

Original Research Article

Purification and Characterization of Thermostable Alkaline Xylanase by *Aspergillus terreus* from elephant dung

ABSTRACT

Aims: Purification and characterization of xylanase by *Aspergillus terreus* isolated from elephant dung.

Study design: Xylanase enzyme produced by *A. terreus* was extracted from the fermented solid medium and purified using chromatographic techniques. The purified enzyme was characterized for physico-chemical and kinetic properties.

Place and Duration of Study: Experiments were performed at the School of Biotechnology, Devi Ahilya University, Indore, INDIA and Maharaja Ranjit Singh College of Professional Sciences, Indore, INDIA, between June, 2019 and September, 2021.

Methodology: The enzyme was extracted and purified using ammonium sulphate fractionation, ion exchange chromatography using DEAE cellulose and gel filtration chromatography (GFC) using Sephadex G-200. The molecular weight of the purified enzyme was determined using native poly acrylamide gel electrophoresis (Native PAGE) and sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE). The purified enzyme was characterized to determine pH and temperature optima. Thermostability, pH stability and substrate kinetics were studied for purified xylanase

Results: The alkali-thermo xylanase of *Aspergillus terreus* was purified to 14.6-fold with a 39.48% recovery through IEC on DEAE-cellulose and GFC using Sephadex G-200. The purified enzyme had a specific activity, 111.6 U/mg. The SDS-PAGE revealed that the enzyme was monomeric with a molecular weight of 87 kDa. The optimum pH and temperature were 8 and 60 °C, respectively. The Km and Vmax values of the partially purified xylanase were found to be 0.016 mg/l and 102.64 U/mg protein, respectively with birch wood xylan as substrate.

Conclusion: The enzyme was active over a wide pH range of 6-11 and temperature range of 40°C to 80°C, indicating its alkali tolerant and thermostable characteristics which is the requirement of different industries. Several ions namely Zn²⁺ enhanced xylanase activity by 187% followed by Ca²⁺ (129%), Mg²⁺ (123 %), NH₄⁺ (146%) and Fe³⁺ (118%) at 10 mM concentration. However, Cu²⁺ and Hg²⁺ completely inhibited xylanase activity. This research provides the basis for future application of xylanase and improves its biotechnological potential mainly in paper pulp industry and in bread baking.

Keywords: *Aspergillus terreus*, purification, DEAE- cellulose, thermostable, alkaline, xylanase, characterization

1. INTRODUCTION

Xylan consist of β-1,4 -linked D-xylopyranose units organized in a homo polymeric main chain carrying short side chains consisting of O-acetyl, α-L -arabinofuranosyl and α-D glucuronyl residues. (Pal and Khanum, 2011; Verma and

Satyanarayana, 2012). Depolymerization of xylan into simple sugars and xylooligosaccharides is completed by xylanase involving a cluster of enzymes such as endo1,4- β -d-xylanases (EC 3.2.1.8), β -d-xylosidases (E.C. 3.2.1.37), α -glucuronidase (EC 3.2.1.139) acetylxylan esterase (EC 3.1.1.72), α -l-arabinofuranosidases (E.C. 3.2.1.55), p-coumaric esterase (3.1.1.B10) and ferulic acid esterase (EC 3.1.1.73) (Gomez et al. 2008; Juturu and Wu 2014; Walia et al. 2017; Romero-Fernandez et al. 2018). Xylanases are broadly rich in nature; they are produced by bacteria, fungi, protozoa, algae, gastropods, arthropods, nematodes, etc. (Rana et al. 2019). Microbial xylanases have involved significant research interest in recent years because of their potential application in the food, animal feed, paper and pulp industries. Initial trials performed in our laboratory showed that *A. terreus* is an excellent producer of xylanase when compared with other isolated fungi. Elephant foot yam (EFY), *Amorphophallus paeoniifolius* (Araceae), commonly known as Suran, is extensively grown in India as a cash crop due to its high industrial potential and gainful economic returns (Jogi et al. 2020). It is a good source of protein and carbohydrate, and is used as a vegetable (Chattopadhyay et al. 2009). EFY peels were dried and used in present study as solid substrate for production of xylanase from *Aspergillus terreus* Thom isolated from elephant dung obtained from Indore Zoo. The xylanase produced was partially purified and characterized. This xylanase revealed notable thermostability, which enhances its biotechnological potential.

