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Characterization and kinetic study of lipoxygenase and its partial purification from serum of a patient with lung cancer in Kirkuk City

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ABSTRACT

Lung cancer is a malignant disease that affects human lung tissue as a result of uncontrolled cell growth in one or both lungs. It commonly begins in the epithelial cells of the airways and progresses through the formation and proliferation of cancerous cells. Lipoxygenase (LOX) belongs to a family of lipid-peroxidizing enzymes found in mammals, fungi, plants, and invertebrates. LOX plays an important role in oxidative processes and may contribute to the production of reactive oxygen species (ROS) in cells. Increased oxidative stress is associated with tumor development and progression, including lung cancer. LOX levels in lung cancer patients may be related to age, sex, tumor spread, and disease stage. In this study, lipoxygenase was partially purified from the serum of a lung cancer patient in Kirkuk City using ion-exchange chromatography. Protein precipitation was performed using ammonium sulfate. A separation column with dimensions of 2.5 × 45 cm and diethylaminoethyl-cellulose A50 (DEAE-cellulose A50) resin was used for ion-exchange separation. LOX activity was highest in the precipitated fraction after dialysis. Two LOX activity peaks, Peak A and Peak B, were obtained with different degrees of purity. LOX activity in Peak A was higher than that in Peak B. The purification yields of Peak A and Peak B were 99.82% and 83.29%, respectively, and their specific activities were 5.01 and 4.21U/mg, respectively. The optimal conditions for LOX activity were as follows: maximum velocity, Vmax = 1 U/mL; Michaelis-Menten constant, Km = 0.21mM; substrate concentration, 0.21 mM; phosphate buffer concentration, 0.02 M; pH, 7.5; temperature, 38 °C; and incubation time, 6 min. The approximate molecular weight of the partially purified LOX was 71 kDa.

Keywords: *Dialysis; Electrophoresis; Ion exchange; Molecular weight.*

1 INTRODUCTION

Lung cancer is a malignant disease that affects human lung tissue as a result of uncontrolled cell growth in one or both lungs. It commonly begins in the epithelial cells lining the airways and then progresses through the proliferation of cancerous cells [1]. Lung cancer is one of the leading causes of cancer-related death worldwide. There are two main types of lung cancer: non-small cell lung cancer (NSCLC) and small cell lung cancer (SCLC) [2]. NSCLC includes three major histological subtypes: adenocarcinoma, squamous cell carcinoma, and large cell carcinoma [3].

Lipoxygenase (LOX; EC 1.13.11) is a lipid-peroxidizing enzyme found in mammals, fungi, invertebrates, and plants. LOX plays an important role in lipid oxidation and may contribute to the production of reactive oxygen species (ROS) in cells. Increased ROS production is associated with oxidative stress, inflammation, and tumor development and progression, including lung cancer. Polyunsaturated fatty acids (PUFAs), docosahexaenoic acid (DHA), and free arachidonic acid are among the most important substrates of LOX enzymes. Lipid peroxides

can also contribute to the co-oxidation of PUFA substrates, leading to ROS formation [4]. LOX levels in lung cancer patients may be related to age, sex, tumor spread, and disease progression [5].

Lung cancer, also known as bronchogenic carcinoma, affects both men and women and remains one of the most serious malignant diseases. It can spread through lymphatic vessels and the bloodstream [6]. In lung cancer, tumors develop as a result of abnormal cell growth. Cancer cells may spread rapidly toward the central chest region and nearby lymphatic structures. Malignant progression occurs when cancer cells invade surrounding tissues or spread to distant organs [7].

Lung cancer is a life-threatening disease, and early detection is crucial for determining the stage of disease development. Tumor size, shape, and spread are important factors used to classify the type and stage of cancer. Accurate and rapid detection of tumor size can also support clinical decision-making and improve patient outcomes [8]. Chronic airway obstruction, persistent inflammation, and recurrent infection, as observed in some chronic lung diseases, may contribute to respiratory dysfunction and tissue damage [9].

The most common types of lung cancer include squamous cell carcinoma, small cell carcinoma, large cell carcinoma, and adenocarcinoma. These types can be diagnosed clinically and histopathologically, and their classification is important for determining prognosis and treatment response [10].

