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#### SOLID STATE CULTIVATION AND APPLICATION OF XYLANASE

Kianoush Khosarvi-Darani<sup>1</sup> and Dina Karamad<sup>2</sup>

Research Department of Food Technology, National Nutrition and Food Technology Research Institute, Faculty of Nutrition Sciences and Food Technology, Shahid Beheshti University of Medical Sciences, P.O. Box 19395-4741, Tehran, Iran. E- mail: <sup>1</sup>k.khosravi@sbmu.ac.ir, <sup>2</sup>dina.karamad@gmail.com

### ABSTRACT

Research for xylanase biosynthesis is an interesting area due to its important industrial application. This review paper serves as an overview of xylanase bioproduction and application as well as its producing microorganisms, substrates and process variables, to consider the future prospects of xylanases in biotechnological applications. Several approaches should be applied to overcome main limitations which inhibit widespread commercial and industrial application of this enzyme; low production yield and the high total cost.

Keywords: xylanase, producing microorganisms, process variables, substrates, solid state fermentation.

### INTRODUCTION

Plant biomass is a huge substrate on the earth in which consists of cellulose, hemicellulose and lignin, which should be hydrolyzed by acids or enzymes to lower molecular weight carbohydrates and finally to monomeric sugars (Yoonan and Kongkiattikajorn, 2004). Xylan, the polymer of xyloseis the main component of hemicellulose. This heteropolysaccharide can be used as substrates for microbial growth and production.

Hydrolysis of xylan to xylose is possible by acid or enzymatic methods. Hydrolysis by enzymes has main advantages of higher purityand lower chemical pollution problem. Xylose can be used for the production of useful biometabolites e.g. alcohols (ethanol, butanol, and xylitol) and single cell proteins. Production of purified xylanase and cellulose enzymes are reported on rice straw and rice husk (Dutta *et al.*, 2014). In this research, the amount of produced xylose and reducing sugars are estimated.

#### Xylanase chemistry

Xylanase as a heteropolysaccharideis a major component of cell walls of plant hemicelluloses. Endoxylanase randomly hydrolyses the main chain of xylan to form xylooligosaccharides, which are then degraded by xylanolytic enzymes such as xylosidase and arabinofuranosidases. Accessory enzymes, are able to cleave side chain groups of heteroxylan. The final hydrolysis products of xylan are xylose and oligosaccharides, which have potential industrial application in the foods, paper, agricultural industries, as well as pharmaceuticals, and renewable fuel (Sriyapai *et al.*, 2011; Heck *et al.*, 2006; He *et al.*, 2010). Based on the physicochemical properties and amino acid sequence similarities of their catalytic domains by hydrophilic cluster analysis, xylanases are classified into two glycoside hydrolase groups: family 10 (formerly family F, a high molecular mass >30 KDa and low isoelectric point) and family 11 (formerly family G, with low molecular mass <30kDa and high isoelectric point) (Coughlan *et al.*, 1993). Many xylanases belonging to family 11 are obtained from *Actinomycetes* (Sriyapai *et al.*, 2011; Callins *et al.*, 2005).

The high optimum temperature of xylanase and its alkaline optimal pH leads to its tremensdous potential for application of enzyme for special benefits e.g. bleaching of kraft pulps and other biotechnological processes (Mohana *et al.*, 2008; Lakshmi *et al.*, 2009).

#### Xylanase producing microorganism

The xylanase producing microorganisms are isolated form soil collected from decaying agricultural waste. Screening of xylanase producing bacteria should be carried out on xylancontaining medium (He *et al.*, 2010). Many isolates are reported as good producer of xylanase in solid state fermentation (Yang *et al.*, 2008; Yang *et al.*, 2006). Table 1 shows a list of xyla-nase producing fungi were grown on agricultural waste. Also in Table 2, different xylanase producers on several substrates in different conditions are listed.

Xylanase of *Acinetobacter junii* has been lyophilized to enhance practical applicability and storage stability (Lo *et al.*, 2010). *Kluyvera*  species strain OM3 isolated from spent mushroom substrate could produce a high level of cellulose - free xylanase (5.12 u/ml) with maximum activities at 70°C and pH 8. In this study, 100% and 71% activity has retained after incubation at 60°C and 70°C and maintain stability over a pH range of 5 to 9 (Xin et al., 2013). Kluvvera species is a good anaerobic bacterium which is capable of producing effective cellulase and xylanase and has high temperature and pH stability (Xin et al., 2013). Production of 41 KDa xylanase from Paenibacillus campinasensis is reported under various pH, temperature as well as alternative carbon and nitrogen sources. The results showed that the highest specific activity of xylanase in crude extract was obtained at 24 h, 37°C, pH 8. Xylanase activities of 56.8 % and 51. 9% were founded after 4 h incubation in pH 7 and 9 at 65°C, respectively (Ko et al., 2010).

*Thermomyces lanuginosus* is reported as producer of thermostable GF11 endo-xylanase encoded by XynA gene. *Escherichia coli* is also one of the most extensively used prokaryotic organism for the industrial production of enzyme because of its well- characterized genetics, and its ability to grow rapidly and at high density an inexpensive substrates (Le *et al.*, 2014).