2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

2.1 Materials

Birchwood xylan, DEAE-cellulose, Sephadex G-25, xylose and xylo-oligosaccharides were purchased from Sigma-Aldrich, USA. All the other chemicals used were of analytical grade and purchased locally. Agricultural residues collected from local fruit and vegetable shops were dried and used.

2.2 Inoculum preparation and Fermentation Conditions

Inoculum was prepared by harvesting spores from a 5 days old fungal culture on PDA slants using sterile distilled water and filtered through sterile glass wool. Spore suspension of 1×10^6 spores/ml, counted using Neubauer's counting chamber was used for inoculation. A 10 g sun dried substrate (2 mm particle size) was taken in 250 ml capacity Erlenmeyer flask, moistened with sterile distilled water to 70% (v/w) and autoclaved at 121°C (15 lbs pressure) for 20 min. The SSF flasks were inoculated with 1 ml of inoculum (1×10^6 spores/ml) and incubated at 30°C for 96 h.

2.3 Enzyme extraction

The crude enzyme was extracted by adding 5 ml of 50 mM citrate buffer (pH 5± 0.5) per gram of fermented substrate and agitated at 120 rpm for 45 min at room temperature. The solid material was separated by passing the slurry through a muslin cloth. The filtrate was centrifuged at 1500 x g for 20 min at 0 to 4°C temperature to obtain a clear supernatant and was used for xylanase assay.

2.4 Xylanase enzyme assay and protein estimation

Xylanase enzyme was assayed using birchwood xylan as a substrate. The 0.1 ml of enzyme solution was added to 0.9 ml of 0.2% birchwood xylan solution prepared in 0.05 M sodium citrate buffer, pH 5.5. The mixture was incubated at 50°C for 10 min, and the 3' 5'- dinitrosalicylic acid (DNS) method (Miller, 1956; Bailey, 1992) was employed for determination of released reducing sugar. One unit of endo-1, 4- β-xylanase was defined as the amount of the enzyme essential to liberate 1 μmole of xylose equivalent in one min under the conditions of enzyme assay (Bhalla et al., 2015). The amount of the protein was determined by Lowry's method using bovine serum albumin (BSA) as standard (Lowry et al., 1951).

2.5 Purification of Xylanase

Xylanase was purified by employing ammonium sulphate precipitation, DEAE-cellulose ion exchange and Sephadex G-200 gel filtration chromatography. The crude enzyme extract obtained was subjected to ammonium sulphate precipitation at 0–90% saturation and placed for overnight incubation at 0–4°C for complete precipitation of proteins. The protein precipitate was collected by centrifugation at 9000×g for 15 min and was suspended in 50 mM sodium phosphate buffer, pH 8.0. Desalting was performed using Sephadex G-25 column chromatography using the same buffer. 5 ml fractions were collected at a flow rate of 1.0 ml/min. 8 fractions of 5 ml each showing xylanase activity were pooled and applied on to DEAE-cellulose column (bed volume, 90 ml) previously equilibrated with 50 mM sodium phosphate buffer, pH 8.0. Unbound fractions were collected at a flow-rate of 1.0 ml/min by eluting with the same buffer. Bound proteins were eluted with a linear 0–1 M NaCl gradient, prepared in equilibrated buffer. The eluted fractions were checked for xylanase activity and absorbance was measured at 280 nm for the protein peaks. The xylanase fractions obtained after DEAE cellulose chromatography (fractions with highest specific activity) were pooled concentrated using reverse dialysis against solid sucrose for 3 h. The concentrated sample (around 1 ml) was loaded onto Sephadex G-200 (bed volume 70 ml) column and eluted with 50 mM sodium phosphate buffer (pH 8.0). The column was pre-equilibrated with the same buffer.