Lipoxygenase was first identified in mammals and later in plants; it has also been detected in trace amounts in some bacteria [11]. In humans, lipoxygenase enzymes are found in platelets, skin, lymphocytes, and epithelial tissues. Six functional lipoxygenase genes have been identified: arachidonate lipoxygenase 3 (ALOXE3), arachidonate 5-lipoxygenase (ALOX5), arachidonate 12-lipoxygenase type B (ALOX12B), arachidonate 12-lipoxygenase, 12R type (ALOX12), arachidonate 15-lipoxygenase type B (ALOX15B), and arachidonate 15-lipoxygenase (ALOX15) [12].

Lipoxygenases play important roles in mammalian metabolism and immune regulation because they are involved in the biosynthesis of oxylipins, including leukotrienes and lipoxins. These mediators can participate in both the promotion and resolution of inflammation [13]. Human 5-lipoxygenase is responsible for leukotriene formation from arachidonic acid in innate immune cells, contributing to inflammatory and allergic responses. Evidence has suggested that this enzyme may contribute to carcinogenesis in solid and hematological malignancies [14].

ALOX15 is expressed in several human tissues, including the lung, skin, vagina, prostate, cervix, and breast. Its activity is also observed in glandular and epithelial tissues, such as the kidney, gallbladder, bladder, pancreas, and duodenum [15]. ALOX15 is also known as 15-lipoxygenase-1 or arachidonate 15-lipoxygenase [16]. Lipoxygenases contain non-heme iron within a single polypeptide chain and catalyze oxygenation reactions involving polyunsaturated fatty acids [17].

In plants, lipoxygenases participate in defense responses against biotic and abiotic stressors, including insects, fungi, bacteria, and viruses. Lipoxygenase-derived oxylipins are involved in responses to microbial pathogens and have physiological roles in plant growth, seed germination, fruit ripening, and aging [18].

Several lipoxygenase inhibitors have been investigated for anti-inflammatory and anticancer applications. Zileuton is one of the most important ALOX5 inhibitors and has been reported to inhibit the activity and proliferation of lung cancer cells [19]. It has also been reported to reduce pancreatic cancer activity [20]. Zileuton inhibits leukotriene formation. Leukotrienes are involved in asthma by promoting inflammation, mucus secretion, and airway narrowing; therefore, reducing leukotriene production may help control asthma symptoms [21].

Baicalein has also been investigated for use against malignant tumors [22]. ALOX5 inhibitors, alone or in combination with other agents, have been explored as anticancer and anti-inflammatory treatments in several cancer cell types [23]. Enzalutamide has been reported to inhibit ALOX5 activity and contribute to prostate cancer cell death [24]. Dexamethasone inhibits the release of inflammatory mediators, including lipoxygenase-related products, histamine, and prostaglandins, and is used to reduce inflammation and alleviate side effects associated with cancer treatment [25].

Studies have suggested a relationship between lipoxygenase enzymes and inflammatory pathways involved in lung infections, particularly in patients with cystic fibrosis, where chronic infection and inflammation may lead to lung damage [26]. Asthma is another major lung disease characterized by airway narrowing, swelling, and inflammation, leading to shortness of breath, coughing, wheezing, and chest tightness. Diagnosis is commonly supported by breathing tests [27].

LOX enzymes contribute to the formation of pro-inflammatory leukotrienes, which can trigger systemic

immune and inflammatory responses. LOX enzymes and leukotrienes are involved in several chronic and acute inflammatory diseases in humans, including cystic fibrosis, asthma, and cancer [28]. In lung cancer, immune cells and inflammatory mediators play important roles in tumor progression and response to therapy. LOX-related pathways may stimulate inflammatory responses and influence cell survival or cell death. The main genes interacting with LOX-related pathways are involved in pro-inflammatory mediator production and lipid oxidation [5].

LOX enzymes have been detected in lung cancers, benign lung tumors, and normal lung tissues. An inverse relationship has been reported between LOX expression and tumor grade or cancer cell proliferation in both malignant and benign lung tissues [29].

This study aims to partially purify lipoxygenase from the serum of a patient with lung cancer and determine the approximate molecular weight of the purified enzyme. The enzyme kinetics will also be studied by calculating the maximum velocity (Vmax) and Michaelis–Menten constant (Km). In addition, the factors affecting lipoxygenase activity and the optimal conditions for enzyme function will be evaluated.

