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Catalase Enzyme role in Drug and Food industry

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Abstract

Catalase enzyme breaks down H_2O_2 and produces water and oxygen. It is present almost in all organisms. Catalase enzyme is used in various sectors of biotechnology like bioremediation, biodegradation etc. Catalase plays role in food processing, improving nutritional values of food. To maintain the color and aroma of food a catalase-based system has been introduced. Sodium azide is a chemical which is poisonous and highly toxic is used in agriculture to control the pests. This chemical is also used as preservative in the laboratories.The utilization of catalases in the pharmaceutical industry has been known for various redox responses. The purged catalaseperoxidase from Bacillus pumilus was abused for oxidation of pharmacophore for anti-infection agents (i.e., β-lactams) into their sulfoxides in less time than the synthetic course with enantio unadulterated structure squares.There are many diseases that are associated with deficiency of catalase. These are divided into main three groups metabolic, neurological and other disorders. Hypertension, diabetes type I, diabetes types II, impaired tolerance to glucose, insulin resistance and osteoporosis are included in metabolic disorders. While neurological disorders included Schizophrenia, Alzheimer, bipolar and Parkinson disorders. Other disorders are Asthma, anemia, Wilson, acatalasemia and cancer.

Key Words: Catalase Enzyme, Role in food industry, anticorrosive, bioremediation, Removal of H_2O_2,role in pharmaceutical industry

1. Introduction

Catalase is the enzyme that catalases the conversion of hydrogen peroxide into the oxygen and water. Hydrogen peroxide is present in large quantities in organisms which respire in the presence of the oxygen. Catalase helps such cells to remove the hydrogen peroxide and prevent them from damage. In mammals catalases are found in the liver and kidney[1]. Catalase is intracellular enzyme and found in the cells of body which contain high concentration of the hydrogen peroxide [2][3]. The catalase enzyme is also found in the prokaryotic organisms. Micrococcus luteus is the first prokaryotic organism from which the catalase enzyme was found

Herbert and Pinsent(1948)[4]. After few years many such kind of prokaryotic organisms were found that contain the catalase enzyme and they were used for the detailed study of the catalase enzymes and their properties [5][6, 7]. Many scientists are working to introduce the gene of catalase enzyme in the other organism to produce a large amount of protein as this play a various useful role in the medicine and other industries [8] Catalase enzyme has low structural stability due to which a lot of work was done initially for the structural stability of the catalase enzyme.
Catalase enzyme is found in aerobic organisms and approximately in all the mammals. In mammals they are performing the catalytic activity in the liver and erythrocytes. On the cellular level they are found in the peroxisomes as they contain a large amount of hydrogen per-oxide. Enzymes found in different cells or tissues vary in their structure and properties[9]. In the erythrocyte's catalase acts as the first line of defense. There are three different kinds of enzymes which have the ability to remove the hydrogen peroxides but the major enzyme which play role in the catalysis of the hydrogen peroxide is the catalase enzyme[10]. The catalase enzyme is most efficient for catalyzing the breakdown of hydrogen peroxide as compared to other enzymes. This is performing the fast catalysis of hydrogen peroxide[11].

In this review we are going to discuss the role of catalase enzyme in different fields like food industry and drug industry.

2.Catalase Enzyme in food processing

Catalase enzyme is helpful for the breakdown of H_2O_2 into hydrogen and oxygen and in this way protects the cells from oxidative damage.Bubbles are formed during the breakdown process of H_2O_2. The major source of catalase enzyme is vegetables and fruits. High ratio of catalase is present in vegetables and fruits. In the early days this enzyme was also obtained from the liver but this method was not so good to obtain large quantities of catalase enzyme[12]. On the industrial level this enzyme is isolated from bacteria and non-motile cultures. The conditions for the working of this enzyme also varies from one specie to another specie which are used as the source of this enzyme[13]. Solid state fermentation technique is used for the production of catalase enzyme on the commercial scale. For commercial production of catalase *Aspersgillusniger*is used. The catalase enzyme are of different types and are used for different purposes like most commonly used catalase enzyme in food industry are glucose oxidase which is used for the food preservation and processing of eggs, sulphydryl oxidase which is used under sterilize conditions and are helpful for the removal sulphhydryl groups which are generated by the thermal induction and which become cause of the bad flavor in ultra-pasteurized milk. Catalase enzyme is used in the processing of milk to remove the hydrogen peroxide before cheese production. It is also used in the food wrappers which prevents food from oxidizing. In baking industry, it is used to remove the glucose from the egg white prior to drying for using in baking industry [13].

2.1. Catalase as biosensor

This type of enzymes is used as a biosensor for the detection of various chemicals mixed with food items. For example, Clark type electrode is developed using catalase enzyme which is used for the detection of azide which is toxic chemical which may be mixed with fruit juices like black cherry juice, orange juice and apricot juice. This was developed by Sezginturk and

coworkers. Plolyaniline based catalase biosensor is another enzyme which also used for the detection of hydrogen peroxide and azide in biological samples [14].

To remove the traces of hydrogen peroxide from the milk during pasteurization process a specialized kind of catalase was prepared from the *Aspergillusniger* which is immoveable on a SiO_2 support. In the dairy industries modern biosensing system was developed in which the catalase enzyme is immobilized on the dissolved oxygen by using the gelatin and this catalase is used to determine the decomposition extent of the hydrogen peroxide in milk products[15]. For the determination of the calcium level in the water and milk another catalase based biodevice was developed in which the enzyme is immobilized on the Teflon membrane. This bio device has the ability to detect the calcium level of 1mM to 10mM with the time lapse of one min. To detect the mastitis infection in milk a biosensor was developed which is based on the activity of the catalase enzyme [16]. To detect the concentration of ethanol in food items a biodevice was developed which contains immobilized catalase enzyme as well as the ethanol oxidase[17]. An amperometric is a device which is catalase based and is used for the detection of amount of alcohol in alcoholic drinks. Using this device, the level of calcium can also be detected in the cow milk.

A biodevice has been developed which is used to detect the level of bacterial contamination, this device also based on the catalase enzyme activity [18]. There are some of the food borne pathogens which can cause serious diseases some of which are Listeria monocytogenes and Staphylococcus aureus. A catalase-based method has been developed to detect and eliminate the food borne pathogens [19, 20].

2.2. As a Preservative:

A catalase enzymehas been used to improve the shelf life of food. To maintain the color and aroma of food a catalase-based system has been introduced [21]. Sodium azide is a chemical which is poisonous and highly toxic is used in agriculture to control the pests. This chemical is also used as preservative in the laboratories.

Due to the increased in need of food and to improve the nutritional value of food bifunctional catalases are being used to attain the more nutritive food. For example, catalase is used in the presence of oxidase which reduces the formation of free radicals which protects the food from spoilage. The combine effect of catalase and oxidase has been studied on the shrimps and fish. The results obtained were good. These things prevent the fish and shrimp not only from the microbial attack but also keep the food items fresh. The possible conclusion of this experiment was that the active oxygen species were produced during the process which kills the microbes and increase the shelf life of food[22].