There are very few reports showing the ability of the fungus to produce industrially important enzymes under nonsterile condition. Anyway, *Promicronospora sp* is capable of producing xylanase from rice straw in nonsterile fermentation (Kumar *et al.*, 2011).*Trichoderma* sp. can secrete large amounts of efficient xylanase for industrial production. (He *et al.*, 2010; Wong *et al.*, 1992).Xylanase production synthesized by *Pleurotus eryngii*. Xylanase activity was checked by using oat-spelt xylan as a substrate and the reducing group was detected through dinitrosalicylic assay method (Altaf *et al.*, 2010).

The selective production of xylooligosaccharides is conducted by partially purified xylanase from *Aspergillus foetidus* MTCC 4895 (Chapla *et al.*, 2012).

In recent years, many cellulolytic bacteria have been recognized for their ability to hydrolyze lignocellulosic materials for bioenergy production. Those cellulolytic bacteria include the genera of *Bacillus, Ruminococcus, Streptomyces, Bacteroides* and *Cellulomonas* (Lo *et al.*, 2010; Gessesse *et al.*, 1999; Rapp *et al.*, 1986).

**Solid state fermentation (SSF) in xylanase production:** SSF is the growth of organisms on moist substrates in the absence of free- flowing water. The use of SSF for the production of enzymes and other products has many advantages over submerged fermentation (Gessesse *et al.*, 1999). SSF do not need for complex machinery and sophisticated control system with less volume of liquid for product recovery, which leads to reduced cost of downstream processing and subsequent waste treatment. Also, other advantages of this system are usability of simple and cheap media for the fermentation and lower energy demand, (often a high product yield) and lower risk of contamination due to the inability of most contamination to grow in the absence of free flowing water (Gessesse *et al.*, 1999).

A large number of fungal species are known to grow well on moist substrates in the absence of free- flowing water whereas many bacteria are unable to grow under this condition. As a result, most studies involving SSF have been conducted by using fungi.

SSF has interest for production of xylanase similar to many other enzymes due to lower operation costs and energy requirements, as well as simple plant and equipment projects in compared to submerged fermentation (Heck *et al.*, 2006; Heck *et al.*, 2005; Khosravi Darani *et al.*, 2008). Xylanase production by *P. thermophile J18* was carried out in SSF using wheat straw as substrate (Yang. *et al.*, 2008). Also, xylanase production by a newly isolated *Aspergillus terreus* MTCC866has been optimized using palm fiber in SSF (Table1) (Lakshmi *et al.*, 2009; Yang *et al.*, 2008).

## Xylanase applications

Research for xylanase biosynthesis is an interesting area due to its important industrial application e.g. improving the digestibility of animal feed, bleaching of kraft pulp, bioconversion of lignocellulosic waste into their constituent sugars, clarification of juices, (Mohana et al., 2008) as well as extraction of plant oils, extracellular polymeric substances, improving nutritional value of silage, green feed, coffee, starch and as bleaching agents in pulp and paper industry (Lakshmi et al., 2009). However, low production yield and the high total cost inhibit widespread commercial and industrial application of this enzyme (Lo et al., 2010; Rapp et al., 1986). As it was mentioned before, xylanase is able to hydrolyze the water soluble arabino-xylanase. This reaction leads to the release of lower molecular weight fraction with improved impact on specific volume expansion capacity and firmness of bread (Primo-Martin et al., 2005). According to this 0.01% (w/w), xylanase led to

approximately 19.6% decline of the total phenolic content (Yang *et al.*, 2014).

The potential application of xylanases also includes reducing sugars by hydrolysis of lingocellulosic biomass. These sugars are further fermented for the biofuel production (e.g., ethanol, butanol). (Xin *et al.*, 2013). In compared to aerobic fungi and bacteria, few investigations are reported on hydrolytic enzymes by anaerobic bacteria (Bajpai 1996).

Browning is a problem of wheat products (e.g. wheat dough, chapatti's, pasta, and fresh oriental noodles) (Demeke et al., 2001) during storage, transport and marketing (Baik et al., 1995). This phenomenon is due to the activity of polyphenol oxides (PPO) and peroxidase (PO) which catalyze the oxidation of free, reduced phenolic compounds to pigment, forming elements (Kruger et al., 1992) (with an exception to the color resulting from carotenoids (Francis, 2000). Reported approaches to overcome browning focus on inactivating the PPO, the PO or eliminating the substrates of these enzymes. Glucose oxidase (GOX) was reported as a dough bleaching enzyme because of it's  $\beta$ -carotene degradation capacity (Gélinas et al., 1998). Apart from GOX, xylanase was also commonly used for improving the properties of whole wheat dough (Bonet et al., 2006; Primo Martin et al., 2005; Steffolani et al., 2012).

One of the exciting application of xylanases is the production of xylo- oligosaccharides (XOS) from many agrowastes such as concorb (also known as maize cores) (Anand *et al.*, 2013). These XOS exhibit prebiotic effect when consumed as a part of the diet (Driss *et al.*, 2014).

## Results

Xylanases can be applied for waste management and production of many useful products. Production of oligosaccharides can be further considered as functional food sweeteners and additives. To meet the needs of industry, more attention of research should be focused on the increasing ability of to hydrolyze soluble or insoluble xylans as well as improved enzyme stability in different temperature pH, and inhibitors. Genetic engineering and recombinant DNA technology may have an important role in the large-scale expression of xylanases. No individual enzyme may meet all of the requirements of the feed and food industries. Moreover, as industrial applications require cheaper enzymes, the elevation of expression levels seems crucial to ensure the sustainability of the process.