2 MATERIALS AND METHODS

2.1 Isolation and purification of lipoxygenase

2.1.1 Preparation of blood serum from the patient

Lipoxygenase (LOX) purification was performed using a blood sample obtained from a 43-year-old male patient with lung cancer who had a normal body mass index. The sample was collected during the patient's visit to Azadi Teaching Hospital, Kirkuk Governorate. Written or verbal consent was obtained from the patient before blood collection, according to the ethical requirements of the study. The patient reported no history of alcohol consumption, smoking, hypertension, heart disease, or diabetes.

A total of 25 mL of venous blood was collected and placed in clean, tightly closed plastic gel tubes without EDTA or other anticoagulants. The blood sample was incubated in a water bath at 37 °C for 15 min and then centrifuged at 3000 × g for 20 min to obtain serum. The serum was divided into two portions, transferred into plastic tubes, and stored at -20 °C until the purification process. All enzyme purification steps were carried out at low temperature, approximately 4 °C.

2.1.2 Estimation of lipoxygenase activity

LOX activity was estimated using the linoleic acid oxidation method [30], in which linoleic acid was used as the substrate. Enzyme activity was monitored by measuring absorbance at 234 nm.

2.1.3 Protein estimation

Protein concentration during purification was estimated using the modified Folin–Lowry method [31].

2.2 Protein precipitation using ammonium sulfate

Protein precipitation was performed using the salting-out method with ammonium sulfate, a neutral salt commonly used because of its high solubility [32]. Ammonium sulfate was gradually added to 15 mL of crude serum extract until 45% saturation was reached. The mixture was then kept at 4 °C for 24 h. The cooled solution was centrifuged at 3000 × g for 15 min. LOX activity and total protein concentration were measured in both the supernatant and precipitate at pH 6.8. Because LOX activity was higher in the precipitate, the supernatant was discarded and the precipitate was used for further purification.

2.3 Dialysis

The protein-containing precipitate obtained after ammonium sulfate precipitation was placed in a semi-permeable dialysis bag. The dialysis bag was tightly sealed at both ends and immersed in a 1000 mL beaker containing 0.02 M phosphate buffer solution at pH 6.8 to remove ammonium sulfate. Dialysis was performed at 4 °C for 24 h with continuous stirring using a magnetic stirrer. The buffer solution was replaced every 6 h. After dialysis was completed, the remaining sample volume was measured [33]. LOX activity and total protein concentration were then determined in the dialyzed sample.

2.4 Ion-exchange chromatography

Ion-exchange chromatography was used to separate LOX isoforms. DEAE-cellulose A50 was used as an anion-exchange resin [34]. The purification process was performed using a separation column measuring 2.5 × 45 cm. The column contained a filter at the bottom to prevent resin leakage. The resin suspension was poured slowly and evenly along the column wall to avoid air-bubble formation, which could interfere with ion exchange. The column was then equilibrated with phosphate buffer solution.

The flow rate was adjusted to 60 mL/h, equivalent to 1 mL/min. A total of 10 mL of the protein solution obtained after dialysis was gently loaded onto the top of the column. The column was then eluted with 500 mL of phosphate buffer solution at pH 6.8 containing sodium chloride. Fractions were collected from the bottom of the column at 2 mL per tube. LOX activity and protein content were then determined in each fraction.

2.5 Determination of optimal conditions for LOX activity

The factors affecting LOX activity were studied by evaluating the effects of substrate concentration, reaction time, temperature, pH, and enzyme concentration.

2.6 Determination of the molecular weight of partially purified LOX by electrophoresis

The molecular weight of partially purified LOX was determined using sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE). This technique is rapid and is based on the linear relationship between the migration distance of standard proteins and the logarithm of their molecular weights within the gel. The gel was calibrated using standard proteins of known molecular weight, which were then used to estimate the molecular weight of the partially purified LOX.

2.7 Materials and instruments

The following materials and instruments were used: Lipoxygenase Activity Kit (Sigma-Aldrich, USA), Total Protein Kit (Biolabo, France), KH_2PO_4 and K_2HPO_4 (Alpha Chemika, India), DEAE-cellulose A50 (Whatman, USA), sodium dodecyl sulfate (SDS; Sigma-Aldrich, USA), ammonium sulfate (Himedia, India), dialysis bag (LAB, China), UV-Vis spectrophotometer (Shimadzu, Japan), water bath and pH meter (Roche, Germany), hot plate stirrer (HYSC, Korea), and incubator (GFL, Germany).

