms like *Aspergillus awanian, Penicilluim purpurogenum* (Haltrich *et al.*, 1996) and alkaliphilic thermophilic Bacillus sp. NCIM 59 (Dey *et al.*, 1996).

Xylanase activity is found to be higher in fungal system with maximum activity of 3350 IU/ml in *Trichoderma reesi* (Hospala *et al.*, 1994) than Bacterial systems. Maximum activity (22,700 IU/g) in solid-state formation was achieved from the fungus *Schizophyllum commune* (Haltrich *et al.*, 1992). *Trichoderma hamatum* with activity of 7000 IU/g have been reported using wheat straw as a substrate (Grajek 1987) for Xylanse production. Cellulose free Xylanase producer has been reported in Bacillus sp and fungi (Dey *et al.*, 1992, Gilbert *et al.*, 1992 & Bishwas *et al.*, 1990). Fungi generally require acidic pH but *Actinomycetes* and bacteria require neutral or alkaline pH optima for Xylanase production. *Trichoderma reesei* (Tenkanen *et al.*, 1992) *Thermomyces* (Bajpai 1999, Gubit *et al.*, 1997), *Aureobasidium pullulans* (Christov *et al.*, 1999). *B. subtilis* are some of the strain for xylanase production at commercial level (Ragauskas *et al.*, 1994, Senior *et al.*, 1992).

Applications of xylanases

Due to their Industrial potential microbial xylanolytic enzymes have drawn a great attention in the last decade. The most promising and wide spread use of Xylanase is in the prebleaching of kraft pulps (Bajpai 1999). On the laboratory scale Xylanases from *Streptomyces roseiscleraticus* (Patel *et al.*, 1993). Actinomycetes (Davis *et al.*, 1992) *T. harzianum* (Senio *et al.*, 1988) and *Humeeala* Sp. (Silva *et al.*, 1994) have been used for enzymatic pulp treatment to check their bleach boosting abilities. Xylanase enzyme from *Thermatoga maritima* was compared with commercial pulpzyme Hc

and was found to be efficient in releasing lignin from kraft pulp (Chen *et al.,* 1997). The cloned xylanase expressed in *Bacillus cereus* (Tremblay and Archibold 1993) and in *E.coli* (Paice *et al.,* 1988) have also been reported to improve the delignification of unbleached kraft pulps. Xylanases produced by many alkali tolerant strains having pH optima around 9 have been used for biobleaching. Thermostable Xylanase produced by *Dictyoglomus* sp has been evaluated for its suitability in pulp bleaching (Ratto *et al.,* 1994), Xylanase from *Bacillus stereothermophilus* T-6 at 65^{o}C and pH 9 bleached the pulp effectively and has been industrially used in successful Metl trial (Lapidat 1996). Novo Nordisk A/S under the brand name of "Pulpzyme HA' marketed first commercial xylanase produced by *T. ressei.* Later on new enzyme from bacterial source were also sold under the same brand name.

Sandoz chemicals also marked 'Cartazyme HS". Ecopulp (from Alko-ICI), cartazyme NS-10 (from clariant) and pulpzyme (from Novo Nordisk) were tested with Eucalyptus kraft pulps and the significant decrease in ClO_2 & H_2O_2 consumption was observed (Vicuna *et al.,* 1997). Some important commercial xylanase and their suppliers are given in table 2. In February 2007 an application has been submitted by DANISCO Animal Nutrition (UK) for approval of DANISCO xylanase G and DANISCO xylanase L as a feed additive.

Apart from the major application of Xylanase in pulp bleaching process, some other applications of Xylanse are as follow (Beg *et al.,* 2001).

1. **Food and Feed Industry:-** For using the xylanase with other enzymes as an animal feed additive for dairy cattle an U.S. patent for a method of xylanase production was granted in 1979 (Garg *et al.,* 2010).
Saccharification of the cellulose and hemicellulose in biomass gives sugar-rich liquid which is useful for the production of a variety of value-added products like ethanol, furfural, and various functional biopolymers (Fuller *et al.,* 1995). An increased possibility of fermentation of both hexose and pentose sugars present in lignocelluloses into methanol has also been reported (Senn and Pieper 2001). Xylanase helps in increasing juice yield from fruits and vegetables. It also reduces the viscosity of the fruit juice by improving the filterability of juices (Biely 1985). Xylanases are useful in beer production, as it improves the extraction of more fermentable sugar from barley (Garg *et al.,* 2010).

Addition of xylanase in animal feed results in better animal growth rates by improving digestibility and quality of animal litter (Biely 1985; Damiano *et al.,* 2003). The endosperm cell walls of cereal grains have good quantity of polysaccharides in the form of arabinoxylans mixed with linked β-glucans, celluloses, mannans, and galactans (Longland *et al.,* 1995) out of which arabinoxylans and β-glucans constitute major portion.

