Aspergillus fumigatus L-Amino Acid Oxidase-Two Step Purification and Characterization of the Enzyme

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Abstract

L-amino acid oxidase (L-aao) obtained from Aspergillus fumigatus was purified by ion exchange and gel filtration chromatographies. The yield of L-aao in the ion-exchange chromatography was 24.40 % while the recovery of purified L-aao by gel filtration was 18.70 % of the crude enzyme. The molecular mass of the purified enzyme was estimated to be 55 kDa by SDS PAGE and 93 kDa by gel filtration. The enzyme was stable up to 40°C and over a broad pH range of 5.6-9.2. The enzyme has higher specificity towards hydrophobic aromatic L-amino acids namely tyrosine and phenylalanine. The kinetic parameters, Km and Vmax were determined as 43.47 mM and 0.0434 μmol/min/mL respectively. Ten mM Benzoic acid and EDTA completely inhibited the enzyme, while minimum inhibition with glycine (29.56%) and α-naphthol (12.4%) were observed. Riboflavin, sodium azide and 8-hydroxyquinoline inhibit the enzyme up to 44.89%, 49.83% and 70.07% respectively. MgSO4 at 10-4 M and 10-3 M increased the enzyme activity by 1.72 and 2.22 fold respectively, while CuSO4 at 10-3 M increased the activity by 1.69 fold. This is the first report of purification of L-aao from Aspergillus fumigatus.

Keywords: L-amino acid oxidase; Aspergillus fumigatus; Purification; Characterization

Introduction

The enzyme L-amino acid oxidase (L-amino acid: O2 oxido reductase, EC 1.4.3.2) (L-aao) is a flavo-enzyme that catalyses the oxidative deamination of L-amino acid substrate into an α-keto acid with the production of ammonia and hydrogen peroxide. L-aao catalyses the oxidative deamination of a number of L-amino acids, following the chemical reaction,

\[ H_2N\text{CHR}COOH + O_2 + H_2O \rightarrow \text{O=CRCOOH} + NH_3 + H_2O_2. \]

These enzymes are widely distributed across diverse phyla from bacteria to mammals including many venomous snakes [1,2]. L-aao in microorganisms is involved in the utilization of nitrogen sources [3] and those in animals have been characterized as having distinct biological and physiological functions. The function of snake venom L-aao is still poorly understood, although they play a role in inducing apoptosis, affect platelets and are considered to be toxins [4].

Much work has been done on snake venom L-aao and the purification of L-aao from various snake venoms has been reported by several groups [5-8].

There are very few reports of fungal, especially Aspergillus L-aao [9]. Few workers report the purification of L-aao from fungi and bacteria. L-aao was purified by Neurospora crassa by combination of ammonium sulphate precipitation, gel filtration and DEAE cellulose chromatography [10]. A novel L-glutamate oxidase was purified to homogeneity from Streptomyces endus [11]. The gram positive bacterium Rhodococcus opacus produces an L-aao which was purified to a high degree of homogeneity [12].

Previously, the optimization of medium and cultivation conditions for maximum production of L-aao from Aspergillus fumigatus [13] and the ability of Aspergillus fumigatus L-aao to cause the racemic resolution of DL-amino acids were reported by us [14]. In this communication, we report the purification of Aspergillus fumigatus L-aao and characterization of the enzyme thereof.

Materials and Methods

Chemicals

The chemicals used were commercially available and of reagent grade. The chemicals were purchased from Qualigens, Merck, HiMedia and Sigma.

Microorganism and culture condition

Aspergillus fumigatus (Gene Bank Accession No: FJ765414) was cultivated in a medium containing (gl-1): glucose 10; Na2HPO4 2.5; KH2PO4 0.5; Na2HPO4 2; (NH4)2SO4 4; yeast extract 4; and metal salts; MgSO4.7H2O 0.5; CaCl2.2H2O. 0.5; H3BO3. 0.5; Na2MoO4. 0.04; ZnSO4.7H2O 0.04; CuSO4.7H2O 0.02; FeSO4.7H2O 0.02 and DL-alanine 20mM as inducer, pH 7.0 at 30°C, in a shaking speed of 200 rpm.

Isolation of L-aao crude enzyme

Aspergillus fumigatus cells (96 h) were harvested by centrifugation at 9400 g and 10°C, for 10 minutes (Sigma Centrifuge 30K, Osterode am Harz, Germany). The cells (38.4 g, wet weight) were then homogenized in a French pressure cell press (Thermo electronic, Rochester, New York, USA) at 1500 psi for 5 minutes in ice cold condition. The cell suspension obtained was centrifuged at 13600 g for 15 minutes at 5°C. The cell debris was discarded and the clear supernatant was taken as the crude enzyme.