3 RESULTS AND DISCUSSION

The results shown in Table 1 describe the partial purification of LOX from the serum of a patient with lung cancer. The specific activity of LOX increased after ammonium sulfate precipitation to 1.10 U/mg compared with 0.88 U/mg in the crude serum. The purification fold increased to 1.26, and the yield reached 89.41%.

After dialysis, the remaining ammonium sulfate from the precipitation step was removed. The specific activity increased to 2.11 U/mg, while the purification fold increased to 2.41 compared with the crude serum, and the yield reached 95.78%.

Following ion-exchange chromatography, two LOX activity peaks, Peak A and Peak B, were obtained with different degrees of purity, as shown in Figure 1. The yields of Peak A and Peak B were 99.82% and 83.29%, respectively, and their specific activities were 5.01 and 4.21 U/mg, respectively. LOX activity in Peak A was higher than that in Peak B. After ion-exchange chromatography, the purification fold of Peak A increased to 5.71 compared with the crude serum.

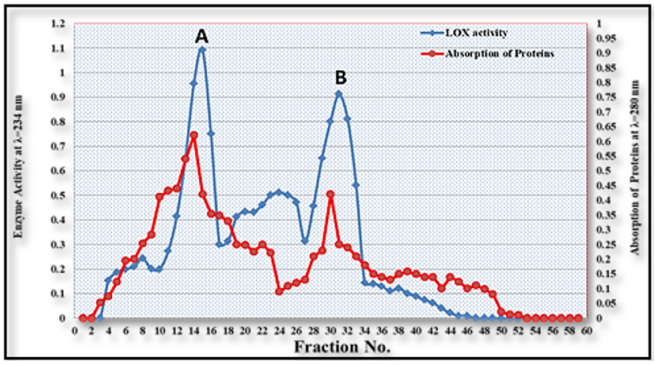

Fig. 1 Lipoxygenases activity and protein absorption in serum of a patient with lung cancer using ion exchange chromatography technique

Table 1 Steps for purifying Lipoxygenases in the serum of a patient with lung cancer

Purification steps	Volume (ml)	activity U/mL	Total protein mg	Total activity U*	Specific activity U/mg	Fold	Yield %
Serum	15	0.584	10	8.67	0.88	1	100
ammonium sulphate (45%)	11	0.712	7.11	7.83	1.10	1.26	89.41
Dialysis	10	0.839	3.97	8.39	2.11	2.41	95.78
Ion Exchange DEAE-Cellulose (A50)							
Pack A	8	1.093	1.749	8.74	5.01	5.71	99.82
Pack B	8	0.912	1.733	7.30	4.21	4.81	83.29

3.1 Study of the factors affecting lipoxygenases activity and optimal conditions

3.1.1 The effect of the concentration of the substrate linoleic acid on the rate of the enzymatic reaction

Linoleic acid was used as the substrate at different concentrations: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 mM. LOX activity was measured at each concentration. The enzyme reaction rate increased with increasing substrate

concentration until the enzyme became saturated with the substrate. After saturation, the reaction rate remained nearly constant despite further increases in substrate concentration and approached the maximum velocity (Vmax), as shown in Figure 2.

The relationship between LOX activity and substrate concentration was analyzed using the Lineweaver–Burk plot, as shown in Figure 3. The maximum velocity and Michaelis–Menten constant were calculated as Vmax = 1 U/mL and Km = 0.21 mM, respectively. Km represents the substrate concentration at which the enzyme activity, or reaction velocity, reaches half of Vmax.