Wheat, triticale, and rye are rich in arabinoxylans (Bonnin *et al.,*1998), whereas oats and barley are rich in β-glucans (Beer *et al.,*1997; Cui *et al.,* 2000). Because of its viscous nature polysaccharides are difficult to digest by domestic animals. Therefore, addition of xylanase in diet enhances the availability of the polysaccharides to the animals (Salih *et al.,* 1991; Amnison 1992; Bedford and Classen 1993).

Endo-1,4-β-D-xylanase thins out the gut contents, allowing increased nutrient

absorption and diffusion of the pancreatic enzymes. It also converts hemicellulose to sugars and because of it, nutrients are trapped in the cell walls and chickens get sufficient energy from lesser amount of feed. Xylanase treatment of forages produces better quality silage that helps in plant cell wall digestion by ruminants. Xylanase treatment increases the nutritive sugar content in the animal feed and hence is useful for digestion in cow and other ruminants (Garg *et al.,* 2010). Xylanase incorporation to a rye-based diet of broiler chickens results in reduced intestinal viscosity; this improves both the weight gain of chicks and their feed conversion efficiency (Bedford and Classen 1992, Van Paridon *et al.*, 1992).

2. Bread Quality Improvement:- Enzymes play a key role in baking industry and Xylanase has been reported to have its use in bread making (Beg *et al.*, 2001). Many endo-1, 4-β-xylanases both form bacterial and fungal sources have been used in baking industries (Pariza and Johnson 2001). Enzymatic hydrolysis of non-starch polysaccharides leads to improvement of rheological properties of dough, bread specific volume, and crumb firmness (Martinez-Anaya *et al.,* 1997). Endo-xylanase attacks arabino-xylan backbone to reduce the degree of polymerization, hence leaving a strong impact on arabino-xylan structure and function (Courtin CM, Delcour 2002; Qi and Drost-Lustenberger 2002). Xylanase improves dough machinability, dough stability, oven spring, loaf volume, crumb structure, and shelf life when used in optimum amount (Hamer 1995; Poutanen 1997).

Xylanase improves the bread quality with an increase in specific bread volume. This can be further enhanced by combining amylase with Xylanse (Maat *et al.,* 1992). Xylanases increases the elasticity of the gluten network, hence used as additives in the baking industry. Increased elasticity improves handling and stability of the dough. Addition of xylanase to wheat flour results in nearly 10% more voluminous loaf (Garg *et al.,* 2010). Arabinoxylans are highly branched xylans present in wheat flour, the raw material for bread making. Xylanase also increases crumb softness after storage but due to substrate specificities, action patterns, interactions with inhibitors and kinetics, all xylanases are not useful for baking industries (Garg *et al.,* 2010). Basinskiene *et al.,* (2006) demonstrated that out of *Aspergillus oryzae*, *Humicola insolens* and *Trichoderma reesei* xylanases isolated from *Aspergillus oryzae*, are more effective to improve the quality of bread. In comparison to bread without addition of xylanase, the addition of xylanase leads to increase in specific volume of bread by 8–13% and crumb firmness decreased by 15–24%. The maximum anti-staling effect was observed by the xylanase of *T. reesei*. Jiang *et al.,* (2005) reported a xylanase from thermophilic bacteria, *Thermomyces lanuginosus* CAU44 with its application in bread making. Gottschalk *et al.,* (1994) got one patent on "A novel xylanase, obtained from *Bacillus subtilis* strains, is provided which improves the consistency and increases the volume of bread and baked goods".

Laurikainen *et al.,* (1998) reported that addition of *Tricoderma* culture filtrate enriched in endo-1,4-β-xylanase leads to increase in softening of wheat dough from 90 BU (in control) to 170 BU. Martinez-Anaya and Jimenez (1997) demonstrated that starch and non-starch hydrolyzing enzymes result in the release of free water and change of soluble fraction of dough.

Redgwell *et al.,* (2001) reported the change in viscosity due to the action of endo-1, 4-β-xylanase on the wheat flour. Jiang *et al.,* (2005) reported an improvement in specific volume of wheat bread using endo-1, 4-β-xylanase. Effect of the addition of glucose oxidase, peroxidase and endo-1, 4-β-xylanase on dough rheological parameters and bread quality was studied by Pescado–Piedra *et al.,* (2009). In their study they found, that the addition of peroxidase and endo-1,4-β-xylanase increases the water absorption, while the incorporation of glucose oxidase had no effect on it.

3. Agro waste treatment: - Hemicelluloses (Xylan) rich agro waste can be treated by Xylanase to convert xylan into xylose by enzymatic hydrolysis. Development of an efficient enzymatic hydrolysis process offers new prospects for treating hemicellulosic wastes (Biely, 1985 and Rani Nand 1996).