2.3.Catalase in production of cheese

Catalase enzyme has been reported to use in specific fields of production of cheese. We know that hydrogen peroxide has oxidizing potential as well as toxic for cells. It is used instead of pasteurization. Catalase enzymes are destroyed at heat of pasteurization which is up to 140 degree centigrade. Hydrogen peroxide has valid application in cold pasteurization and used for

production of cheese allowed by FDA (Food and Development Authority). But it should keep in mind that hydrogen peroxide can stop bacterial colonies that are responsible for cheese production in milk. So, hydrogen peroxide must be removed completely. These catalase enzymes are extracted from microbial sources or bovine livers and are added to change hydrogen peroxide into molecular oxygen and water. So, in this pathway catalase is used against reactive oxygen after cold pasteurization from milk [23]. Its use is very cost effective and eco-friendly and saves thing from huge hydrogen peroxide for cheese production from milk samples [24].

2.4.Catalase as indicator of degradation of hydrocarbons

Pollution related to crude oil has become issue because it pollutes water, soil and quality of them. There is mixture of hydrocarbons with elements like oxygen, Sulphur and nitrogen in crude oil and it is naturally found [25]. Many carcinogens are toxic compounds found in it and these are formed by branched and straight chains of hydrocarbons. Current issue of spreading pollution is crude oil [25]. The sites of polluted soil have been increasing continuously because of advancements in petroleum industry [26]. Crude oil permeates in soil through various ways and it interacts with enzymes of soil. The enzyme of degrading microorganisms from soil can act as indicator for physiochemical features and amount of crude oil. This process is majorly utilized for bioremediation of soil through artificial microorganisms or naturally microorganism adding there that can degrade hydrocarbons [27-30][31]. Various enzymes like catalase, lipase and dehydrogenase have been found indicator of degradation of hydrocarbons in process of bioremediation. Here activities of these enzymes can be easily observed [32]. In other case of studies, the activity of catalase was seen present in soil due to availability of catalase forming microbes. A control was made in which soil free of contamination of oil and activity of catalase used as marker for normal activity. The acivity was seen to reduce in contaminated soil with crude oil. Arthrobactor species of bacteria were used for that purpose [33]. This reduction in activity of enzyme is because of unfavorable conditions for enzymes. These may be changes in pH, hypoxia and nutrient unavailability [34]. These finding confirms that these catalase enzymes are useful marker for indication of initial of biodegradation process because their activities reduce as biodegradation process slows down. another report was conducted on rhodococcus species that show effect of crude oil on catalase activity till 120 days [35]. This study demonstrated that reduce in catalase activity initially and increase in activity during end days when successful biodegradation occurs [36, 37].

3.As an antioxidant

An ongoing pattern in the nourishment business is the misuse of reactant catalysts showing phenol oxidase movement notwithstanding catalase action (CATPO) as a cell reinforcement has been watched. Catalase-phenol oxidase has been found to show action towards some phenolic substrates, for example, catechin, catechol, caffeic corrosive, and so on. The investigation of finished results of these substrates uncovered the development of various metabolites also, these phenolic optional metabolites which serve different physiological jobs, for example, enemies of oxidants, genius oxidants and sign transduction particles [38, 39]. CATPO may likewise be created as a significant biocatalytic instrument for nourishment and biotechnological applications planned for changing the cancer prevention agent capability of

phenolic mixes. Further comprehensive work concentrated on their misuse (CATPO) in human utilization as a major aspect of the eating regimen or an enhancement is in progress [40].

4.As an anticorrosive

Treated steel is utilized in a wide scope of businesses, extending from nourishment industry to sewage tanks, all because of its quality and protection from consumption however it is inclined to microbial erosion. Microbiologically-activated consumption is liable for a huge part of the consumption on machines in nourishment and maturation ventures as biofilm development modifies the electrochemical conditions on the metal surface [41]. Recently, catalases are likewise focused for consumption counteraction techniques in the nourishment what's more, maturation industry devices and utensils which are inclined to microbial consumption during aging procedures [42]. Bacterial societies of E. coli what's more, a catalase insufficient E. coli strain were likewise utilized for drenching of tempered steel to show the powerlessness of the later cells to cause consumption, which further demonstrates that catalases are an intriguing objective for erosion counteraction systems [43].

5.Removel of H_2O_2:

Hydrogen peroxide (H_2O_2) is generally utilized for the expulsion of microbiological contaminants (microbes, growths) present in refreshments and this procedure is regularly alluded to as cool sanitization. In any case, the expulsion of H_2O_2 before application in the nourishment business is significant. A productive strategy was created for expulsion of H_2O_2 from refreshments before bundling utilizing catalase ensnared in alginate containers[44]

6. Bioremediation:

Stringent natural enactments control removal of $_{H2O2}$-containing modern effluents into open streams [45, 46]. $H_2O_2$is ordinarily utilized as a dying operator in the material and paper businesses. Customary techniques to expel the unused H_2O_2include broad washing of faded textures, coming about in the age of huge volumes of soluble waste water. Then again, $H_2O_2$is evacuated with synthetic substances, for example, sodium bisulphite that additionally lead to high salt levels in the process streams [47]. The high synergist rates render catalases as alluring eco-accommodating choices for H_2O_2 expulsion. Different scientists have effectively abused the utilization of catalase chemical to evacuate hydrogen peroxide from the material and blanching industry effluents to decrease the contamination load.

An improvement in coloring nature of cotton textures was likewise seen after the end of hydrogen peroxide deposits with catalase [48]. [49] utilized immobilized thermoalkalistable catalase from Bacillus sp. for corruption of hydrogen peroxide in material fading gushing which empowered the reuse of treated water for coloring. In another examination, catalase-delivering alginate entangled Bacillus sp. TE-7 cells were utilized to corrupt H_2O_2 in a pressed bed reactor [50]. The corruption of phenolic mixes by the activity of catalaseperoxidase from Comamonasterrigena N3H has been accounted for [51]. An actual existence cycle investigation of material assembling planned for supplanting conventional washing ventures with a modernly created catalase proposed water reserve funds of 20 m3/t of yarn when utilizing 1 kg of

Novozymes' Terminox Ultra® 50-L catalase readiness. Utilization of catalase lessens the water utilization and misuse of vitality considerably, and costs of synthetics up to 83 percent, and recoveries 33 percent of time required for culmination of procedure [52].