## Conclusion

Agricultural wastes possess large quantities of hemicellulose (e.g. 25% in rice straw). The process for bioconversion of them to value-added products e.g. biofuels and chemicals are receiving increased attention. Such renewable resources are required for reduction of petroleum consumption. This is the best way for hydrolysis of agro-industrial wastes inan enzymatic solution.

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Microorganisms	Substrate	Xylanase activity	References		
······					
Aspergillus terreus	Palm oil fiber	115269u/g	Lakshmi et al., 2009		
(MTCC8661)					
Thermomyces lanuginosus	Sorghum straw	48000u/g	Bakri et al., 2003		
Trichoderma	Wheat bran and wheat	592.7 u/g	Azin et al., 2007		
longibrachiatum	straw				
Aspergillus niger BO3	1.5% wheat bran+ 2.4%	996 u/ml	Dobrev et al., 2006		
	corn cobs+0.6% malt sprout				
Fusarium oxysporum	2% corn cobs	245 u/ml	Kekos et al., 1996		
Pseudomonas sp.WLUNO24	7% wheat bran	450 u/ml	Xu et al., 2005		
Aspergillus terreus mutated	1% xylan, 0.5% peptone,	42.2 u/ml	Geweely et al., 2006		
strain	0.5% yeast extract, 0.1%				
	KH <sub>2</sub> PO <sub>4</sub> , 0.05% MgSO <sub>4</sub>				

Table-1: Comparison of xylanase production from other fungi strains grown on agricultural waste

Table - 2: Comparison of different xylanase producers on several substrates in different condi	tion
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No ·	Microorganism	Substrate	Enzyme activity	Production rate	Productivity	Heat Resistance (C)	Optimal pH	Culture method	References
1	Streptomyces thermocarboxud us subsp MW8	1%(w/v) soytone+ 1% (w/v) NaCl, and 0.5%(w/v) xylan	35714 u/g	96 hours	372.02 u/g/h	50	7	Solid-state fermentation	Chi <i>et al.</i> , 2013
2	Bulkholderia sp. DMAX	Distillery spent wash	5200- 5600 u/g	15 hours	346.66- 373.33 u/g/h	50	8.6	Solid-state fermentation	Mohana <i>et al.</i> , 2008
3	Bacillus stearothermophil us ATCC12980 (Rockville Co.)	Xylan, 10g/ polypepton, 20g/ yeast extract, 2.5g/ Ammonium nitrate, 2g/ phosphate mono- potasic, 2g/ MgSO <sub>4</sub> .H <sub>2</sub> O, 1g/ MnSO <sub>4</sub> , 0.05g	8700 u/g	48 hours	181.25 u/g/h	60	7	Solid-state fermentation	
4	Paecilomyces thermophile J18	Wheat straw	18580 u/g	168 hours	110.59 u/g/h	50		Solid-state fermentation	Yang <i>et</i> <i>al.</i> , 2006
5	Aspergillus niger P 602	Corncob Wheat Straw	6320u/g	64 hours	98.75 u/g/h	55	5	Solid-state fermentation	Gawande <i>et al.</i> , 1999
6	Streptomyces albus & Streptomyces chromofuseus	Rice straw pulp	4301 u/g	48 hours	89.60 u/g/h	28	7.2	Solid-state fermentation	Rifaat <i>et</i> <i>al.</i> , 2005
8	Paenibacillus Campinasensis BL11	Kraft pulp mill	2939 u/g	24-48 hours	61.22- 122.45 u/g/h	37	8	Solid-state fermentation	Ko <i>et al.</i> , 2010
9	Aspergillus niger	Cottonseed oil	1761 u/g	36 hours	48.91 u/g/h	40	4.6	Solid state fermentation	Wang <i>et</i> <i>al.</i> , 2006
10	Bacillus Stearothrmophil uss SDX	Wheat bran	3446 U/g	72 hours	47.86 u/g/h	37	7	Solid state fermentation	Dhiman <i>et</i> al., 2008
11	Aspergillus niger KK2	Straw rice	5071u/g	120hours	42.25 u/g/h	50	4.8	Solid state fermentation	Kalogeris et al., 1999
12	Aspergillus awamori	Sugarcane	2500 II I/g	60 hours	41.66 u/g/h	30		Solid state	Lemos <i>et</i>
13	Aspergillus niger	Corncob	2989	72	41.51	55	5	Solid state	Gawande <i>et</i>
14	N218 Thermoascuc	Straw wheat	u/g 5465u/g	168	u/g/h 32.52	50	5	Solid-State	al., 1999 Topakaset
15	aurantiacus Aspergillus	Corncob	3065u/g	hours 96hours	u/g/h 31.92	50	5.3	Fermentation Solid-State	<i>al.</i> , 2003 Wu <i>et al.</i> ,
16	Bacillus circulans BL53	Fibrous soybean residue	3700 u / g	120 hours	u/g/n 30.83 u/g/h	60	7	Strong inhibitors: Hg, SDS Slight: Na, Cu Fe, Zn, g, Ca, PHMB General :Ions react with sulphydryl group e.g. Hg <sup>+</sup>	Heck <i>et</i> <i>al.</i> , 2005
17	Aspergillus niger CCUG33991	wheat Straw & bran	1465u/g	50 hours	29.30u/g/h	40	5	Solid state fermentation	Shahi <i>et</i> <i>al.</i> , 2011
18	Aspergillus niger LPB 326	Sugarcane bagasse +soybean meal	1937 IU/g	96 hours	20.17 u/g/h	30		Solid state fermentation	Maciel <i>et</i> <i>al.</i> , 2008