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Protein concentration determination

Protein concentration determination was done by the method of Lowry et al. [15], by taking Bovine albumin fraction V (Sigma, USA) as the standard protein.

L-amino acid oxidase assay

The assay of L-aoa activity was carried out by measuring the formation of keto acid according to the method of Jian et al. [16], with slight modifications.

0.5 mL (1.2 mg) of the enzyme was allowed to react with 0.5 mL of 100 mM substrate (DL-alanine, unless otherwise stated) in 50 mM sodium phosphate buffer, pH 7.2 at 23°C, 200 rpm. After the reaction, a total of 0.5 mL of the reaction mixture was diluted 5 times with distilled water and reacted with 0.4 mL of 2, 4-dinitrophenylhydrazine (0.2% saturated in 2 N HCl) for 10 minutes. To this 1.5 mL of 3M NaOH was added and absorbance at 550 nm was recorded after 15 minutes. Respective blanks and controls were also taken during the assay. One unit of L-aoa activity is defined as the amount of enzyme that produces 1 μmol of pyruvate / minute /ml of enzyme, under the conditions described above.

Purification of A. fumigatus L-aoa

Ammonium sulphate was added to the crude enzyme (40 mL) of A. fumigatus at increasing concentrations of 25-90 % with continuous stirring at 5°C. The mixture was kept overnight at 5°C for the precipitation of proteins to occur. The protein precipitate that was formed was discarded, the protein pellet was dissolved in minimal volume (6 mL) of 50 mM sodium phosphate buffer, pH 7.2 and dialysed against 10 mM of the inhibitors (α-napthol, EDTA, Glycine, Sodium azide, fructose 6-phosphate kinase (84 kDa); ovalbumin (45 kDa) and carbonic anhydrase (29 kDa). The elution was carried out with 10 mM sodium phosphate buffer, pH 7.2 at a flow rate of 0.5 mL/min.

High performance reverse-phase column analysis

The purified L-aoa was loaded on a reverse-phase C18 HPLC column (Novapack, 3.9 x150 mm, Waters). Elution buffer A was 0.1% (v/v) Trifluoroacetic acid (TFA) in acetonitrile; elution buffer B was 0.1% (v/v) TFA in HPLC grade water. The column was eluted with a linear gradient (100% A for 0-5 min; 0-75% B for 5-25 min; 100% B for 25-30 min).

Characterization of L-aoa

pH optima, temperature optima and heat inactivation of L-aoa:

For the pH optima, 50 mM buffers of different pH i.e. sodium acetate (pH 4.0, 5.6); sodium phosphate (pH 6.0, 7.2); Tris-HCl (pH 8.8) and carbonate-bicarbonate buffer (pH 9.2, 10.0) were used under the standard assay conditions. For determining the temperature optima of the enzyme, the reaction temperature was varied from 25°C to 35°C, at pH 7.2. The heat inactivation of the A. fumigatus L-aoa was performed by incubating the enzyme at temperatures from 40°C to 90°C for 5-10 minutes at pH 7.2. The effect of heat inactivation in the presence of substrate was determined by taking 50 mM of DL-alanine during the study.

Substrate specificity and enzyme kinetics:
The substrate specificity of the enzyme was tested against various DL-/L- and D-amino acids. The substrates were added in 50 mM concentration and the enzyme activity was performed under standard assay conditions as stated previously.

The kinetic parameters Km and Vmax were determined by taking DL-alanine as the substrate.

Effect of inhibitors and metal ions on L-aoa activity:
The effect of inhibitors on the activity of the enzyme was investigated by adding 10mM of the inhibitors (α-naphthol, EDTA, Glycine, Sodium azide, 8-hydroxyquinolone, Benzoic acid and Riboflavin) in the reaction mixture. After the reaction, the reaction mixture was centrifuged at 9400 g for 10 minutes and the assay was done with 0.5 mL as described previously.

The effect of metal ions (MgSO4, CaCl2, H3BO3, Na2MO4, ZnSO4, CuSO4 and FeSO4) on enzyme activity was investigated by adding the metal ions in the reaction mixture at 10 -3 M and 10 -2 M concentration and performing the enzyme reaction.