4. Food Industry:- Xylanase with cellulase and pectinase are used for clarifying must and juices, for liquefying fruits and vegetables (Biely 1985) α-L-arabinofuranosidase and β- D- gluco pyranosidase have been employed for aromatizing musts wines and fruit juices (Spagna *et al.,* 1998)

5. Plants: - Xylanase can induce glycosylation and fatty acylation of phytosterols in plant cells treatment of tobacco cell suspension (*Nicotiana tobaccum* CV. KY 14) with a purified endo-xylanase from *T. viride* caused a 13 – fold increase in the levels of acylated sterol glycosides and elicited the syntheses of phytoalexins (Moreau *et al.,* 1994). Wong *et al.,* (1988) have reported that few xylanases can be used for improving cell wall maceration for the production of plant protoplast. Truncated bacterial xylanase gene from *Clostridium thermocellum* has been demonstrated in rhizosecretion in transgenic tobacco plants (Borisjuk *et al.,* 1999).

6. Biofuels:- Xylanase in synergism with mannanase xylosidase, glucanase, ligninase, glucosidase etc, may be used for the generation of biological fuels, such as ethanol and xylital from lignocelluloic biomass (Dominguez 1998, Kuhad & Singh 1993). The bio process of ethanol fuel production requires de-lignification of lignocelluloses to liberate cellulose and hemicellulose from their complex with lignin, followed by cellulose and hemicelluloses de-polymerization, to produce free sugars and finally fermentation of mixed pentose & hexose to produce ethanol (Lee 1997).

7. Degumming: - Xylanase system with pectinolytic enzyme system can be used for the degumming of bast fibers such as flax, hamp, jute and ramie (Puchart *et al.,* 1999). Xylanase pectinase combination can also be used in the debarking process, the first step in wood processing (Bajpai 1999, Wrong & Saddler 1997). Pectinase are believed to play a major role in removal of binding materials from plant tissues, but xylanase may also be involved in this process.

8. Seed germination: - Xylanases from the germinating plant seed convert reserve food to the assailable end product. It is proposed that xylanase play a key role in cell elongation and fruit softening (Kulkami *et al.,* 1997).

9. Xylooligosaccharides (XOs) Production: - Xylanase has a recent and exciting application for the production of xylo-oligosaccharides (XOs) and at present XOs are produced mainly by enzymatic hydrolysis of liquir (Tan *et al.,* 2008). XOs are functional oligosaccharides and have many beneficial biomedical and health

benefits (Yang *et al.,* 2005). Xylan results in the formation of xylose, arabinose and methyl-glucuronic acid containing xylooligosaccharides. Xylooligosaccharides have many practical applications in various fields like pharmaceuticals, feed formulations, agricultural purposes and food applications (Vazquez *et al.,* 2000. As a food additives, XOs have pre-biotic action by improving the intestinal function due to increase the number of healthy *Bifidobacteria* (Rycroft *et al.,* 2001; Fooks and Gibson 2002; Izumi and Kojo 2003). If xylooligosaccharides used as dietary supplements then due to their beneficial effect on gastrointestinal tract, they may reduce the risk of colon cancer (Whitehead and Cotta 2001). XOs have an acceptable odor, and are non-carcinogenic in nature (Kazumitsu *et al.,* 1987; Kazumitsu *et al.,* 1997). XOs have low-calorific value and can be used in anti-obesity diet products (Taeko *et al.,* 1998; Toshio *et al.,* 1990).

10. Bio-energy: - Chiranjeevi *et al.,* (2012) studied the production of a mixture of cellulases and xylanases (holocellulases) from *Cladosporium cladosporioides.* In their study they found that efficient holocellulases cocktail plays a significant role in commercialization of biorefinery, textile, detergent formulation and paper manufacturing industries (Sharma and Kumar 2013). Wheat straw is an abundant co-product of the agri-food industry which could be a primary source of lignocellulosic biomass for second generation biorefining (Song *et al.,* 2012). In order to develop better biomass degrading ability Song *et al.,* (2012) engineered GH11 xylanase by mutating at position 111. However, they also reported that enzyme engineering alone cannot resolve the limits imposed by the complex structure of the plant cell wall. For production of liquid biofuel and biocatalysts Cavka *et al.,* (2011) studied the possibility to utilize fiber sludge, waste fibers from pulp mills and lignocellulose based biorefineries.

