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REVIEW ARTICLE

Oxidative Stress and Reproductive Inefficiencies: The Science, Evidences, and Solutions

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ABSTRACT

Oxidative stress is a metabolic process causing imbalance between prooxidants and antioxidants favouring abundance and overbearing effects of the prooxidants. When it occurs, there is disruption in redox signals, biochemical pathways, and control leading to impaired systemic functions. It is an implicated biological mechanism behind pathological development and diseases conditions including reproductive inefficiency, cardiovascular diseases, aging, alcohol-related diseases, adult respiratory distress, atherosclerosis, and inborn error of metabolism. In animal production poor reproductive performance currently, threaten livestock productivity. Several efforts toward overcoming this challenge (poor reproductive performance) have culminated to identification of oxidative stress as the culprit because animals' productivity is impaired either directly or indirectly by oxidative stress. In this paper, we reviewed oxidative stress as a biochemical process affecting reproduction and also hypothesized that oxidative stress is a nexus between functional biochemical process and improved productivity. Therefore, the study concluded that the abatement of oxidative stress is possible by exploring natural sources of antioxidants for the promotion of productivity through optimized reproductive index.

Key words: Antioxidants, oxidative stress biomarkers, oxidative stress, reproductive performance

INTRODUCTION

Oxidative stress occurs in the body system whenever there is elevated level of free radicals over body antioxidant defense system. Oxidative stress cause alteration in body homeostasis condition leading to production of free radical species over internal antioxidants and impede normal physiological activities.[8] Oxidative stress is a metabolic process of imbalance between prooxidants and antioxidants favoring abundance and overbearing effects of the prooxidants; it causes disruption of redox signals, biochemical pathways and control leading to molecular damage in the body systems. Oxidative stress has been reported widely as the mechanism behind many pathological developments and diseases conditions including reproductive inefficiency, cardiovascular diseases, aging, alcohol-related diseases, adult respiratory distress, atherosclerosis, and inborn error of metabolism.

Oxidative stress are categorized as photooxidative stress (oxidative stress triggered as a result of exposure to light or radiation), drug-dependent oxidative stress, metabolic oxidative stress and environmental oxidative stress (oxidative stress occurring as a result of changes or critical environmental conditions such as nutrition, drought, and salinity) based on the sources of generation but in any case, what is common to oxidative stress is that there is imbalance between prooxidants and antioxidants which favours the prooxidants.[43] Considering their metabolic roles; prooxidants can be regarded as double-edged sword which can attack or defend because, despite their roles as destroyers, inhibitors, and modifiers of normal metabolic processes, they are important components of body protection system.[1]

Under normal physiological conditions, prooxidants are involved in many body processes for protection

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against foreign agents at low concentrations. However, they become harmful and cause disease conditions when there is overproduction which reduces natural body antioxidants capacity. As part of the immune system complex, prooxidants use their reactive capacities to inhibit pathogenic organisms' activities hence keeping diseases development at bay – this is the mechanism of action of macrophage cells in the neutrophils. At cellular level, prooxidants over production alter roles of genetic functionalities by destruction of purines and pyrimidine bases causing genetic mutation and errors of genetic expression.[3]

Reproduction is the most important system ensuring procreation of living organisms. In both animals and humans, reproduction ensures giving birth to offspring and increasing population. Reproduction apart from leading to parturition holds the key to increase population and productivity of animal species. Through increased population and productivity, supply of animal products for human consumption, and industrial uses are sustained. Reproduction generally can be regarded as set of activities in sequential order leading to the emergence of new young offspring of a given species of living organism and increase existence of living organisms under different environmental conditions.[33]

Reproduction has both biological and economic benefits in livestock production enterprises because it brings forth younger offspring of an animal species for production of consumable and industrial animal products as well as conservation of the animal species. In promotion of reproduction in animals; reproductive performance including conception rates, gestation length, sexual receptivity, litter size, parturition loss or survival, weaning weight, litter weight, litter growth rates, and milk production capacity are economic parameters that are continuously on improvement in animal production enterprises. In rabbits production, for example, they are very important parameters for reproductive performance evaluation because they determine profitability, products yield and are major factors determining enterprise profitability and production objectives.

FUNCTIONAL BIOCHEMICAL PROCESS OF OXIDATIVE STRESS

Oxidative stress can be traced back to oxygen which is one of the most valuable elements for survival of living organisms (aerobic) because it is the main element for respiration. It is, however, paradoxical that the same oxygen could be toxic through production of its derivatives known as prooxidants which includes ozone-oxygen, singlet oxygen, superoxide, and hydrogen peroxide. Formation of all these oxygen derivatives changes oxygen an element hitherto known to be beneficial, to become hazardous and damaging to body systems. Although this does not occur under normal body functioning; in any situation of shift in balance of prooxidants and antioxidant defense, either by exogenous or internal factors leading to overproduction of the prooxidants, it results into a condition known as oxidative stress – condition which is causal, or at least an ancillary factor in the pathology of many diseases.[37]

Biologically, oxygen is sourced as a waste product from the process of photosynthesis in green plants by absorption of energy from sunlight for production of plant foods. This is the process that guarantees availability of oxygen for respiration in humans and animals. Oxygen is the only element with the most appropriate physical state, satisfactory solubility in water and with desirable combination of kinetic and thermodynamic properties to serve as biological oxidant. However, there is high cost associated with the use of oxygen as a biological oxidant which is its reduction to formation of prooxidants and other biological damaging species. These prooxidants and other damaging species are responsible for damage at both cellular and systemic levels in both humans and animals because they cause oxidative damage.[29]