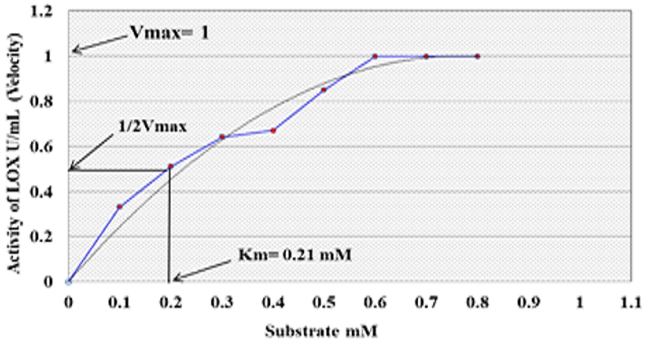

Fig. 2 Impact of The substrate concentration on the activity of the LOX

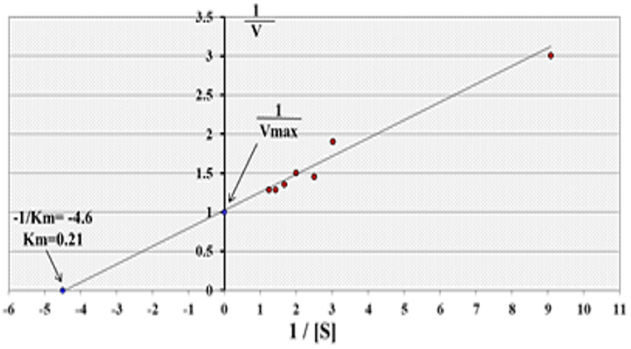

Fig. 3 Lineweaver-Burke plot to find the values of Vmax and Km for the activity of the LOX enzyme

3.1.2 Effect of purified LOX enzyme concentration on the rate of enzymatic reaction

Different concentrations of the partially purified LOX enzyme were prepared by using enzyme volumes of 5, 10, 15, 20, 25, 30, and 40 µL to evaluate LOX activity. As shown in Figure 4, the rate of the enzymatic reaction increased with increasing enzyme concentration.

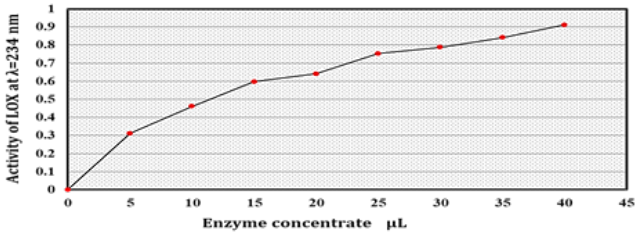

Fig. 4 Impact of purified LOX enzyme concentration on the rate of enzymatic reaction

3.1.3 The effect of the concentration of the buffer solution on purified LOX activity

The effect of phosphate buffer concentration on LOX activity was studied at a constant pH of 6.8. Different phosphate buffer concentrations were tested: 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, and 0.07 M. The optimal phosphate buffer concentration was 0.02 M at pH 6.8, as shown in Figure 5.

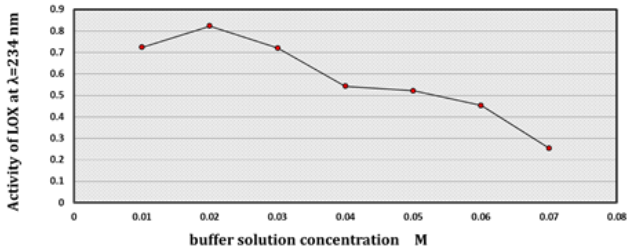

Fig. 5 Impact of the concentration of the buffer solution on purified LOX activity

The effect of pH on the activity of the purified lipoxygenase enzyme was studied using a phosphate buffer concentration of 0.02 M. The tested pH values were 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, and 8.5. The optimal pH for LOX activity was 7.5, as shown in Figure 6.

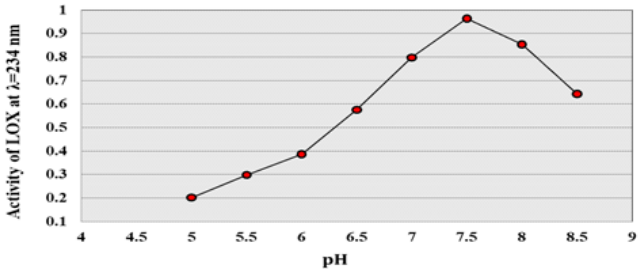

Fig. 6 Impact of pH on purified LOX activity

3.1.4 Impact of temperature on purified LOX activity enzyme

The effect of temperature on LOX activity was evaluated, as shown in Figure 7. Lipoxygenase activity was measured at different temperatures: 30, 32, 34, 36, 38, 40, 42, 44, and 46 °C. The optimal temperature for LOX activity was 38 °C. Enzyme activity gradually decreased at higher temperatures, most likely due to thermal denaturation of the enzyme molecule.