19Deciding \$1507What has here (1) \$	10	Davillua SV204	Wheat bron	1157	70	16.06	55	7	Solid state	1
10 $(y_1), (x_1)(x_2), (y_1)(x_2), (y_2), (y_1)(x_2), (y_2), (y_1)(y_2), (y_2), (y_1)(y_2), (y_2), (y_2), (y_1)(y_2), (y_2), (y_2), (y_2), (y_1)(y_2), (y_2), (y_2), (y_2), (y_2), (y_1)(y_2), (y_2), (y_2), (y_2), (y_1)(y_2), (y_2), (y_$	19	Ducilius STSUA	wheat drain $(\pi/L)$ , $K$ LIDO	1157	12	10.00	33	(1 10)	Solid state	
1, 180, 1, 1, 0, 1,			$+$ (g/L). $\mathbf{N}_2 \mathbf{\Pi} \mathbf{P} \mathbf{O}_4$ , 1: NoCL 2:	u/g	nours	u/g/n	(40-73)	(4-10)	lermentation	
20Appenditus funiçates $F - 993$ White con flour $u'g$ 72 $u'g$ 48 			$M_{\alpha}$ SO 74 O							
20Aspergillus funigates $F-993$ White corn flour u'g720 u'g48 hours15 u'g/h50 (3.5- (3.5-)3.5 (3.5-)Solid state fermentationFadeler al., 201421Aspergillus fixederi Fxn 1Wheat Straw u'g1024 hours72 u'g/h14.22 u'g/h506Solid state fermentationFadeler al., 200222Thermoascue arrantizcusBagasse arrantizcus2700u'g u'ml240 hours11.25 u'g/h506Solid state fermentationPangioto uet al., 200223Streptomyces sp (strain 1b 240)Tomato pomace u'ml1447 hours240 u'ml600 hours6.5Submerge (5-9)Submerge stateRawakle bet al., 200224Bacillus subtilis NS7Nutrient broth uppl. With ylan, u'ml NS7377 u'ml hours6.5Submerge (5-9)Submerge stateSubmerge al., 201225Bacillus mojavensisDat husk + yeast spelt xylan, 5g' pepton, 5g' k_HPO, 1g/ MRL724.9 MRL737 u'ml/h hours33 u'ml/h30 (25-37)5Submerge stateSaleemer al., 201126Poliporus gl (NHJ)SQD, D.014/ D.05/RSO, 0.016/278.52216 hours1.35 u'ml/h30 (25-37)5Submerge stateSaleemer al., 201427Lentius pigrinus MRL6gl_1.7Netous pepton, 0.57 u'ml278.52216 hours1.28 u'ml/h30 (25-37)5Submerge stat			$10300_{4.711_{2}0}$							
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Imagency 1 > 100 $u^{2}g$ India 3 $u^{2}g$ $(50 \text{ GS})$ $(50 \text{ GS})$ $(51 \text{ GS})$ $(11, 200)$ 21Aspergillus fischer Ern 1Bagasse $2700u'g$ $u'gh$ $14.22$ hours $14.22$ $u'gh$ $50$ $6$ Solid state fermentation $u^{2}$ $u'gh$ 22Thermoaxcue sp(strain b 24D)Bagasse $2700u'g$ $u'ml$ $240$ hours $11.25$ $u'gh$ $50$ $5$ Solid-state fermentationPanagioto $2003$ 23Streptomyces sp(strain b 24D)Tomato pomace $u'ml$ $1447$ hours $240$ $u'ml$ $6.2$ $u'mlh$ $6.5$ $statefermentationSubmergestatefermentationRawashdetet al.200524Bacillus subtilissuppl. With ylan,sobean meal,NS7Nutrient brothsuppl. With ylan,sobean meal,NS7533u'ml72hours447u'ml/h6.5u'ml/hSubmerge(5-9)8amsaleal., 201225BacillusmojavensisDat husk + yeast249.30848u'ml4.36hours55u'ml/h9(35-65)Submerge(7-11)8alaseleal., 201226Poliporuselimentsy'_{L} (NH,2SO,1.4 (gO, 7H_Q),0.057 (gO, 7H_Q),0.014 / COCL_{2},0.02/MnSO_{2}, 0.016)2161.4 (gO, 7H_Q),0.014 / COCL_{2},0.02/MnSO_{2}, 0.016)2161.4 (gO, 7H_Q),0.014 / COCL_{2},0.02/MnSO_{2}, 0.016)2161.4 (gO, 7H_Q),0.014 / COCL_{2},0.02/MnSO_{2}, 0.02/MnSO_{2},0.016)2161.4 (gO, 7H_Q),0$	20	fumigates F-993	white com nour	1/σ	hours	1.5 11/g/h	(50-65)	(3.5-	fermentation	al 2014
21Aspergillus fischeri Fan 1Wheat Straw $u'g$ 1024 hours72 		junugutes i 775		" B	nouis	u g n	(50 05)	6.5)	lennenauon	<i>un.</i> , 2011