2.6 Native and SDS PAGE

Polyacrylamide gel electrophoresis was performed to determine purity and functionality using 10% resolving gel along with 0.1% xylan. After electrophoresis, gel was cut vertically into two halves, one was stained with Coomassie brilliant blue R-250 while another half was used for activity staining using 0.1 % Congo red. For SDS PAGE, 10% separating gel

with pH 8.8 and 4 % stacking gel with pH 6.8 were used. Resolved protein bands were visualized after staining with 0.1% (w/v) Coomassie brilliant blue R-250 dissolved in methanol, acetic acid, and distilled water (4:1:5; v/v/v).

2.7 Kinetic Parameters

The enzyme assay was carried out at different substrate concentrations ranging from 0.2- 30 mg/ml. The enzyme concentration was kept constant for all assays. Determination of K_m and V_{max} values was done by Lineweaver Burk plot.

2.8 Optimum temperature and thermal stability

The optimum temperature was determined by assaying the enzyme activity at various temperatures, ranging from 10°C to 90°C for 15 min in 50 mM sodium phosphate buffer (pH 8.0) under the standard xylanase assay conditions. For thermal stability, partially purified xylanase was incubated at different temperatures (40 to 90 °C) and activity was checked after every 30 minutes for 3 h. After cooling to room temperature, xylanase activity was measured according to the standard assay conditions.

2.9 Optimum pH and pH stability

The optimum pH of the enzyme was determined at different pH ranging from 3.0 to 12.0. The buffers used were as follows: 0.1 M sodium citrate (pH 3.0-5.0), 0.05 M sodium phosphate (pH6.0-8.0), 0.05 M Tris-HCl (pH 9.0-10.0), and 0.05 M glycine-NaOH (pH 11.0-12.0). Determination of the pH stability of partially purified xylanase enzyme was done after incubating enzyme in the buffers described above, at 37°C for 3 h and by measuring the enzyme activity under the standard assay conditions.

2.10 Effect of Metal ions

The effect of metal ions on xylanase activity was examined using different ions such as Cu^{2+} , Co^{2+} , Fe^{2+} , Mn^{2+} , Ca^{2+} , Na^+ , Mg^{2+} , Zn^{2+} , K^+ , NH_4^+ and Hg^+ at 5- and 10-mM concentration. Xylanase activity was estimated after pre-incubating the enzyme with respective ions at 37°C for 1 h under standard assay conditions. Activity of the enzyme in the absence of any metal ion was considered as 100%.

3. RESULTS AND DISCUSSION

3.1 Purification of xylanase

Xylanase purification from *Aspergillus terreus* EF1 was performed using ammonium sulfate precipitation, DEAE-cellulose and size exclusion chromatography. Specific activity of purified protein was found to be 111.59 U/mg with 14.6-folds purification and 39.48% yield. The molecular weight of the enzyme as determined using SDS PAGE was found to be nearly 87 kDa. Lee et al. (2009) purified thermostable xylanase from Basidiomycete, *Laetiporus sulphureus* employing three consecutive steps of purification and obtained a single protein band having molecular mass of 69.3 kDa achieving 9-

folds purification and 68.7% yield. Knob and Carmona (2010) reported two xylanases from *Penicillium sclerotiorum* using ion exchange and molecular exclusion chromatography. The estimated molecular masses of xylanases I and II by SDS PAGE were 23.9 and 33.1 kDa, respectively. Pal and Khanum (2011) purified an extracellular xylanase to homogeneity from *Aspergillus niger* DFR-5 by using gel filtration chromatography over Sephadex G-100, and SDS -PAGE confirmed its monomeric nature. Hienen et al. (2014) used ion exchange chromatography to purify xylanase from *Fusarium heterosporum* and achieved 2.3-folds purity and reported 19.5kDa molecular weight of xylanase. However, Seemakram et al. (2020) reported mercury ion tolerant and low molecular weight of 25 kDa thermo-alkali stable xylanase from *Thermomyces dupontii* KKU-CLD-E2-3, which was purified to homogeneity using ammonium sulfate precipitation, Sephadex G-100 and DEAE cellulose resulting in 27.92-folds purification, specific activity of 56.19 U/mg protein and a recovery yield of 2.01%.