7.Role in pharmaceutical industries:

As of late, the mission for green advancements for amalgamation of pharmaceutical substances has expanded. Subsequently, the industry is searching for minimal effort and greener biocatalytic pathways as options in contrast to conventional synthetic procedures [53, 54]. The utilization of catalases in the pharmaceutical industry has been known for various redox responses. The purged catalaseperoxidase from Bacillus pumilus was abused for oxidation of pharmacophore for anti-infection agents (i.e., β-lactams) into their sulfoxides in less time than the synthetic course with enantio unadulterated structure squares. A biocatalytic technique for sound system particular oxidation of pharmacophores with potential applications in the treatment of bacterial diseases was likewise evolved [55]. Magner and [56] researched the catalase-interceded enantio-specifically biotransformation of some chiral alcohols (2, 3-butanediol, trans-1, 2-cyclohexanediol, trans-3-methylcyclohexanol, menthol, 2-methyl-1-butanol, and so forth.) in natural solvents. The reactant job of catalase in rot response of peroxynitrite in the engineered polymer industry has additionally been illustrated by [57].

In polymer combination, catalase additionally fills in as an impetus to corrupt remaining H_2O_2 after a peroxide-activated polymerization response [58]. Remaining H_2O_2 must be demolished after the polymerization response as it can settle long haul stockpiling of polyacrylate arrangements or may meddle with polyacrylate details [59]. As these responses are completed at low pH, acidophilic catalase-delivering microorganisms are required that can work productively under acidic conditions [60].

7.1. Catalase related disease

There are many diseases that are associated with deficiency of catalase. These are divided into main three groups metabolic, neurological and other disorders. Hypertension, diabetes type I, diabetes types II, impaired tolerance to glucose, insulin resistance and osteoporosis are included in metabolic disorders. While neurological disorders included Schizophrenia, Alzheimer, bipolar and Parkinson disorders. Other disorders are Asthma, anemia, Wilson, acatalasemia and cancer [61-63].

7.2.Diabetes Mellitus

In present era diabetes mellitus is common disease. It has various symptoms like lower level of blood glucose, higher level of blood glucose, stroke, heart problems, nerve damage and blindness etc. but in present duration its affected population has been increased. It is estimated that in 2025, this population will approximately 300 Million [64], 629 in 2045[65] and now is increasing in many developing countries like Pakistan. Diabetes mellitus has two distinct forms and these are types i and ii. Types I is insulin dependent juvenile diabetes are it occurs 10 % of all cases. Adults can also become its victim [66]. In this case, autoantibodies destroy the beta cells that are responsible for production of insulin. So, it is autoimmune disease. It has

correlation between genetic and immunologic factors. In this type I, main three antibodies present IA2, GDP65 and insulin autoantibodies. But antibodies against insulin may lack in adults and mostly present in young patients [67][68]. Mostly these antibodies attach to epitopes on B cells of insulin. If we observe genetic features then it shows that there is a relationship between alleles of HLA and diabetes type i. diabetes type ii accounts for 90% and most common disease. Here low amount of insulin in body is produced and also due to resistance body own cells. Here beta cells of pancrease are damaged and hence they cannot produce insulin. Oxidative stress is vital factor for spreading of diabetes type ii. Hydrogen peroxide damages the B cells because it acts as oxidant [69], [70], [71]. It has been observed that concentration of hydrogen peroxide is four-fold more in diabetes type ii than healthy samples of control. This was due to low activity of catalase [72]. Third type of diabetes mellitus also found that is called pancreatogenic diabetes and can be written as T3cDM.This 3rd types of diabetes occurs due to both chronic and acute pancreatitis, inflammation, pancreatic tissues cystic fibrosis and pancreatic tissue damaged [73], [74]. During early pancreatic diabetes, pancreatic enzymes and pancreatic peptides that are exogenous are destroyed. This helps in hyperglycemia because glucagon level elevated [75]. The destruction of pancreatic enzymes and exocrine pancreatic peptides occurs during start phase of pancreatic diabetes. When alpha cells damage then glycogen level is reduced and it happened during late pancreatic diabetes phase. This leads to hyperglycemia because glucagon level is increases here. There are several factors associated with patho-physiology of the diabetes. One of the important is immunopathogenesis that leads to development of the pancreatic diabetes. Various pro-inflammatory cytokines like interferon gamma, necrosis factor alpha and interleukin 1 B are included in pancreatic diabetes pathogenesis [75]. When cytokines are in higher concentration then they lead to dysfunction of beta cells of chronic pancreatic [76]. And higher concentration of interleukin 1B responsible for apoptosis of beta cells [77]. Hydrogen peroxide acts as signaling molecule at its lower concentration while it adapts toxic form when present in higher concentration [78]. Catalase is involved in homeostasis of cell because of its degrading ability of hydrogen peroxide. In serum, activity of catalase was also observed in high concentration in acute pancreatitis [79]. Among pregnant women, GDM (Gestational Diabetes mellitus) is common type of diabetes. The pathogenesis of gestational diabetes mellitus is nearly similar to diabetes type ii. There are many factors that are associated with gestational diabetes mellitus that are maternal age, obesity, hypertension, ethnicity and polycystic ovary syndrome [80]. Risk of diabetes type ii becomes higher in pregnant women after pregnancy [81]. The descendants of gestational diabetic mothers may victim of various diseases like metabolic syndrome, hypertension and dangerous kidney diseases [81], [82]. These defects birth may due to high amount of reactive oxygen species and low antioxidant defense [83]. Various reports on link between GDM and catalase are very conflicting. During 2nd and 3rd trimesters of pregnancy, activity of catalase is low due to high ox[84]idative stress in this period [85], [86]. Cellular protection occurs in liver by catalase because it degrades hydrogen peroxide into oxygen and water [69, 87]. The chances of diabetes mellitusm may increase many times due to lack of catalase [88],[84]. It was also put forward that lack of catalase is responsible for diabetes in direct pathway [61]. Beta cells of pancreas are highly sensitive towards oxidants. These cells lack of catalase as well as they have higher number of mitochondria that are main sites of hydrogen peroxide and superoxide [89]. Several complications may produce in diabetes both types I and ii due to oxidation conditions. The concentration of hydrogen peroxide increases due

to low expression of catalase that leads to many complications. Retina is damaged in diabetes retinopathy by retina neocascularization. Here new vessel develops from existing one and spreads to inner cells of retina and causes blindness [90], [91]. Now scientists are able to make five clusters of diabetes mellitus by joining parameters like insulin secretion, insulin resistance, age and blood sugar level [92].

7.3. Alzheimer's disease

It is a neurological disorder. It is demential disease found in the adults [93]. About 5.5 Million people in United States in 2017 were affected by Alzheimer and its rate will increase upto 13.8 Million in 2050 according to rough estimation [94]. Here dementia occurs due to diabetes and smoking. This disease happened due to accumulation of amyloid beta peptides in brain [95, 96]. These amyloid peptides are very toxic to neurons [97, 98]. Amyloid beta is soluble part of cerebrospinal fluid and plasma. Soluble beta amyloid is changed into insoluble fibrils [97, 99, 100]. Nascent beta is not toxic but older amyloid beta is toxic for neurons is observed by vitro cell cultur[101]. This amyloid peptide is main reason of accumulation hydrogen peroxide with in hippocampal and neuroblastoma neurons [102, 103]. Catalase has direct and indirect both relationship with Alzheimer pathogenesis [65, 104].