Results

Purification of L-aoa from A. fumigatus

Following ion-exchange chromatography on DEAE Sephadex A-50, the enzyme was eluted in a single peak, fraction F1 (Figure 1a) Catalase was co-eluted along with the L-aoa (results not shown). Fraction F1 was further separated into 2 peaks on a Sephadex G-75 column, of which L-aoa activity was detected in fraction F2 (Figure 1b). The catalase was separated from the L-aoa at this step which was confirmed by the qualitative catalase test. The protein yield of this purification is shown in Table 1. The homogeneity of purified L-aoa was corroborated by C18 RP-HPLC which showed one major peak (Figure 2c). The minor peak that was seen was that of the solvent.
The purified *A. fumigatus* L-aao migrated as a single band in SDS-PAGE under reducing condition. The molecular mass of purified L-aao was found to be 55 kDa as estimated from SDS-PAGE (Figure 2a). The apparent molecular weight of *A. fumigatus* L-aao was 93 kDa as determined by gel filtration chromatography (Figure 2b), which suggests that the *A. fumigatus* L-aao is a dimeric protein.

**pH optima, temperature optima and heat inactivation of L-aao**

The *A. fumigatus* L-aao is stable over a broad pH range i.e. 5.6-9.2 and the highest enzyme activity is found at pH 7.2 (Figure 3a). The enzyme activity was maximum at 30ºC of reaction temperature, while the enzyme activity was 88.78% and 41.98% of the activity at 30ºC, at reaction temperatures 25ºC and 35ºC respectively. The enzyme is stable over temperatures up to 40ºC although loss in enzyme activity is seen. Treatment of the enzyme at 40ºC and 50ºC for 5 minutes causes 38.47% and 67.19% loss in activity as compared to the activity of the untreated enzyme. When the time of incubation of the enzyme at 40ºC and 50ºC is increased to 10 minutes, total loss of enzyme activity occurs. Treatment of the enzyme at higher temperatures of 60ºC-90ºC for 5 minutes completely inactivates the enzyme.

**Substrate specificity and enzyme kinetics**

The best substrates were found to be DL-tyrosine and L-phenylalanine, which are aromatic amino acids. L-amino acids like L-threonine, L-cystin, L-tryptophan, L-glutamic acid are not attacked by the enzyme. Also there was no activity against the basic amino acid L-arginine. No enzyme activity was detected against the D-amino acids. Table 2 gives a comparison of the enzyme activity with different substrates.

The substrate saturation kinetics of the enzyme was investigated with DL-alanine as the substrate. The enzyme activity increased simultaneously with increasing substrate concentration and reached its maximum at 100 mM. The activity at 150 mM and 200 mM were...
almost equal to the activity at 100mM. The substrate saturation graph was drawn by plotting the substrate concentration vs. the velocity of reaction (Figure 3b). The kinetic parameter, \( K_m \) was 43.47 mM and \( V_{max} \) was 0.0434 \( \mu \)mol/min/mL as determined from the Lineweaver-Burk plot (Figure 3c).

**Effect of inhibitors and metal ions on L-aao activity**

The compounds had inhibitory effects up to various degrees (Table 3). Benzoic acid and EDTA, at concentration of 10mM completely inhibited the enzyme. The enzyme showed minimum inhibition with glycine (29.56%) while α-napthol inhibited the enzyme up to 12.4% only. Riboflavin and sodium azide inhibits the enzyme moderately up to 44.89% and 49.63% respectively while 8-hydroxyquinoline inhibits the enzyme up to 70.07%.

MgSO₄, at 10⁻⁴ M and 10⁻³ M both increased the enzyme activity by 1.65 fold (Figure 3(d)). The metal salts like Ca²⁺, Mg²⁺, Na₂MO₄, Zn²⁺, and FeSO₄ did not have positive effect and FeSO₄, CuSO₄ at 10⁻³ M increased the enzyme activity by 1.65 fold (Figure 3(d)). The metal salts like Ca²⁺, Mg²⁺, Na₂MO₄, Zn²⁺, and FeSO₄ did not have positive effect and MgSO₄ at 10⁻⁴ M and 10⁻³ M both increased the enzyme activity by 1.65 fold (Figure 3(d)).