Table.1 Characteristics of xylanases from different microorganisms (Goswami and Pathak 2013)

Microorganism	pl	Molecular weight (kDa)	Optimum		References
			pH	Temperature (^{0}C)	
Bacteria					
Acidobacterium capsulatum	7.3	41	5	65	Inagaki *et al.,* 1998
Bacillus circulans WL-12	9.1	15	5.5-7	-	Esteban *et al.,* 1982
Bacillus stearothermophilus T-6	7,9	43	6.5	55	Khasin *et al.,* 1993
Bacillus polymyxa CECT 153	4.7	61	6.5	50	Morales *et al.,* 1995
Bacillus sp. strain K-1	-	23	5.5	60	Ratannaka-nokchai *et al.,*

					1999
Bacillus sp. NG-27	-	-	7, 8.4	70	Gupta *et al.*, 1992
Cellulomonas fimi	4.5-8.5	14-150	5-6.5	40-45	Khanna and Gauri 1993
Cellulomonas sp. N.C.I.M. 2353	8	22,33,53	6.5	55	Chaudhary and Deobagkar 1997
Staphylococcus sp. SG-13	-	60	7.5, 9.2	50	Gupta *et al.*, 2000
Thermoanaerobacterium sp. JW/SL-YS485	4.37	24-180	6.2	80	Shao *et al.*, 1995
Thermotoga maritima MSB8	5.6	40, 120	5.4, 6.2	92-105	Winterhalter and Liebel 1995
Fungi					
Aspergillus niger	9	13.5-14.0	5.5	45	Frederick *et al.*, 1985
Aspergillus kawachii IFO 4308	3.5-6.7	26-35	2-5.5	50-60	Ito *et al.*, 1992
Aspergillus sojae	3.5,3.75	32.7, 35.5	5, 5.5	60,50	Kimura *et al.*, 1995
Aspergillus sydowii MG 49	-	30	5.5	60	Ghosh and Nanda 1994
Cephalosporium sp.	-	30,70	8	40	Bansod *et al.*, 1993
Fusarium oxysporum	-	20.8,23.5	6	60,55	Christako-polous *et al.*, 1996
Geotrichum candidum	3.4	60-67	4	50	Radionova *et al.*, 2000
Penicillim purpurogenum	8.6, 5.9	33,23	7,3.5	60,50	Belancic *et al.*, 1995
Thermomyces lanuginosus DSM 5826	4.1	25.5	7	60-70	Cesar and Mrsa 1996
Trichoderma harzianum	-	20	5	50	Tan *et al.*, 1985
Trichoderma reesei	9,5.5	20,19	5-5.5, 4-4.5	45,40	Tenkanen *et al.*, 1992
Yeast		-	-		
Aureobasidium pullulans Y-2311-1	9.4	25	4.4	54	Li *et al.*, 1993

Cryptococcus albidus	-	48	5	25	Morosoli *et al.*, 1986
Trichosporon cutaneum SL409	-	-	6.5	50	Liu *et al.*, 1998
Streptomyces sp B-12-2	4.8-8.3	23.8,40.5	6-7	55-60	Elegir *et al.*, 1994
Streptomyces thermoviolaceus OPC-520	4.2,8	33,54	7	60-70	Tsujibo *et al.*, 1992
Streptomyces viridisporus T7A	10.2-10.5	59	7-8	65-70	Magnuson and Crawford 1997
Streptomyces sp. QG-11-3	-	-	8.6	60	Beg *et al.*, 2000a
Thermomonospora curvata	4.2-8.4	15-36	6.8-7.8	75	Stutzenberger and Bodine 1992

Table.2 Commercial Xylanase and their suppliers (Goswami and Pathak 2013)

S.No.	Enzyme	Commercial Supplier
1.	Ecopulp	Alko Rajamaki, Finland
2.	Cartazyme	Sandoz,Charlotte,N.C. and Basel,Switzerland
3.	Cartazyme HS 10, Cartazyme SR 10 Cartazyme PS10, Cartazyme 9407, Cartazyme NS10	Clarient, UK
4.	Irgazyme 40-4X/Albazyme 40-4X, Irgazyme-10A,Albazyme-10A	Genercor, Finland; Ciba Giegy, Switzerland
5.	VAI Xylanase	Voest Alpine, Austria
6.	Pulpzyme HA, HB and HC	Novo Nordisk, Denmark
7.	Ecopulp X-100,200, 200/4,TX-100,TX200 and Ecopulp XM	Rohn Enzyme 0Y;Primalco, Finland
8.	Xylanase	Meito Sankyo, Nogaya Japan
9.	Ecozyme	Thomas Swan, UK
10.	GS-35, HS70	Iogen, Canada
11.	Sanzyme X,PX and Alpelase F	Sankyo, Japan
12.	Enzeko xylanase	Enzyme Development,USA

Conclusion

Microbial Xylanases have great potential for industrial applications. Xylanase enzyme should be promoted in the food processing and pulp and paper industry to replace the (harsh) chemical used during the processing. Xylanase enzyme in combination with some other enzyme can provide better results for sustainable industrial processes.

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