7.4. Parkinson's disease

It is also neurological age-associated disease with starting symptom tremor of hand which then spreads whole body and reduces the life quality. It initiates with regular limbs tremor during sleeping or rest period. So here slow movement occurs. This occurs due to removal of dopamine because dopamine producing neurons are affected badly [105, 106]. The patient affected by Parkinson disease face to hundred to two hundred damaged substantianigra pars compacta each day [107]. Understanding about pathogenesis of Parkinson disease is tough work. Several factors like oxidative stress, mitochondrial dysfunction and environmental toxins are included in pathogenesis of this disease. It is observed that alpha synuclein protein is closely related to histopathology and cytopathology of Parkinson disease [108]. If mutation occurs in gene that produces alpha synuclein then mutant protein is produced that enhances accumulation of dopamine in neuron cytoplasm [109]. Dopamine is small neurotransmitter molecule and is formed in cytoplasm. It then moves to small vesicles and becomes as oxidized. When alpha synuclein is mutant then it permeabilizes small vesicles and leakage of dopamine occurs into cytoplasm. Here it is auto-oxidized and produce superoxide and hydrogen peroxide molecules that create oxidative stress [110]. There is also inhibition the activity and expression of catalase when alpha synuclein protein is mutant [111].

7.5. Vitiligo

It is pigmentary disorder and here pigments for skin (melanocytes) are destroyed. Hence these pigments cannot produce melanin. It is demonstrated that catalase level is lower in epidermis of patient of vitiligo than control samples. So, they have higher level of hydrogen peroxide [112, 113], 125]. Hydroxyl radicals can be formed automatically from hydrogen peroxide via photochemical reduction in cell [114]. Hydroxyl radicals can oxidize lipids molecules in cell membrane. This is reason of damage of t and keratinocytes in skin epidermis in

affected patients [115, 116]. The activity of catalase is lowered due to changes in CAT gene or inhibition of hydrogen peroxide. There is strong relation between vitiligo and catalase polymorphism [117, 118]. It has been demonstrated that mutant CAT gene causes false expression or structural modifications in melanocytes or keratinocytes [117]. The overall results show that here is relation between pathogenesis of vitiligo and catalase.

7.6.Acatalasemia

This is hereditary disorder and affects the activity of catalase. It was first reported by Takahara in 1948 [119, 120]. He demonstrated that in Japan 4/7 people had similar genetic flaw [121]. He performed experiment of ex-vivo and filled ulcer patient's mouth with hydrogen peroxide. There was no bubble formation when results were seen that show catalase is affected or its activity is absent in saliva of ulcer patient. This disease was given name Takahara because of his work. Acatlasemia patients have half activity of catalase than normal people and its phenotype called as hypocatalasemia[122]. It has various types according to areas where it was studied like Swiss, Peruvian, German, Hungarian and Japanese. Almost one hundred and thirteen patients of acatalasemia have been listed from whole world. In case of Japanese acatlasemia, two types of mutations are found in catalase gene. One is splicing mutation in which adenine is replaced by guanine at 5 position [123]. And second is fram shift mutation in which thymine is deleted at position 358 of axon and stop stop codon TGA is produced. Translation of mutated TGA forms protein of 133 amino acids which is nonfunctional and not stable. Aebi and coworkers were first who demonstrated Swiss acatalasemia[124, 125]. When Swiss acatalasemia was studied then it was observed that structural mutational of gene CAT is reason for catalase inactivation [126]. Goth first time demonstrated Hungarian acatalasemia in two two Hungarian sisters in 1992. According to him activity of catalase in blood of these sisters was 4.4 % and in normal blood was 6.7%. According to him mutation of CAT that causes structural changes is main reason for Hungarian acatlasemia. He performed it in his lab. He also demonstrated that in family acatalasemia[126].

7.7. Therapeutic Role of Catalase

Catalase is most vital antioxidant enzyme. It is used against various oxidative stress concerned diseases because it converts hydrogen peroxide into simpler products like oxygen and water. The main difficulty is that we should use catalase at suitable sit and in adequate concentration. Catalase can be delivered to neuronal cells of human by poly nanoparticles [127]. There is positive effect of nanoparticles loaded with catalase on neuronal cells which are exposed to hydrogen peroxide. These studies confirmed that nanoparticles are loaded with catalase can be utilized as therapeutic agent against oxidative stress concerned neurological diseases [127]. Same research has been reported utilizing EUK 134 that is form of synthetic superoxide catalase is effective against stroke [128]. ALS (Amyotrophic lateral sclerosis is common kind of fatal and progressive neurological disorder in which motor neuron is damaged in spinal cord and brain stem. ALS has two types and one of them is familial kind (FALS). It is found 10% of total ALS and occurs due to mutation in gene SOD1(antioxidant enzyme that destroys the superoxide radicals). It has been reported in some case that mutation in SOD1 is not concerned with lowering SOD 1 activity. Here it was seen that this mutated SOD 1 has toxic features instead of

lower catalase activity. When this mutated SOD 1 binds with hydrogen peroxide and forms hydroxyl radicals that can potentially damage the important biomolecules [129]. This mutated SOD 1 can also power to use peroxynitrite as substrate and forms 3-nitrotyrosine that has ability to make non-functional protein from normal functional protein [129, 130]. Catalase has potential to reduce hydrogen peroxide by breaking down it. Therapeutic techniques utilizing putriscine in treatment of FALS have been reported [131].

8.Other application

Catalase is accounted for to assume a significant job in the deterioration of hydrogen peroxide inside the red platelets, with half of the hydrogen peroxide created in cells being arranged by this protein [132]. Catalase-based treatment for repressing tumor in different pieces of the body has been created by [133]. An epic chemical complex (containing catalase, superoxide dismutase, carbonic anhydrase and polyhemoglobin) created as a blood-substitute vehicles oxygen and carbon dioxide [134]. The complex additionally goes about as a cancer prevention agent furthermore, remedial specialist against ischemia-reperfusion wounds. [135]moreover, exhibited the utilization of an immunomodulatory recombinant catalase for battling H1N1 pneumonia. Beside its utilization in biomedical and clinical analyses, the use of catalase for the expulsion of hydrogen peroxide from contact focal points has been licensed [136].

9.Conclusion:

Catalase is antioxidant enzyme. This enzyme is found in fruits and vegetables. It is involved in homeostasis in organisms. Shelf life of various foods can be enhanced by using catalase. Catalase protects fruits and vegetables from various oxidative damages. It is also used in baking industry. It is utilized to preserve steel for longer use by protecting it from corrosion. Several age-related disorders can be treated by catalase. It is used as biosensor, food preservative. Catalase has several potential applications in pharmaceutical industries. This enzyme is also used in process of polymerization. Catalase can be used along with nanoparticles for therapeutic purposes. Cheese is also produced with the help of catalase. So, it can be used as drug against many diseases in future.