**Discussion**

In the present work, we purified a novel L-aao from *Aspergillus fumigatus* to a high degree of molecular homogeneity after two chromatographic steps. The yield of L-aao in the ion-exchange chromatography was 24.40% while the recovery of purified L-aao by gel filtration was 18.70% of the crude enzyme. Co-elution of catalase occurred in DEAE Sephadex A-50 chromatography but catalase was separated from the L-aao during gel filtration. The molecular mass of L-aao was found to be 55 kDa when estimated by SDS-PAGE and the apparent molecular mass was found to be 93 kDa as estimated by gel filtration chromatography which suggests that the enzyme is a dimeric protein, which is consistent with the molecular mass of Streptomyces endus L-aao (50 kDa by SDS-PAGE and 90 kDa by gel chromatography) [11]; Rhodococcus opacus L-aao (53.2 kDa by SDS-PAGE and 99 kDa by gel chromatography) [12] and that of snake venom L-aao like Daboia russelli siamensis L-aao (58.0 kDa) [18] and Agkistrodon contortrix laticeps L-aao (60 kDa) [19]. Snake venom L-aao are usually homodimeric glycoproteins with a molecular mass of around 110-150 kDa when measured by gel filtration. However, when assayed by SDS-PAGE, both under reducing as well as non-reducing conditions, the molecular mass is around 50 -70 kDa [6,20,21]. The HPLC of the purified A. fumigatus L-aao in a RP C18 column showed one major peak of the enzyme and a minor peak corresponding to the solvent. This chromatogram pattern of the purified enzyme is similar to the Bothrops alternatus L-aao [6] and Bungarus fasciatus L-aao [22] which show a major peak corresponding to the purified enzyme and a peak corresponding to the solvent.

A. fumigatus L-aao is stable over a broad pH range of 5.6-9.2 with the highest enzyme activity detected at pH 7.2. The *S. endus* L-glutamate oxidase was stable in the pH range of 5.5-7.5 [11], while the optimal activity of the *R. opacus* L-aao was at pH 8-9 [12]. The neutral, cell free L-aoo solution of Proteus vulgaris was stable for weeks at 0°C [23]. The stability decreased as the pH was lowered and below pH 4 the enzyme was rapidly inactivated.

Crotalus adamanteus L-aao was stable to heat (70°C) in presence of L-leucine with only one third losses in activity after 60 minutes incubation [24]. However, treatment of the enzyme at 70°C in the absence of L-leucine lost all activity within 5 minutes. L-phenylalanine and L-methionine (at concentrations of 0.0091M) also protected the enzyme from heat denaturation, whereas equimolar concentrations of D-leucine and L-lysine did not protect the enzyme and L-valine and L-alanine afforded less or no protection [24]. The *R. opacus* L-aao was greatly inhibited by incubation at temperatures above 37°C and there was almost total loss in enzyme activity when the enzyme was incubated for 5 minutes at 50°C [12]. Also, the *P. vulgaris* L-aao was unstable in neutral salt solution above 50°C. 5 minutes at 55°C destroyed 78% of the activity, while 5 minutes at 60°C destroyed all enzyme activity [23]. This is in compliance with our findings that *A. fumigatus* L-aao is inhibited by temperatures above 40°C. Treatment of the enzyme at 40°C and 50°C for 5 minutes causes 38.47% and 67.19% loss in activity as compared to the activity of the untreated enzyme. The presence of substrate (50mM, DL-alanine) during the heat treatment did not offer any protection for our enzyme.

*A. fumigatus* L-aao shows a certain degree of substrate preference. The enzyme has a greater specificity towards hydrophobic aromatic amino acids namely DL-tyrosine and L-phenylalanine. D-amino acids are not attacked. The substrate specificity in decreasing order is

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**Table 1:** Purification table for *A. fumigatus* L-aao.

<table>
<thead>
<tr>
<th>Step</th>
<th>Vol. (mL)</th>
<th>Total A. (U)</th>
<th>Total Prot. (mg)</th>
<th>S.A. (U/mg)</th>
<th>Yield (%)</th>
<th>Purif. fold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude</td>
<td>40</td>
<td>1.23</td>
<td>96.8</td>
<td>0.012</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>ASF</td>
<td>6</td>
<td>0.92</td>
<td>38</td>
<td>0.024</td>
<td>74.8</td>
<td>2</td>
</tr>
<tr>
<td>IEC</td>
<td>14</td>
<td>0.3</td>
<td>7</td>
<td>0.043</td>
<td>24.4</td>
<td>3.6</td>
</tr>
<tr>
<td>GFC</td>
<td>12</td>
<td>0.23</td>
<td>1.9</td>
<td>0.121</td>
<td>18.7</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table 2:** Comparison of the enzyme activity with different substrates.