3.2 Native PAGE and Activity Staining

Xylanase, purified using DEAE cellulose and Sephadex G-200 chromatography showed a single band on native gel polymerised with xylan. A single band of protein with xylanolytic activity was observed on the xylan gel, when stained by Congo red (Fig. 1).

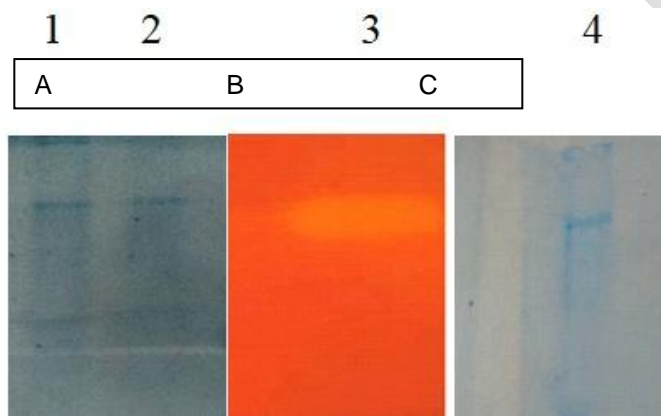


Fig. 1. Native PAGE study of partially purified xylanase enzyme: Fig 1 (A) Lane 1- showing DEAE cellulose purified sample, Lane 2- showing G-200purified enzyme, Fig 1 (B) 3- Activity Staining and Fig 1 (c) 4 - purified xylanase on 10% SDS PAGE.

Table 1. Summary of purification steps of an extracellular xylanase from *A. terreus*

Purification step	Total activity (U)	Total protein (mg)	Specific activity (U/mg protein)	Purification fold	Yield (%)
Crude Enzyme	1950	255	7.64	1	100
Ammonium sulphate fraction (0-90%)	1830	146	12.53	1.64	93.84
Anion exchange chromatography on DEAE-cellulose	1329	31.6	37.33	4.80	68.15
Sephadex- G 200 Gel filtration chromatography	770	6.9	111.59	14.60	39.48

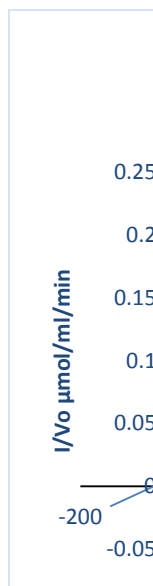


Fig. 2. Lineweaver Burk Plot for purified xylanase of *Aspergillus terreus* produced under SSF.

The kinetic parameters K_m and V_{max} were determined by incubating the enzyme with different concentrations of birchwood xylan (0.2 to 30 mg/ml) under optimal conditions of enzyme assay. The values of K_m and V_{max} determined by Lineweaver Burk plot were found to be 0.016 mg/l and 102.64 U/mg protein, respectively (Fig.2). Kinetic studies help in understanding the affinity of xylanase for the substrate used. Zheng et al. (2013) reported K_m value 0.548 mg/ml and V_{max} 108.89 U/mg protein at 60°C for the purified xylanase (Xyn II) from *Volvariella volvacea* using birchwood xylan. Sadaf and Khare (2014) reported a K_m value of 12.54 mg/ml and V_{max} of 454 U/ml/min from *Sporotrichum thermophilic* using oat spelt xylan as substrate. The K_m and V_{max} of purified xylanase from *Aspergillus terreus* UL4209 using oat spelt xylan were found to be 3.57mg/ml and 55.5 $\mu\text{mol}/\text{min}/\text{mg}$, respectively as reported by Chidi et al. (2008). Ribeiro et al. (2014) reported K_m and V_{max} of $4.6 \pm 0.3\text{mg}/\text{ml}$ and 82 $\mu\text{mol}/\text{min}/\text{mg}$, respectively, for xylanase from *Malbranchea pulchella* using birchwood xylan.