References:

1. Deisseroth, A. and A.L. Dounce, *Catalase: Physical and chemical properties, mechanism of catalysis, and physiological role.* Physiological reviews, 1970. **50**(3): p. 319-375.
2. Zámocký, M. and F. Koller, *Understanding the structure and function of catalases: clues from molecular evolution and in vitro mutagenesis.* Progress in biophysics and molecular biology, 1999. **72**(1): p. 19-66.
3. Chelikani, P., I. Fita, and P.C. Loewen, *Diversity of structures and properties among catalases.* Cellular and Molecular Life Sciences CMLS, 2004. **61**(2): p. 192-208.
4. Herbert, D. and J. Pinsent, *Crystalline human erythrocyte catalase.* Biochemical Journal, 1948. **43**(2): p. 203.

5. Wetter, L. and H. Deutsch, *Immunological studies on egg white proteins.* J. biol. Chem, 1951. **192**: p. 237-242.
6. Slocum, R.D., R. Kaur-Sawhney, and A.W. Galston, *The physiology and biochemistry of polyamines in plants.* Archives of Biochemistry and Biophysics, 1984. **235**(2): p. 283-303.
7. Pepys, J., et al., *Clinical and immunologic significance of Aspergillus fumigatus in the sputum.* American Review of Respiratory Disease, 1959. **80**(2): p. 167-180.
8. Shaked, Z.e. and S. Wolfe, *[54] Stabilization of pyranose 2-oxidase and catalase by chemical modification,* in *Methods in enzymology*. 1988, Elsevier. p. 599-615.
9. Ahmed, S., et al., *Cryptic Rac-binding and p21 Cdc42HS/Rac-activated kinase phosphorylation sites of NADPH oxidase component p67 phox.* Journal of Biological Chemistry, 1998. **273**(25): p. 15693-15701.
10. Ames, B.N., *DNA damage by endogenous oxidants as a cause of aging and cancer.* Oxidative Damage and Repair: Chemical, Biological and Medical Aspects, 1991: p. 181-187.
11. Brand, K., et al., *Role of nuclear factor-kappa B in atherogenesis.* Experimental Physiology: Translation and Integration, 1997. **82**(2): p. 297-304.
12. Mirto, H., et al., *Intracellular behaviour of uranium (VI) on renal epithelial cell in culture (LLC-PK1): influence of uranium speciation.* Toxicology letters, 1999. **104**(3): p. 249-256.
13. Christopher, N. and M. Kumbalwar, *Enzymes used in food industry a systematic review.* International Journal of Innovative Research in Science, Engineering and Technology, 2015. **4**(10): p. 9830-9836.
14. Singh, R.P., et al., *Polyaniline based catalase biosensor for the detection of hydrogen peroxide and azide.* Biotechnology and Bioprocess Engineering, 2009. **14**(4): p. 443-449.
15. Yildiz, H., E. Akyilmaz, and E. Dinçkaya, *Catalase immobilization in cellulose acetate beads and determination of its hydrogen peroxide decomposition level by using a catalase biosensor.* Artificial cells, blood substitutes, and biotechnology, 2004. **32**(3): p. 443-452.
16. Fűtő, P., et al., *Development of a Catalase-Based Amperometric Biosensor for the Determination of Increased Catalase Content in Milk Samples.* Electroanalysis, 2012. **24**(1): p. 107-113.
17. Hnaien, M., F. Lagarde, and N. Jaffrezic-Renault, *A rapid and sensitive alcohol oxidase/catalase conductometric biosensor for alcohol determination.* Talanta, 2010. **81**(1-2): p. 222-227.
18. Kroll, R., E.R. FREARS, and A. BAYLISS, *An oxygen electrode-based assay of catalase activity as a rapid method for estimating the bacterial content of foods.* Journal of applied bacteriology, 1989. **66**(3): p. 209-217.
19. Patel, J.R. and L.R. Beuchat, *Enrichment in Fraser broth supplemented with catalase or Oxyrase®, combined with the microcolony immunoblot technique, for detecting heat-injured Listeria monocytogenes in foods.* International journal of food microbiology, 1995. **26**(2): p. 165-176.
20. Majumdar, T., R. Chakraborty, and U. Raychaudhuri, *Rapid electrochemical quantification of food borne pathogen Staphylococcus aureus based on hydrogen peroxide degradation by catalase.* Journal of The Electrochemical Society, 2013. **160**(4): p. G75-G78.
21. Castellari, M., et al., *Effects of high hydrostatic pressure processing and of glucose oxidase-catalase addition on the color stability and sensorial score of grape juice/Efectos del tratamiento con altas presiones y de la adición de glucosa oxidasa-catalasa en la estabilidad del color y en la evaluación sensorial del zumo de uva.* Food science and technology international, 2000. **6**(1): p. 17-23.
22. DONDERO, M., et al., *Glucose oxidase/Cqtalase improves preservation of shrimp (Heterocarpus reedi).* Journal of food science, 1993. **58**(4): p. 774-779.
23. Geciova, J., D. Bury, and P. Jelen, *Methods for disruption of microbial cells for potential use in the dairy industry—a review.* International Dairy Journal, 2002. **12**(6): p. 541-553.
24. Kilcawley, K.N., M.G. Wilkinson, and P.F. Fox, *Enzyme-modified cheese.* International Dairy Journal, 1998. **8**(1): p. 1-10.