Internolascue aurantiacusBagase Bagase2700u'g 200'ghoursu'gh 240IncFermentation fermentation $d_1, 2002$ 23Streptomyces sp(strain 1b 24D)Ionato pomace i/ml1447 aurantiacus240 hours6.02 u'ml/h e**min**6.0 ementation6.5 submerge state fermentationSubmerge aurashout 200524Bacillus subtilis NS7Nutrient broth suppl. With ylan, NGC1, and KHPO4353 u'ml72 hours4.9 hours37 u'ml/h6.5 (5-9)Submerge state fermentationBasalet al., 200525Bacillus mojavensis spelt vylan, 5g/ K-HPO4, 1g/ D, 0.37cS04, 7H_2, 0.1g249, 308 u'ml/h48 hours4.36 u'ml/h55 (35-65)9 (7-11)Submerge state fermentationAkhavan Sepahyer al., 201226Poliporus caliauts 1.4/MgS04, 7H_2 D, 0.014 / COC1, 0.002/ MRL7292.8 u'ml216 hours1.35 u'ml/h30 (25-37)5 submerge state fermentationSaleemer al., 201427Lentinus pigrinus MRL6J.(NH4)SO4, H2 u'ml u'ml278.52 al., 2161.28 hours30 u'ml/h5 submerge state fermentationSaleemer al., 201428Phanerochaete sordid MRL3g'L. Proteous appingenus MRL6278.52, N27 al., 202 aca(2, 0.3/Ween al., 2014216 hours1.28 al.30 u'ml/h5 al.Submerge state fermentationSaleem et al., 201429Lentinus appine, 0	21	Aspergillus	Wheat Straw	1024	72	14.22	50	6	Solid state	Weber et
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $		fischeri Fxn 1		u/g	hours	u/g/h			fermentation	al., 2002
aurantiacushours $u'g/h$ fermentation $uet al., 2003$ 23Streptomyces sp.(strain 1b 2003Fomato pomace1447 u/ml240 hours6.02 u/ml/h6.0 u/ml/h6.5Submerge state fermentationRawashde het al., fermentation24Bacillus subtilis NS7Nutrient broth soybean meal, NS7353 suppl. With ylan, and X1LyPQ,72 hours4.9 u/ml/h37 u/ml/h6.5Submerge state fermentationBansalet al., 201225Bacillus mojavensisat husk + yeast extract, 5g/ pet twylan, 5g/ pet twylan, 5g/ pet twylan, 5g/ pet twylan, 5g/ pet twylan, 2g/, 31PO, 1g/ MRL74.9 pol, 31FeSQ, to 0.14 / COCl_2, 0.014 / COCl_2, 0.02/ MnSQ, 0.06/ ZnRSQ, 7H-Q, D.014 / COCl_3, 0.05/ ZnRSQ, 7H-Q, D.014 / COCl_2, 0.02/ MnSQ, 0.016216 thours1.35 thours30 u/ml/h5Submerge state fermentationSaleem et al., 201427Lentinus pigrinus MRL6J.Proteous 1.44 gSQ, 7H-Q, D.014 / COCl_3, D.014 / COCl_2, 0.02/ MnSQ, 10.16/ ZnRSQ, 7H-Q, D.014 / COCl_3, 0.02/ ZnRSQ, 7H-Q, D.014 / COCl_3, 0.02/ CaCl_2, 0.37/ KH-PO, 0.27 CaCl_2, 0.37/ KH-PO, 0.27 CaCl_2, 0.37/ KH-PO, 0.27 CaCl_2, 0.37/ w/ml216 hours1.28 u/ml/h30 (25-37)5Submerge state fermentationSaleem et al., 201428Phanerochaete sordid MRL3pl.Proteous p.027MnSQ, 10.37 ZnRSQ, 7H-Q, D.014 / COCl_3, D.027MnSQ, 10.47 ZnRSQ, 7H-Q, D.014 / COCl_3, D.027MnSQ, 10.47 ZnRSQ, 7H-Q, Zn	22	Thermoascuc	Bagasse	2700u/g	240	11.25	50	5	Solid-state	Panagioto
23Supplementation200323Streptomyces sp.(strain 1b 24D)Fomato pomace1447 u'ml240 hours6.02 u'ml/h **min**6.5Submerge fermentationRawashde her al., 200524Bacillus subtilis NS7Nutrient broth suppl. With ylan, avpbean meal, NS7353 suppl. With ylan, u'ml hours72 hours4.9 powr37 (37-70)6.5 (5-9)Submerge state fermentationBansalet al., 201225Bacillus mojavensisDat husk + yeast extract, 5g/ out wiml splt xylan, 5g/ peptrone, 5g/ K_HPO4, 1g/ MgSO4, 71B, 0, 1g48 hours4.36 u'ml/h55 (35-65)9 (7-11)Submerge state fermentationAkhavan Sepahyet al., 201126Poliporus caliatus caliatus pigrinus MRL61.4/(MgSO4, 71B_2 U/M1/JSO4, D.05/ZnSO4, 71B_2 D, 0.014 / COC12, 0.02/ MnSO4, 0.05/ ZnSO4, 71B_2 D, 0.014 / COC12, 0.02/ CaCL_20.3/tween sordid MRL327.27 eptrone, 0.57 u'ml hours216 hours1.28 u'ml/h30 (25-37)5 Submerge state fermentationSaleem et al., 201428Phanerochaete sordid MRL3g/L.(Pitq.)20, u'ml petrone, 0.5/ u/ml1216 hours1.25 u'ml/h30 (25-37)5 Submerge state fermentationSaleem et al., 201429<		aurantiacus	C C	Ũ	hours	u/g/h			fermentation	uet al.,
23Streptomyces sy (strain 1b 24D)Tomato pomace u'ml1447 u'ml240 hours6.02 u'ml/h **min**606.5Submerge state fermentationRawashde het al., 200524Bacillus subtilis NS7Nutrient broth suppl. With ylan, NS7Nutrient broth suppl. With ylan, NaCL, and KH-PO435372 hours4.9 u'ml/h37 (37-70)6.5 (5-9)Submerge state fermentationBansalet al., 201225Bacillus mojavensisDat husk + yeast petrone, 5g/ K-HPO4, 1g/ MgS0, 7H_2, 0, 0.03/ EQ (AMgS0, 7H_2, 0, 0.014 / COCl3, 0.061240.08 u'ml hours48 u'ml/h4.36 u'ml/h55 (35-65)9 (7-11)State fermentationAkhavan Sepahyet al., 201126Poliporus MgRL7g/L (NH,02SO4, D.03/FESO4, 0.061228, U/ML7216 hours1.35 u'ml hours30 u'ml/h5 (25-37)Submerge state fermentationSaleemet al., 201427Lentinus pigrinus MRL6g/L (NH,02SO4, D.03/FESO4, 0.05/ LA(SO4,7H;0, 0, 0.016)278.52, u'ml D.03/FESO4, 0.05/ LA(SO4,7H;0, 0, 0.014 / COCl3, 0.05/ LA(SO4,7H;0, 0, 0.02/ CaCl2,0.03/Ween Sol,7H;0, 0, 0.014 / COCl3, 0.02/ CaCl2,0.03/Ween Sol, 20,02/ CaCl2,0.03/Ween Sol, 20,02						_				2003