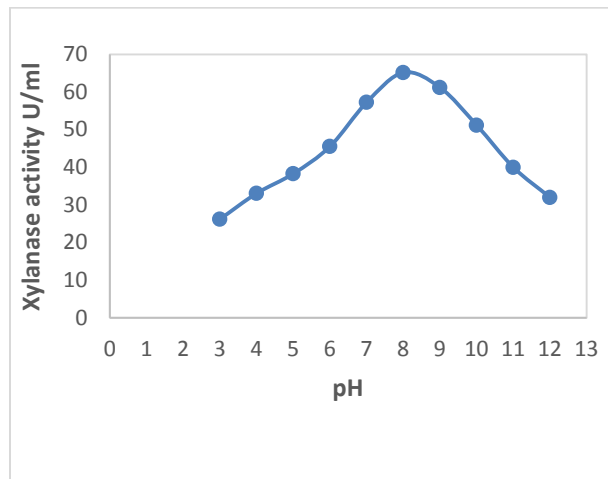


Fig. 3. Effect of different pH on xylanase activity.

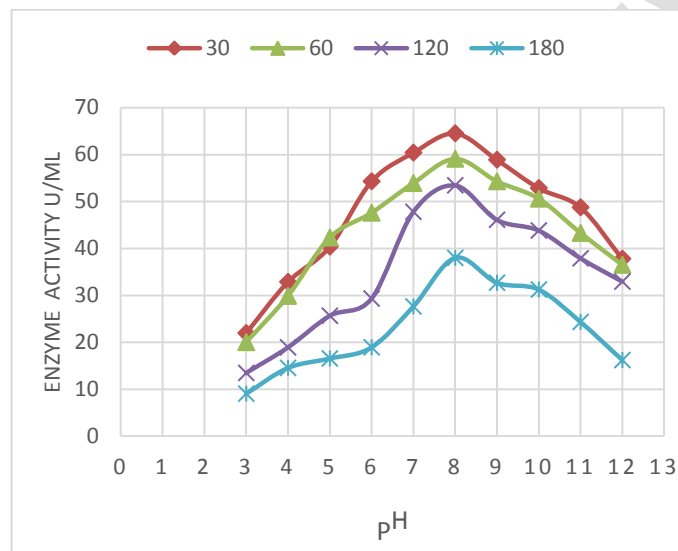


Fig. 4. Effect of pH on the stability of xylanase

3.3 Effect of pH on xylanase activity and pH stability

The optimum pH of xylanase enzyme was found to be 8.0 where 65.2 ± 4.2 U/ml enzyme activity was observed (Fig.3). Xylanase isolated from *Cephalosporium* showed maximum activity at pH ranging from 6.5 to 9.0 (Bansod et al., 1993). Chandra et al. (1995) reported the maximum xylanase activity of *Aspergillus fischeri* fxn1 between pH 6 and 10. Bajaj et al. (2011) reported optimum pH 8 for xylanase activity of an alkali tolerant fungus from *A. fumigatus* MA28. However, Gomes et al. (2016) reported maximum xylanase activity by *A. fumigatus* at pH 4.5 with wide range of pH stability and tolerance to ethanol, xylose and glucose. Seemakram et al. (2020) reported optimum pH 9 for a thermo-alkali stable and mercury ion tolerant xylanase from *Thermomyces dupontii* KKU-CLC-E23.