25. Achuba, F.I. and P.N. Okoh, *Effect of petroleum products on soil catalase and dehydrogenase activities.* Open Journal of Soil Science, 2014. **4**(12): p. 399.
26. Frankenberger Jr, W. and J. Johanson, *Effect of pH on enzyme stability in soils.* Soil Biology and Biochemistry, 1982. **14**(5): p. 433-437.
27. Cowell, J.K., *Synthetic studies towards asteriscanolide*. 1997, University of East Anglia.
28. Vainshtein, B., et al., *Three-dimensional structure of the enzyme catalase.* Nature, 1981. **293**(5831): p. 411-412.
29. Witteveen, C.F., M. Veenhuis, and J. Visser, *Localization of glucose oxidase and catalase activities in Aspergillus niger.* Appl. Environ. Microbiol., 1992. **58**(4): p. 1190-1194.
30. Mukhopadhyay, S. and H.E. Schellhorn, *Induction of Escherichia coli hydroperoxidase I by acetate and other weak acids.* Journal of bacteriology, 1994. **176**(8): p. 2300-2307.
31. Erdogan, E.E. and A. Karaca, *Bioremediation of crude oil polluted soils.* Asian Journal of Biotechnology, 2011. **3**(3): p. 206-213.
32. Karigar, C.S. and S.S. Rao, *Role of microbial enzymes in the bioremediation of pollutants: a review.* Enzyme research, 2011. **2011**.
33. Ogbolosingha, A., E. Essien, and R. Ohiri, *Variation of lipase, catalase and dehydrogenase activities during bioremediation of crude oil polluted soil.* Journal of Environmental and Health Science, 2015. **5**(14): p. 128-141.
34. Achuba, F. and B. Peretiemo-Clarke, *Effect of spent engine oil on soil catalase and dehydrogenase activities.* International Agrophysics, 2008. **22**(1): p. 1.
35. Wang, Z.L., et al., *Graphene oxide gel-derived, free-standing, hierarchically porous carbon for high-capacity and high-rate rechargeable Li-O2 batteries.* Advanced Functional Materials, 2012. **22**(17): p. 3699-3705.
36. Tafesh, A., et al., *Synergistic antibacterial effects of polyphenolic compounds from olive mill wastewater*. Evidence-Based Complementary and Alternative Medicine, 2011. **2011**.
37. Jeong, H., et al., *Red phosphorescene compounds and organic electroluminescence device using the same*. 2006, Google Patents.
38. Perron, N.R. and J.L. Brumaghim, *A review of the antioxidant mechanisms of polyphenol compounds related to iron binding.* Cell biochemistry and biophysics, 2009. **53**(2): p. 75-100.
39. Maqsood, S., et al., *Phenolic compounds and plant phenolic extracts as natural antioxidants in prevention of lipid oxidation in seafood: A detailed review.* Comprehensive Reviews in Food Science and Food Safety, 2014. **13**(6): p. 1125-1140.
40. Avci, G.K., et al., *Oxidation of phenolic compounds by the bifunctional catalase–phenol oxidase (CATPO) from Scytalidium thermophilum.* Applied microbiology and biotechnology, 2013. **97**(2): p. 661-672.
41. Little, B.J. and J.S. Lee, *Microbiologically influenced corrosion: an update.* International Materials Reviews, 2014. **59**(7): p. 384-393.
42. Busalmen, J.P., M. Vazquez, and S. De Sanchez, *New evidences on the catalase mechanism of microbial corrosion.* Electrochimica Acta, 2002. **47**(12): p. 1857-1865.
43. Baeza, S., et al., *New evidence on the role of catalase in Escherichia coli-mediated biocorrosion.* Corrosion science, 2013. **67**: p. 32-41.
44. Trusek-Holownia, A. and A. Noworyta, *Catalase immobilized in capsules in microorganisms removal from drinking water, milk, and beverages.* Desalination and Water Treatment, 2015. **55**(10): p. 2721-2727.
45. Correia, V.M., T. Stephenson, and S.J. Judd, *Characterisation of textile wastewaters-a review.* Environmental technology, 1994. **15**(10): p. 917-929.
46. Sooch, B.S., B.S. Kauldhar, and M. Puri, *Types, Structure, Applications and Future Outlook.* Microbial Enzyme Technology in Food Applications, 2017: p. 241.
47. Switala, J. and P.C. Loewen, *Diversity of properties among catalases.* Archives of biochemistry and biophysics, 2002. **401**(2): p. 145-154.

48. Amorim, A.M., et al., *The application of catalase for the elimination of hydrogen peroxide residues after bleaching of cotton fabrics.* Anais da Academia Brasileira de Ciências, 2002. **74**(3): p. 433-436.
49. Paar, A., et al., *Thermo-alkali-stable catalases from newly isolated Bacillus sp. for the treatment and recycling of textile bleaching effluents.* Journal of biotechnology, 2001. **89**(2-3): p. 147-153.
50. Sooch, B.S. and B.S. Kauldhar, *Development of an eco-friendly whole cell based continuous system for the degradation of hydrogen peroxide.* J Bioprocess Biotech, 2015. **5**(6): p. 1-5.
51. Zámocký, M., et al., *Potential application of catalase-peroxidase from Comamonas terrigena N3H in the biodegradation of phenolic compounds.* Antonie van Leeuwenhoek, 2001. **79**(2): p. 109-117.
52. Blackburn, R., *Sustainable textiles: life cycle and environmental impact*. 2009: Elsevier.
53. Tomsho, J.W., et al., *Ring structure and aromatic substituent effects on the p K a of the benzoxaborole pharmacophore.* ACS medicinal chemistry letters, 2012. **3**(1): p. 48-52.
54. Huisman, G.W. and S.J. Collier, *On the development of new biocatalytic processes for practical pharmaceutical synthesis.* Current opinion in chemical biology, 2013. **17**(2): p. 284-292.
55. Sangar, S., et al., *A catalase–peroxidase for oxidation of β-lactams to their (R)-sulfoxides.* Bioresource technology, 2012. **115**: p. 102-110.
56. Magner, E. and A.M. Klibanov, *The oxidation of chiral alcohols catalyzed by catalase in organic solvents.* Biotechnology and bioengineering, 1995. **46**(2): p. 175-179.
57. Gebicka, L. and J. Didik, *Catalytic scavenging of peroxynitrite by catalase.* Journal of inorganic biochemistry, 2009. **103**(10): p. 1375-1379.
58. Lončar, N. and M.W. Fraaije, *Catalases as biocatalysts in technical applications: current state and perspectives.* Applied microbiology and biotechnology, 2015. **99**(8): p. 3351-3357.
59. Di Gennaro, P., et al., *Purification of recombinant catalase-peroxidase HPI from E. coli and its application in enzymatic polymerization reactions.* Applied microbiology and biotechnology, 2014. **98**(3): p. 1119-1126.
60. Sooch, B.S., B.S. Kauldhar, and M. Puri, *Recent insights into microbial catalases: isolation, production and purification.* Biotechnology advances, 2014. **32**(8): p. 1429-1447.
61. Góth, L., *Two cases of acatalasemia in Hungary.* Clinica chimica acta, 1992. **207**(1-2): p. 155-158.
62. Al-Abrash, A., F.A. Al-Quobaili, and G.N. Al-Akhras, *Catalase evaluation in different human diseases associated with oxidative stress.* Saudi medical journal, 2000. **21**(9): p. 826-830.
63. Habib, L.K., M.T. Lee, and J. Yang, *Inhibitors of catalase-amyloid interactions protect cells from β-amyloid-induced oxidative stress and toxicity.* Journal of Biological Chemistry, 2010. **285**(50): p. 38933-38943.
64. Rolo, A.P. and C.M. Palmeira, *Diabetes and mitochondrial function: role of hyperglycemia and oxidative stress.* Toxicology and applied pharmacology, 2006. **212**(2): p. 167-178.
65. Saeedi, P., et al., *Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: Results from the International Diabetes Federation Diabetes Atlas.* Diabetes research and clinical practice, 2019. **157**: p. 107843.
66. Chiang, J.L., et al., *Type 1 diabetes in children and adolescents: a position statement by the American Diabetes Association.* Diabetes Care, 2018. **41**(9): p. 2026-2044.
67. Laugesen, E., et al., *Latent autoimmune diabetes of the adult: current knowledge and uncertainty.* Diabetic medicine, 2015. **32**(7): p. 843-852.
68. Juneja, R., et al., *Islet cell antibodies and glutamic acid decarboxylase antibodies, but not the clinical phenotype, help to identify type 1 [frac12] diabetes in patients presenting with type 2 diabetes.* Metabolism-Clinical and Experimental, 2001. **50**(9): p. 1008-1013.
69. Tiedge, M., et al., *Relation between antioxidant enzyme gene expression and antioxidative defense status of insulin-producing cells.* Diabetes, 1997. **46**(11): p. 1733-1742.
70. Murata, M., et al., *Metal-mediated DNA damage induced by diabetogenic alloxan in the presence of NADH.* Free Radical Biology and Medicine, 1998. **25**(4-5): p. 586-595.