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	23	Streptomyces	Tomato pomace	1447	240	6.02	60	6.5	Submerge	Rawashde
24D)****fermentation200524Bacillus subtilisNutrient broth353724.9376.5SubmergeBansalerNS7NS7Soybean meal, soybean meal, NaCL, and KH_PO_4u'ml/h376.5SubmergeBansaler25Bacillus mojavensisOat husk + yeast spelt xylan, 5g/ peptone, 5g/ K-HPO_4, 1g/ MgS0_7H_5O_1g249.308484.36559Submerge (7-11)Akhavan26Poliporus caliatus (altus)[1 (NH4)2SO4, 0, 0.3/rESO4, 0.05/ ZnSO4, 7H_2 O, 0.014 / COCl2, 0.02/ MRSO4, 016)292.82161.35 u'ml305Submerge state fermentationSaleemet al., 201127Lentinus pigrinus MRL6g/L (NH4)2SO4, 1.4/gSO4, 1/H2, O, 0.3/rESO4, 0.05/ ZnSO4, 7H_2, O, 0.014 / COCl2, 0.02/ MRSO4, 0.05/278.52 Lentinus pigrinus MRL6218.52 Lentinus pigrinus MRL6278.52 Lentinus pigrinus MRL6278.52 Lentinus Planerochaete sordid MRL3271.72 Lentinus Planerochaete sordid MRL3272.77 Lentinus Planerochaete sordid MRL3272.77 Lentinus HapO4, 0.2/ CaCL_30.3/tween state216 Lentinus Lift1.25 Lentinus Lift30 Lentinus Lift5Submerge state gla., 201428Phanerochaete sordid MRL3g/L :Proteous Planerokaete solo // Lift272.77 Lift216 Hours1.25 Lift30 Lift5Submerge state fermentationSaleem er al., 201429Aspergillusniger<		sp.(strain 1b		u/ml	hours	u/ml/h			state	h <i>et al.</i> ,
24       Bacillus subtilis       Nutrient broth       533       72       4.9       37       6.5       Submerge       Bansaler         387       NS7       suppl. With ylan,       u/ml       hours       u/ml/h       (37-70)       (5.5       Submerge       Bansaler         25       Bacillus       Oat husk + yeast       249.308       48       4.36       55       9       (7-11)       Submerge       Akhavan         26       Bacillus       Oat husk + yeast       249.308       44       hours       u/ml/h       (35-65)       9       Submerge       Akhavan         26       Poliporus       grl. (NHq)2SQ4,       129       292.8       216       1.35       30       5       Submerge       Saleemet         acilatus       I.4/MgSQ4,7H2,       0,0.3/FeSQ4,       292.8       1/ml       hours       u/ml/h       (25-37)       5       Submerge       Saleemet         al., 2014       COCl3, 0.02/       MRL7       0,0.3/FeSQ4,       278.52       216       1.28       30       (25-37)       5       Submerge       Saleem et         al., 2014       COCl3, 0.02/       MRL6       I.4/g SQ6,7H2,       µ/ml       hours       1/ml       30       (25-37) <td></td> <td>24D)</td> <td></td> <td></td> <td></td> <td>**min**</td> <td></td> <td></td> <td>fermentation</td> <td>2005</td>		24D)				**min**			fermentation	2005
NS7       suppl. With ylan, µ/ml soybean meal, NaCL, and KH_POA,       hours       µ/ml hours       (37-70)       (5-9)       state fermentation       al., 2012         25       Bacillus       Dat husk + yeast       249.308       48       hours       µ/ml hours       (35-65)       9       Submerge       Akhavan         26       Poliporus caliatus       g/L (NH_4)2SO4, MRL7       12/       292.8, 0.03/FeSO4, 0.016/       216       1.35       30       5       Submerge state       Saleemet al., 2014         27       Lentinus       g/L (NH_4)2SO4, 