The enzyme xylanase showed considerable stability at pH range 6 to 11 when incubated for 30 min. At pH 6, 7, 8, 9, 10 and 11, the enzyme activity was found to be 84.2%, 93.17%, 100%, 90%, 81.26%, and 75.6%, respectively. After 1 h, xylanase retained 91.5% activity at pH 8 and more than 70% activity at pH 9 and 10. After 2.5 h of incubation, enzyme

retained more than 50% activity at pH 8-10 and nearly 30% activity at pH 6 and 7 (Fig.4). In 1992, Mathrani and Ahring reported that thermophilic and alkaliphilic xylanase from *Dictyoglomus* isolates retained 100% activity at pH range 5.5–9.0. An alkali-tolerant xylanase from *Aspergillus fischeri* was reported to exhibit remarkable stability at pH 9.0 (Raj et al.,1996). Chipeta et al. (2005) reported xylanolytic activity from *A. oryzae* to remain stable at 50°C over pH range of 4.5–10. Rhomdane et al. (2010) reported the maximum xylanase activity at 75°C from *Talaromyces thermophilus* at pH 8 which exhibited a notable stability and retained 100% of its original activity at 50°C for 7 days at pH 7.0–8.0. The half-lives of the enzyme were 4 h at 80°C, 2 h at 90°C, and 1 h at 100°C. Kocabas et al. (2015) reported xylanase from *Scytalidium thermophilum* ATCC No. 16454 which retained 80% of its maximum activity at pH 8.0. It was also reported that enzyme exhibited most stability in the pH range of 6-8 after 6 h of incubation and highest pH stability at pH 8. Seemakram et al. (2020) reported that the xylanase can maintain more than 70% of the original activity in pH range of 7-10 after incubating at 70°C for 1.5 h in its purified state.