71. Jörns, A., et al., *Effect of superoxide dismutase, catalase, chelating agents, and free radical scavengers on the toxicity of alloxan to isolated pancreatic islets in vitro.* Free Radical Biology and Medicine, 1999. **26**(9-10): p. 1300-1304.
72. Grankvist, K., S.L. Marklund, and I. Täljedal, *CuZn-superoxide dismutase, Mn-superoxide dismutase, catalase and glutathione peroxidase in pancreatic islets and other tissues in the mouse.* Biochemical Journal, 1981. **199**(2): p. 393-398.
73. Colhoun, H.M., et al., *No effect of PCSK9 inhibitor alirocumab on the incidence of diabetes in a pooled analysis from 10 ODYSSEY Phase 3 studies.* European heart journal, 2016. **37**(39): p. 2981-2989.
74. Ewald, N., et al., *Prevalence of diabetes mellitus secondary to pancreatic diseases (type 3c).* Diabetes/metabolism research and reviews, 2012. **28**(4): p. 338-342.
75. Bhattamisra, S.K., et al., *Type-3c diabetes mellitus, diabetes of exocrine pancreas-an update.* Current diabetes reviews, 2019. **15(**5): p. 382-394.
76. Sasikala, M., et al., *β-Cell dysfunction in chronic pancreatitis.* Digestive diseases and sciences, 2012. **57**(7): p. 1764-1772.
77. Donath, M.Y., *Targeting inflammation in the treatment of type 2 diabetes: time to start.* Nature reviews Drug discovery, 2014. **13**(6): p. 465-476.
78. Veal, E. and A. Day, *Hydrogen peroxide as a signaling molecule*. 2011, Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801 USA.
79. Meszaros, I., L. Goth, and G. Vattay, *The value of serum catalase activity determinations in acute pancreatitis.* The American journal of digestive diseases, 1973. **18**(12): p. 1035-1041.
80. Kim, C., *Gestational diabetes: risks, management, and treatment options.* International journal of women's health, 2010. **2**: p. 339.
81. Association, A.D., *Gestational diabetes mellitus.* Diabetes care, 2004. **27**(Suppl 1): p. S88-90.
82. Simeoni, U., et al., *Adverse consequences of accelerated neonatal growth: cardiovascular and renal issues.* Pediatric Nephrology, 2011. **26**(4): p. 493-508.
83. Ornoy, A., *Embryonic oxidative stress as a mechanism of teratogenesis with special emphasis on diabetic embryopathy.* Reproductive toxicology, 2007. **24**(1): p. 31-41.
84. Goth, L. and J.W. Eaton, *Hereditary catalase deficiencies and increased risk of diabetes.* The Lancet, 2000. **356**(9244): p. 1820-1821.
85. Góth, L., et al., *Blood catalase activity in gestational diabetes is decreased but not associated with pregnancy complications.* Clinical chemistry, 2005. **51**(12): p. 2401-2404.
86. Lekharu, R., et al., *A study of lipid peroxidation and antioxidant enzymes in normal pregnancy.* GCSMC J Med Sci, 2014. **3**: p. 55-56.
87. Nandi, A., et al., *Role of Catalase in Oxidative Stress-and Age-Associated Degenerative Diseases.* Oxidative Medicine and Cellular Longevity, 2019. **2019**.
88. Góth, L., *Catalase deficiency and type 2 diabetes.* Diabetes Care, 2008. **31**(12): p. e93-e93.
89. Heales, S.J., *Catalase deficiency, diabetes, and mitochondrial function.* The Lancet, 2001. **357**(9252): p. 314.
90. Li, J., J.J. Wang, and S.X. Zhang, *NADPH oxidase 4-derived H2O2 promotes aberrant retinal neovascularization via activation of VEGF receptor 2 pathway in oxygen-induced retinopathy.* Journal of diabetes research, 2015. **2015**.
91. Kowluru, R.A. and P.-S. Chan, *Oxidative stress and diabetic retinopathy.* Experimental diabetes research, 2007. **2007**.
92. Ahlqvist, E., et al., *Novel subgroups of adult-onset diabetes and their association with outcomes: a data-driven cluster analysis of six variables.* The lancet Diabetes & endocrinology, 2018. **6**(5): p. 361-369.
93. Markesbery, W.R., *Oxidative stress hypothesis in Alzheimer's disease.* Free Radical Biology and Medicine, 1997. **23**(1): p. 134-147.
94. Hebert, L.E., et al., *Alzheimer disease in the United States (2010–2050) estimated using the 2010 census.* Neurology, 2013. **80**(19): p. 1778-1783.