0.014 / COCl <sub>2</sub> , 0.02/ MnSO4, 0.016       278.52       216       1.28       30       5       Submerge state       Saleem et al., 2014         27       Lentinus       g/L (NH_4)2SO4, 0.014 / COCl <sub>2</sub> , 0.02/ MnSO4, 0.016       278.52       216       1.28       30       5       Submerge state       Saleem et al., 2014         28       Phanerochaete       g/L .Proteous       272.7       216       1.25       30       5       Submerge state       Saleem et al., 2014         28       Phanerochaete sordid MRL3       g/L .Proteous       272.7       216       1.25       30       5       Submerge state       Saleem et al., 2014         29       Aspergillusniger       2.56/ 3/9/ 3.5%       39.	24	Bacillus subtilis	Nutrient broth	353	72	4.9	37	6.5	Submerge	Bansal <i>et</i>
Soybean meal, NaCL, and KH2PO4     Soybean meal, KH2PO4     Ashavan Sepalyzet       25     Bacillus mojavensis     Oat husk + yeast synet xylan, 5g/ peptone, 5g/ K_2HPO4, 1g/ MgS04,7H2,01g     249.308     48 hours     4.36     55     9     Submerge     Akhavan Sepalyzet       26     Poliporus     JL (NH4)2SO4, 0.03/FSO4, 7H2, 0.0.014/     12.8     216     1.35     30     5     Submerge state     Saleemet       27     Lentinus pigrinus MRL6     J.4/ gSO4, 7H2, 1.4/ gSO4, 0.05/ ZnSO4, 0.05/ ZnSO4, 7H3, 0.016)     278.52     216     1.28     30     5     Submerge state     Saleem et al., 2014       28     Phanerochaete sordid MRL3     gPtone, 0.5/ mea, 0.3/ KH2PO4, 0.2/ CaCL3, 0.3/tween a0.02     272.7     216     1.25     30     5     Submerge state     Saleem et al., 2014       29     Aspergillusniger     25% / 3% / 3.5%     89.07     72     0.54     37     5.5     Submerge state     Robl et al., 2015		NS7	suppl. With ylan,	u/ml	hours	u/ml/h	(37-70)	(5-9)	state	al., 2012
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			soybean meal,						fermentation	
25Bacillus mojavensisCH <sub>2</sub> PO <sub>4</sub> 249.308 u/ml spelt xylan, 5g/ peptone, 5g/ K_HPO <sub>4</sub> , 1g/ MgSO <sub>4</sub> ,7H <sub>2</sub> O,1g4.36 u/ml hours55 u/ml hours9Submerge (7-11)Akhavan Sepahyet atl.26Poliporus caliatusgL (NH <sub>4</sub> )2SO <sub>4</sub> , 292.8 0, 0.3/FeSO <sub>4</sub> , 0, 0.014/ COCl <sub>2</sub> , 0.02/ MnSO <sub>4</sub> , 0.016)216 hours1.35 u/ml hours30 u/ml/h5 (25-37)Submerge state fermentationSaleemet al., 201427Lentinus pigrinus MRL6gL (NH <sub>4</sub> )2SO <sub>4</sub> , 278.52 (1.4' gSO <sub>4</sub> , 7H <sub>2</sub> O, 0.03/FeSO <sub>4</sub> , 0.05/ZnSO <sub>4</sub> , 7H <sub>2</sub> O, 0.014/ COCl <sub>2</sub> , 0.02/ MnSO <sub>4</sub> , 0.016)216 thours1.28 u/ml hours30 u/ml/h5 Submerge state fermentationSaleemet al., 201427Lentinus pigrinus MRL6gL (NH <sub>4</sub> )2SO <sub>4</sub> , 278.52 th (9O, 20/MnSO <sub>4</sub> , 0.03/FeSO <sub>4</sub> , 0.05/ ZnSO <sub>4</sub> , 7H <sub>2</sub> O, 0.014 / COCl <sub>2</sub> , 0.02MnSO <sub>4</sub> , 0.02/MnSO <sub>4</sub> , 0.016216 thours1.28 u/ml hours30 u/ml thours5 submerge state fermentationSaleem et al., 201428Phanerochaete sordid MRL3gL (Proteous petone, 0.5/ u/ml KH <sub>2</sub> PO <sub>4</sub> , 0.2/ CaCL <sub>2</sub> O, 3/Ween 80, 0.2)216 u/ml Hours1.25 u/ml/h30 cliptical solution5 submerge state fermentationSaleem et al., 201429Aspergillusniger bagasse2.5% / 3%/3.5% bagasse90.7 u/ml72 hours0.54 u/ml/h37 cliptical cliptical solutical solutical solutical solutical5.5 submerge solutical solutical sol			NaCL, and							
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	25	D 11	$KH_2PO_4$	240.200	40	1.26	5.5	0	G 1	411
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	25	Bacillus	Oat nusk + yeast	249.308	48 hours	4.30	33	9	Submerge	Aknavan