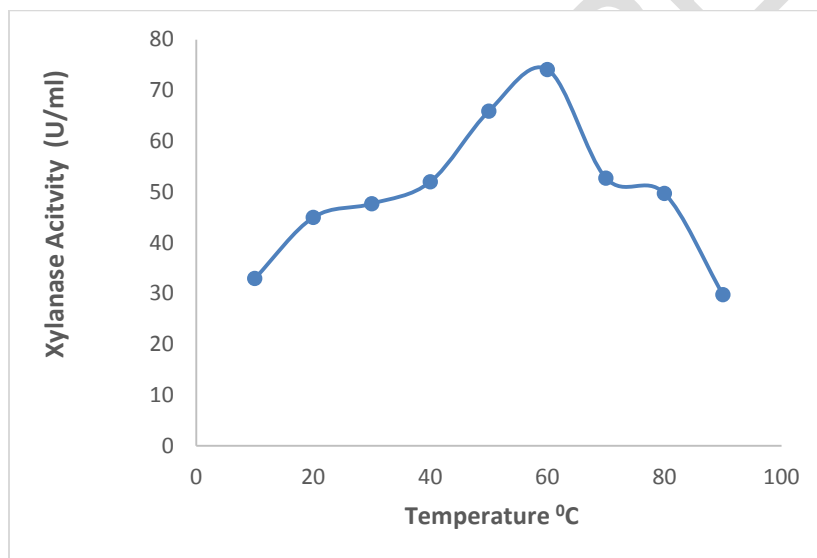


Fig.5. Effect of Temperature on xylanase enzyme activity

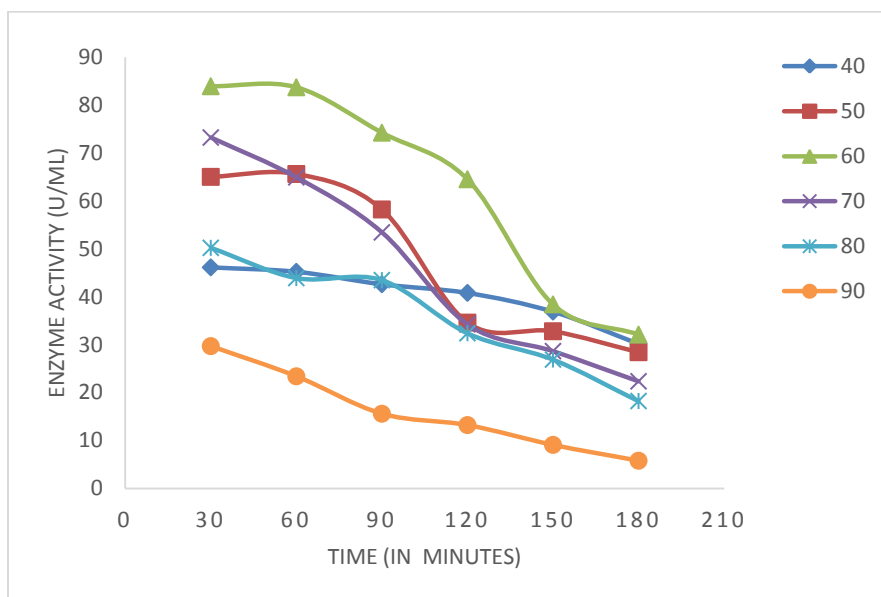


Fig.6. Effect of temperature on activity and thermostability

3.4 Effect of temperature on xylanase activity and stability

The optimum enzyme activity 74.1 ± 4.5 U/ml was found at 60°C (Fig. 5). Upon increasing or decreasing temperature, enzyme activity was declined. At 50 and 70°C , xylanase retained 69% and 64% activity, respectively after 1.5 h of incubation (Fig.6). At temperature 80 and 90°C , the enzyme retained 60% and 35.4 % activity, respectively after 30 min incubation. Previous reports revealed that xylanase isolated from members of the genus *Aspergillus* showed maximal activity at 50°C (Carmona et al., 2005, Medicuti et al., 1997). In 2005, Kolenova et al. purified Xyn B and Xyn C from *Schizophyllum commune*, which were most active at 50°C . Most of the xylanolytic enzymes showed maximum activity at $50\text{--}60^\circ\text{C}$ (Saha, 2002; Ahmed et al., 2012; Kamble and Jadhav, 2012). Bakri et al. (2010) revealed that xylanases from *A. tubingensis* and *A. terreus* exhibited optimum activity at 65°C . Similarly, xylanase has been reported from *T. thermophilus* with temperature optima of $75\text{--}80^\circ\text{C}$ (Maalej et al., 2009). However, Chidi et al. (2008) reported xylanase activity from *Aspergillus terreus* UL4209 strain at 50°C and enzyme retained 95% activity at $35\text{--}40^\circ\text{C}$ after 4 h of incubation at pH 6 and at 50°C the half-life was 5.8 h. Bajaj et al. (2011) reported optimum temperature 50°C for xylanase activity and temperature optima of 80°C for xylanase from *T. dupontii* KKU-CLC-E23.

An extensive range of thermostability has been reported for xylanases from mesophilic fungi and thermophilic fungi (Chadha et al., 2019). Kitpreechavanich et al. (1984) reported xylanase stability at 65°C , produced by *Aspergillus fumigatus*. A strain of *Aspergillus niger* reported by John et al. (1979) which produced two enzymes with extensive temperature stability between 65°C and 80°C . Gawande and Kamat (1998) reported a half-life of xylanase purified from two *Aspergillus* sp. at 50°C for 240 and 260 min and stable only for 10 min at 50°C and 35°C , respectively. Kocabas et al. (2015) reported xylanase from *Scytalidium thermophilum* ATCC No. 16454 which retained more than 95% activity at 40°C

after 4 h of incubation. He also reported that purified xylanase retained 98%, 85% and 50% of its initial activity after 1h incubation at 40, 50 and 60°C and after 2 h of incubation at 70°C enzyme activity was entirely lost. Atalla et al. (2020) reported crude xylanase from *Chaetomium globosum* which on increasing incubation time from 30 min at 40°C decreased xylanase activity upto 45% while at 60°C enzyme lost 85% of its activity.