95. Glenner, G.G. and C.W. Wong, *Alzheimer's disease: initial report of the purification and characterization of a novel cerebrovascular amyloid protein.* Biochemical and biophysical research communications, 1984. **120**(3): p. 885-890.
96. Masters, C.L., et al., *Amyloid plaque core protein in Alzheimer disease and Down syndrome.* Proceedings of the National Academy of Sciences, 1985. **82**(12): p. 4245-4249.
97. Yankner, B.A., et al., *Neurotoxicity of a fragment of the amyloid precursor associated with Alzheimer's disease.* Science, 1989. **245**(4916): p. 417-420.
98. Yatin, S., et al., *Effect of transglutaminase on A beta (1-40) fibril formation and neurotoxicity.* ALZHEIMERS REPORTS, 1999. **2**(3): p. 165-170.
99. Kowall, N.W., et al., *An in vivo model for the neurodegenerative effects of beta amyloid and protection by substance P.* Proceedings of the National Academy of Sciences, 1991. **88**(16): p. 7247-7251.
100. Howlett, D.R., et al., *Aggregation state and neurotoxic properties of Alzheimer beta-amyloid peptide.* Neurodegeneration, 1995. **4**(1): p. 23-32.
101. Varadarajan, S., et al., *Alzheimer's amyloid β-peptide-associated free radical oxidative stress and neurotoxicity.* Journal of structural biology, 2000. **130**(2-3): p. 184-208.
102. Mattson, M.P., et al., *Neurotrophic factors attenuate glutamate-induced accumulation of peroxides, elevation of intracellular Ca2+ concentration, and neurotoxicity and increase antioxidant enzyme activities in hippocampal neurons.* Journal of neurochemistry, 1995. **65**(4): p. 1740-1751.
103. Behl, C., et al., *Hydrogen peroxide mediates amyloid β protein toxicity.* Cell, 1994. **77**(6): p. 817-827.
104. Samara, A., P.T. Andersen, and A.R. Aro, *Health promotion and obesity in the arab gulf states: Challenges and good practices.* Journal of obesity, 2019. **2019**.
105. Hornykiewicz, O., *Biochemical pathophysiology of Parkinson's disease.* Parkinson's disease. Advances in neurology, 1986. **45**: p. 19-34.
106. Kedar, N., *Can we prevent Parkinson's and Alzheimer's disease?* Journal of postgraduate medicine, 2003. **49**(3): p. 236.
107. Orr, C., D. Rowe, and G. Halliday, *An inflammatory review of Parkinson's disease.* Progress in neurobiology, 2002. **68**(5): p. 325-340.
108. Vekrellis, K., et al., *Pathological roles of α-synuclein in neurological disorders.* The Lancet Neurology, 2011. **10**(11): p. 1015-1025.
109. Lotharius, J. and P. Brundin, *Pathogenesis of Parkinson's disease: dopamine, vesicles and α-synuclein.* Nature Reviews Neuroscience, 2002. **3**(12): p. 932-942.
110. GRAHAM, D.G., *Oxidative pathways for catecholamines in the genesis of neuromelanin and cytotoxic quinones.* Molecular pharmacology, 1978. **14**(4): p. 633-643.
111. Yakunin, E., et al., *The regulation of catalase activity by PPAR γ is affected by α-synuclein.* Annals of clinical and translational neurology, 2014. **1**(3): p. 145-159.
112. Schallreuter, K.U., J.M. Wood, and J. Berger, *Low catalase levels in the epidermis of patients with vitiligo.* Journal of Investigative Dermatology, 1991. **97**(6).
113. Maresca, V., et al., *Increased sensitivity to peroxidative agents as a possible pathogenic factor of melanocyte damage in vitiligo.* Journal of investigative dermatology, 1997. **109**(3): p. 310-313.
114. Halliwell, B. and J. Gutteridge, *Oxygen toxicity, oxygen radicals, transition metals and disease.* Biochemical journal, 1984. **219**(1): p. 1.
115. NORDLUND, J.J. and B. LERNER, *Extracellular granular material and degeneration of keratinocytes in the normally pigmented epidermis of patients with vitiligo.* Clin Exp Immunol, 1978. **31**: p. 391-396.
116. Schallreuter, K.U., et al., *Estrogens can contribute to hydrogen peroxide generation and quinone-mediated DNA damage in peripheral blood lymphocytes from patients with vitiligo.* Journal of investigative dermatology, 2006. **126**(5): p. 1036-1042.

117. Casp, C.B., J.X. She, and W.T. Mccormack, *Genetic association of the catalase gene (CAT) with vitiligo susceptibility.* Pigment cell research, 2002. **15**(1): p. 62-66.
118. Gavalas, N.G., et al., *Analysis of allelic variants in the catalase gene in patients with the skin depigmenting disorder vitiligo.* Biochemical and biophysical research communications, 2006. **345**(4): p. 1586-1591.
119. Takahara, S., *Clinical and experimental studies on the odontogenous progressive necrotic ostitis due to lack of blood catalase.* J. Otorhinol. Soc. Jpn., 1948. **51**: p. 163-164.
120. Takahara, S., *Progressive oral gangrene probably due to lack of catalase in the blood (acatalasaemia): Report of nine cases.* The Lancet, 1952. **260**(6745): p. 1101-1104.
121. Beutler, E., *Hereditary disorders of erythrocyte metabolism.* Vol. 1. 1968: Grune & Stratton.
122. Takahara, S., et al., *Hypocatalasemia: a new genetic carrier state.* The Journal of Clinical Investigation, 1960. **39**(4): p. 610-619.
123. Wen, J.-K., et al., *Molecular analysis of human acatalasemia: identification of a splicing mutation.* Journal of molecular biology, 1990. **211**(2): p. 383-393.
124. Aebi, H., et al., *Observations in two Swiss families with acatalasia.* Enzymologia biologica et clinica, 1962. **2**: p. 1-22.
125. Aebi, H., et al., *Properties of erythrocyte catalase from homozygotes and heterozygotes for Swiss-type acatalasemia.* Biochemical Genetics, 1976. **14**(9-10): p. 791-807.
126. Crawford, D.R., et al., *Molecular defect in human acatalasia fibroblasts.* Biochemical and biophysical research communications, 1988. **153**(1): p. 59-66.
127. Singhal, A., et al., *Nanoparticle-mediated catalase delivery protects human neurons from oxidative stress.* Cell death & disease, 2013. **4**(11): p. e903-e903.
128. Baker, K., et al., *Synthetic combined superoxide dismutase/catalase mimetics are protective as a delayed treatment in a rat stroke model: a key role for reactive oxygen species in ischemic brain injury.* Journal of Pharmacology and Experimental Therapeutics, 1998. **284**(1): p. 215-221.
129. Wiedau-Pazos, M., et al., *Altered reactivity of superoxide dismutase in familial amyotrophic lateral sclerosis.* Science, 1996. **271**(5248): p. 515-518.
130. Beckman, J.S., et al., *ALS, SOD and peroxynitrite.* Nature, 1993. **364**(6438): p. 584-584.
131. Reinholz, M.M., C.M. Merkle, and J.F. Poduslo, *Therapeutic benefits of putrescine-modified catalase in a transgenic mouse model of familial amyotrophic lateral sclerosis.* Experimental neurology, 1999. **159**(1): p. 204-216.
132. Gaetani, G.F., et al., *Importance of catalase in the disposal of hydrogen peroxide within human erythrocytes.* 1994.
133. Nishikawa, M., et al., *Inhibition of metastatic tumor growth by targeted delivery of antioxidant enzymes.* Journal of controlled release, 2005. **109**(1-3): p. 101-107.
134. Bian, Y., Z. Rong, and T.M.S. Chang, *Polyhemoglobin-superoxide dismutase-catalase-carbonic anhydrase: a novel biotechnology-based blood substitute that transports both oxygen and carbon dioxide and also acts as an antioxidant.* Artificial Cells, Blood Substitutes, and Biotechnology, 2011. **39**(3): p. 127-136.
135. Shi, X., et al., *PEGylated human catalase elicits potent therapeutic effects on H1N1 influenza-induced pneumonia in mice.* Applied microbiology and biotechnology, 2013. **97**(23): p. 10025-10033.
136. Cook, J.N. and J.L. Worsley, *Compositions and method for destroying hydrogen peroxide on contact lens*. 1996, Google Patents.