26Poliporus caliatus MRL7yl. (NH <sub>4</sub> )2SO <sub>4</sub> , 292.8 (V,HQSO <sub>4</sub> , 7H <sub>2</sub> , 1g) 		mojavensis	extract, Sg/ Oat	u/1111	nours	u/1111/11	(55-65)	(/-11)	formontation	
26Poliporus (24) (24) (24) (24)292.8 (24) (24)216 hours1.35 u/ml/h30 (25-37)5Submerge state fermentationSaleemet al., 201426Poliporus (25-37)1.4/MgSQ4, 7H2 (25-37)u/ml hours1.35 u/ml/h30 (25-37)5Submerge state fermentationSaleemet al., 201427Lentinus pigrinus MRL6g/L.(NH4)2SO4, (25-37)278.52 (25-37)216 u/ml hours1.28 u/ml/h30 (25-37)5Submerge state fermentationSaleem et al., 201427Lentinus pigrinus MRL6g/L.(NH4)2SO4, (25-37)278.52 (25-37)216 u/ml hours1.28 u/ml/h30 (25-37)5Submerge state fermentationSaleem et al., 201428Phanerochaete sordid MRL3g/L. Proteous peptone, 0.5/ urea, 0.3/ KH2PO4, 0.2/ (23-20, 3)tween272.7 u/ml Hours216 u/ml/h1.25 u/ml/h30 (25-37)5Submerge state fermentationSaleem et al., 201429Aspergillusniger Sugarcane pagasse2.5% / 3%/ 3.5% by 3% 3.5%39.07 u/ml hours72 u/ml/h0.54 u/ml/h37 (25-32.5)5.5 (5-6.5)Submerge state fermentationRobl et al., 2015			pent xylall, 5g/						rennentation	<i>ai.</i> , 2011
Image of the second			K <sub>2</sub> HPO <sub>4</sub> 1g/							
26       Poliporus caliatus       Poliporus L(NH4)2SO4, MRL7       292.8 u/ml       216 hours       1.35 u/ml/h       30 (25-37)       5       Submerge state fermentation       Saleemet al., 2014         27       Lentinus pigrinus MRL6       /L.(NH4)2SO4, 0.05/ZnSO4,7H2 O, 0.014 / COCl2, 0.02/ MnSO4, 0.016)       278.52 u/ml       216 hours       1.28 u/ml/h       30 (25-37)       5       Submerge state fermentation       Saleemet al., 2014         27       Lentinus pigrinus MRL6       /L.(NH4)2SO4, 1.4/gSO4,7H2O, 0.3/FeSO4, 0.05/ ZnSO4,7H2O, 0.014 / COCl2, 0.02/MnSO4, 0.016)       278.52 u/ml       216 hours       1.28 u/ml/h       30 (25-37)       5       Submerge state fermentation       Saleem et al., 2014         28       Phanerochaete sordid MRL3       g/L. Proteous peptone, 0.5/ urea, 0.3/ KH2PO4, 0.2/ CaCL2,0.3/tween 80, 0.2)       272.7 u/ml       216 Hours       1.25 u/ml       30 (25-37)       5.5 (5-6.5)       Submerge state fermentation       Saleem et al., 2014         29       Aspergillusniger       2.5% / 3% / 3.5% Sugarcane bagasse       39.07 u/ml       72 hours       0.54 u/ml/h       37 (25-32.5)       5.5 (5-6.5)       Submerge state fermentation       Robl et al., 2015			$M_{\sigma}SO_{4}, Tg$							
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28       Phanerochaete sordid MRL3       g/L :Proteous peptone, 0.5/ urea, 0.3/ KH <sub>2</sub> PO <sub>4</sub> , 0.2/ CaCL <sub>2</sub> ,0.3/tween -80, 0.2)       272.7 u/ml       216 Hours       1.25 u/ml/h       30 (25-37)       5       Submerge state fermentation       Saleem et al., 2014         29       Aspergillusniger       2.5% / 3%/ 3.5%       39.07 u/ml       72 hours       0.54 u/ml       37 (25-32.5)       5.5 (5-6.5)       Submerge state fermentation       Robl et al., 2015			$0.02/MnSO_4$ ,							
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29     Aspergillusniger     2.5% / 3%/ 3.5%     39.07     72     0.54     37     5.5     Submerge     Robl et       al., 2015		soraia MIKLS	$\frac{1}{1}$	u/1111	nours	u/1111/11	(23-37)		fermentation	<i>ai.</i> , 2014
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Sugarcane bagasse			concentration	u/ml	hours	u/ml/h	(25-32.5)	(5-6.5)	state	al., 2015
bagasse			Sugarcane				()	(0 0.0)	fermentation	, =010
			bagasse							



Figure - 1: Xylanase production Flowchart (modified from Shahi et al., 2011)