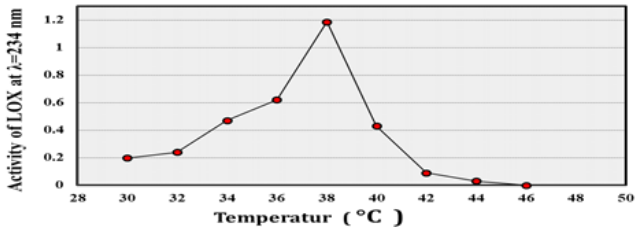

Fig. 7 Impact of temperature on purified LOX activity

3.1.5 impact of reaction time on purified LOX enzyme activity

Different reaction times were tested to measure LOX activity: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 min. The assay was started immediately after initiating the enzymatic reaction to determine the time at which enzyme activity was highest. As shown in Figure 8, the optimal reaction time for LOX activity was 6 min.

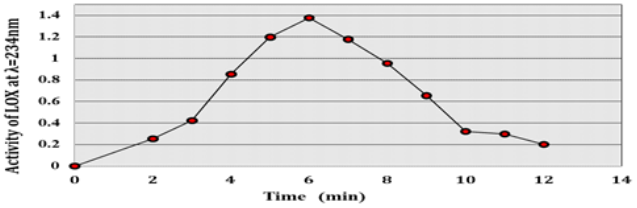

Fig. 8 Impact of reaction time on purified LOX activity

3.2 Estimation molecular weight of LOX enzyme in the serum of a patient with lung cancer by electrophoresis technique

Electrophoresis was used to estimate the approximate molecular weight of LOX. A distinct protein band corresponding to the enzyme was observed. The molecular weight of LOX was calculated after determining the migration distance of the band from the starting point toward the positive electrode. The approximate molecular weight was 71 kDa, as shown in Figure 9. This result is consistent with several studies conducted on mammalian and plant lipoxygenases, which reported molecular weights ranging from 69 to 93 kDa [35–37].

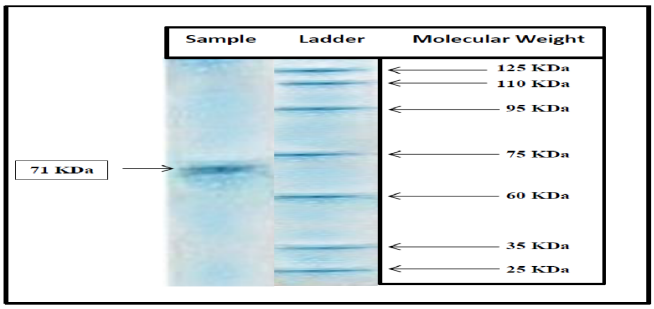

Fig. 9 Molecular weight of LOX enzyme purified by electrophoresis technique

4 CONCLUSION

This study concluded that lipoxygenase (LOX) can be partially purified from the serum of a patient with lung cancer using ammonium sulfate precipitation, dialysis, and ion-exchange chromatography. LOX is associated with lipid oxidation and the generation of reactive oxygen species (ROS), which may contribute to oxidative stress, inflammation, and tumor progression. In addition, lipoxygenase-related pathways may be involved in lung inflammation and tissue damage, and LOX inhibitors have potential applications in cancer and inflammatory disease treatment.

Ion-exchange chromatography produced two LOX activity peaks, Peak A and Peak B. LOX activity in Peak A was higher than that in Peak B. Peak A showed the highest yield, reaching 99.82%, and the purification fold after ion-exchange chromatography increased to 5.71 compared with crude serum. The specific activity of Peak A was 5.01 U/mg.

The optimal conditions for LOX activity were as follows: Vmax = 1 U/mL, Km = 0.21 mM, linoleic acid substrate concentration = 0.21 mM, phosphate buffer concentration = 0.02 M, pH = 7.5, temperature = 38 °C, and reaction time = 6 min. The approximate molecular weight of the partially purified LOX was 71 kDa.

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Data availability

Study data will be available upon request from the corresponding.

DECLARATIONS

Conflict of interest

The authors declare no competing interests

Consent to publish

N/A

Ethical approval

This study received approval from the Medical Ethics Committee at Azadi Teaching Hospital, Kirkuk, Iraq. Patient consent was also obtained when conducting the research.

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