<table>
<thead>
<tr>
<th>Substrate (50mM)</th>
<th>U/mL</th>
<th>% R.A^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL-alanine</td>
<td>0.028</td>
<td>42</td>
</tr>
<tr>
<td>L-alanine</td>
<td>0.036</td>
<td>54.1</td>
</tr>
<tr>
<td>D-alanine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DL-leucine</td>
<td>0.037</td>
<td>55.6</td>
</tr>
<tr>
<td>L-methionine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-lysine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-phenylalanine</td>
<td>0.051</td>
<td>76</td>
</tr>
<tr>
<td>DL-tyrosine</td>
<td>0.067</td>
<td>100</td>
</tr>
<tr>
<td>L-tryptophan</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-serine</td>
<td>0.044</td>
<td>66</td>
</tr>
<tr>
<td>L-threonine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-aspartic acid</td>
<td>0.009</td>
<td>13.2</td>
</tr>
<tr>
<td>L-glutamic acid</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L-arginine</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

^a: % Relative activity (i.e. activity with respect to maximum)

**Table 3:** Effect of inhibitors on the *A. fumigatus* L-aao.

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>Units</th>
<th>% Inhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>0.0274±0.0008</td>
<td>0</td>
</tr>
<tr>
<td>8-hydroxyquinoline</td>
<td>0.0082±0.0002</td>
<td>70.07</td>
</tr>
<tr>
<td>EDTA</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Glycine</td>
<td>0.0193±0.0004</td>
<td>29.56</td>
</tr>
<tr>
<td>Sod.azide</td>
<td>0.0138±0.0002</td>
<td>49.63</td>
</tr>
<tr>
<td>α-naphthol</td>
<td>0.024±0.0025</td>
<td>12.4</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.0151±0.0002</td>
<td>44.89</td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

The data are expressed as mean of three individual experiments ± std.dev.
as follows Tyr > Phe > Ser > Leu > Ala > Asp. The enzyme did not act on the tested basic amino acids. This is in disagreement with the R. opacus L-aaO [12] and B. alternatus snake venom L-aaO [6] since basic amino acids seemed to be good substrates for these organisms. The best substrates for the snake venom L-aaO are the L-isomers of phenylalanine, tyrosine, leucine, isoleucine, methionine and tryptophan [5,19,25] and this is also true for A. fumigatus L-aaO with the exception of L-methionine and L-tryptophan which are not recognized as substrates by this enzyme.

Benzoic acid and EDTA, at concentration of 10 mM completely inhibited the enzyme. Klein and Kamin [26] studied the effect of benzoate on D-amino acid oxidase and suggested that the inhibition was related to the formation of a benzoic acid-enzyme complex and the action of this inhibitor is mainly substrate competitive. This may be true for A. fumigatus L-aaO since the benzoic acid completely inhibits the enzyme. Benzoic acid also inhibits Penicillium chrysogenum L-aaO [27] and snake venom L-aaO of Crotalus adamanteus [28], Trimeresurus m. microsquamatus [29] and Rattus norvegicus [28]. The Chlamydomonas reinhardtii L-aaO was inhibited upto 90% by 10 mM EDTA [30]. Naphthol and glycine were found to inhibit the L-aaO of Anacystis nidulans and R. opacus [12,31]. The activity of the R. opacus enzyme was strongly decreased by competitive inhibition in glycine buffer. This is in slight disagreement in our case, since A. fumigatus L-aaO showed minimum inhibition with glycine (29.56%) while α-naphthol inhibited the enzyme upto 12.4 % only. Sodium azide was reported to be an inhibitor of L-aaO of A. nidulans [31] and Proteus sp. [32] and this was also true for the A. fumigatus enzyme which is inhibited upto 49.63%. Riboflavin inhibits the A. fumigatus enzyme moderately upto 44.89% and this was also observed for L-aaO of Bombyx mori [33]. Deurre et al. [34] found that 8-hydroxyquinoline is an inhibitor of Proteus rettgeri L-aaO and this is also true for our enzyme.

Ca²⁺, Zn²⁺, Mg²⁺ and Cu²⁺ were reported to be inhibitors of A. nidulans L-aaO [31]. This was partly true for A. fumigatus L-aaO, which was inhibited by Ca²⁺ and Zn²⁺ but Mg²⁺ and Cu²⁺ activated the enzyme up to many fold.

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