3.5 Effect of metal ions on xylanase activity:

The effect of various metal ions on xylanase enzyme activity is shown in Table 2. The data indicated metal ions Zn^{2+} , Ca^{2+} , Fe^{3+} , Mg^{2+} and NH_4^+ when added at 10 mM concentration, stimulated the activity by 187%, 129%, 118%, 123% and 146%, respectively. These metal ions were used as salts of sulphate. However, the activity was mildly inhibited by EDTA at 10 mM concentration. The Cu^{2+} and Hg^{2+} completely inhibited xylanase activity at 10 mM concentration. Hg^{2+} inhibition of xylanase has been related to the presence of tryptophan residues which oxidize indole ring, thereby inhibiting the enzyme activity. There are limited studies reporting the action of ionic SDS in xylanase, at low concentration (1-2mM) it can stimulate enzyme activity whereas in higher concentration (10-20 mM), they can cause inhibitory effect. Similarly, this study can be considered for metal ions and non-ionic detergents showing this property (Debeche et al., 2000). In the present study, surfactants like Tween 20 and Triton X increased the activity at 5 mM concentration while decrease in activity at higher concentration of 10mM. Urea enhanced xylanase activity at both 5 mM and 10 mM concentrations upto 113% and 139%, respectively. However, 5mM EDTA increased activity upto 10% and at its higher concentration, enzyme activity decreased. The interaction between cations and amino acid residues involved in enzymatic catalytic domains modulates enzyme activity either positively or negatively. Mn^{2+} , Zn^{2+} , Ca^{2+} , Fe^{3+} , Mg^{2+} and NH_4^+ ions stimulated xylanase activity signifying the possible role of both metal ions as cofactors for enzyme substrate reactions, in count to a stability effect on many other enzymes (Sorgatto et al.,2012). Roy et al. (2013) revealed the strong inhibition of xylanase activity from *Simplicillium obclavatum* MTCC9604 by addition of 3 mM and 6 mM of Mg^{2+} , Ni^2 , Cu^{2+} and Hg^{2+} whereas 3mM concentration of Zn^{2+} enhanced the xylanase activity.

Table 2. Effect of metal ions and solvents on the relative activity of a purified xylanase from *A. terreus*.

Metal ions and Solvents	5mM concentration Enzyme activity (%) ^a	10mM concentration Enzyme activity (%) ^a
Control	100 ± 1.12	100 ± 1.12
CuSO ₄	5.13 ± 2.12	6.45 ± 2.14
CoCl ₂	95.40 ± 1.02	48.75 ± 2.08

HgCl ₂	0.0	0.0
MnSO ₄	112.14 ± 1.25	128 ± 2.12
ZnSO ₄	107 ± 2.10	187 ± 1.62
FeSO ₄	128 ± 1.29	118 ± 1.72
CaCO ₃	109 ± 1.38	129 ± 1.10
MgSO ₄	115 ± 2.52	123 ± 2.19
(NH ₄) ₂ SO ₄	134 ± 1.62	146 ± 2.06
Tween 20	131 ± 1.92	85 ± 1.43
Tween 80	112 ± 2.2	78.65 ± 1.54
EDTA	10.6 ± 2.70	81.81 ± 1.32
Urea	113 ± 1.16	139 ± 2.59
Triton- X-100	123 ± 1.15	118 ± 1.81

Values

a

are

means ±SD of three experiments.

4. CONCLUSION

The results presented in this paper demonstrated that enzyme xylanase was active over a wide pH range of 6-11 and temperature range of 40°C to 80°C, indicating its alkali tolerant and thermostable characteristics which is the requirement of different industries. Zn²⁺ ions enhanced xylanase activity by 187% followed by Ca²⁺ (129%), Mg²⁺ (123 %), NH₄⁺ (146%) and Fe³⁺ (118%) at 10 mM concentration. However, Cu²⁺ and Hg²⁺ completely inhibited xylanase activity. Thus, this research provides the basis for forthcoming application of xylanase and improves its biotechnological potential in paper pulp industry, bread baking and bioconversion processes.

CONSENT (WHERE EVER APPLICABLE)

Not applicable

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

Not applicable

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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