Oxidative damage is associated with energy demanding activities whereby prooxidants because of their strong reactivity pick up useful biomolecules in the animals system thereby causing damage and unhealthy state. Other high energy demanding activities such as thermoregulation also cause oxidative damages but to a lesser extent compared with level of damages associated with energy demanding activities of reproduction. For instance, studies have revealed that oxidative damage in lactating animals was higher than oxidative damage for thermoregulation by non-breeding animals which is also an energy focus activity in animals. Since it is not economical and even hardly feasible to raise animals without them reproducing, overcoming challenges of oxidative

damages associated with reproduction is highly desirable.[14,27,45]

Oxidative balance as presented in Figure 1 when triggered cause damages in reproductive activities in animals and human being. Major problems of reproductive performance associated with oxidative stress damage are infertility in female human subjects while in male subjects; it reduces fertilizing capabilities of sperm.[9] All damages associated with oxidative stress can be summarized to inhibit production of primary and accessory reproductive cells, reproductive organs dysfunction, inhibition of embryonic development, and growth. Unexplained infertility in human female is associated with oxidative stress based on reports from studies revealing higher concentration of reactive oxygen species (ROS) and malondialdehyde conjugated diene but lower antioxidants concentration in peritoneal fluids.[32,42]

Oxidative stress because of its roles as an important functional biochemical process involved in reproduction got serious attention of researchers who conducted several research on oxidative stress effects on reproduction; summary of some of the works is as summarized in Table 1.

PHYSIOLOGICAL SIGNIFICANCE OF OXIDATIVE STRESS ON REPRODUCTIVE PERFORMANCE

Production of ROS trigger imbalance between antioxidants and prooxidants which cause high damages in reproductive activities not in animals alone but also in human being. Major problems of reproductive performance including infertility in female human subjects; reduced fertilizing capabilities of sperm in male have been linked with negative effects of oxidative stress. All damages associated with oxidative stress can be summarized to inhibit production of primary and accessory reproductive cells, reproductive organs functionalities, embryonic development, and growth. Unexplained infertility in human female participants has been linked to oxidative stress based on reports from studies which revealed higher concentration of ROS concentration in and malondialdehyde conjugated diene but lower antioxidants peritoneal fluids.

ROS cause oxidative stress which has strong relevancy in reproductive inefficiencies in both humans and animals. In male organisms, it affect both seminal qualities and reproductive functions of the spermatozoa while in female organisms, it affect suitability of reproductive environment for oocytes maturation and development of embryo. As ROS increases more than the natural balance of antioxidants body system naturally increase effort to overcome this situation and this has been reported to lead to aging because of damages inflicted on vital biological components which naturally supports and promote structural integrity of the body. This is an indication again that reproduction is a trade-off for aging.[33]

Oxidative stress occasioned by elevated levels of free radicals negatively impact on performance of animals reproduction, especially during gestation and lactation periods. Workers stated that the impact is as a result of increased need for nutrients for the growing fetus, and growth and development of mammary structures for milk production which all require high nutrients that is usually limited due to poor intake by animals during these periods. Oxidative stress physiologically reduces the secretions of gonadotropin-releasing hormones by the hypothalamus and subsequently limiting the flow of luteinizing and follicle-stimulating hormones by the pituitary and sex steroids by the gonads. This physiological failures cause reduced fertility rates and retardation of embryo growth.[9]

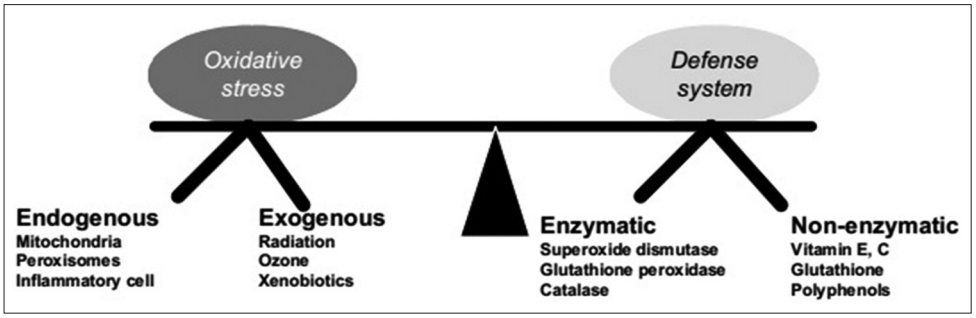

Figure 1: Oxidative stress balance[46]

Table 1: Some literature evidence on oxidative stress effects on reproduction

Title	Summary	Authors
Birds sacrifice oxidative protection for reproduction	ROS are unavoidable by-products of oxidative metabolism and these by-products through damages on DNA, lipids and cellular proteins and cause aging	[33]
Constraint and cost of oxidative stress on reproduction: Correlative evidence in laboratory mice and review of the literature	Evolutionary ecology pointed that current and residual reproductive values are negatively linked by the so-called cost of reproduction among which oxidative stress is the most prominent	[7]
Good genes, oxidative stress, and condition-dependent sexual signals	Oxidative stress through generation of free radicals modulate reproductive immunity	[41]
Oxidants, antioxidants, and the degenerative diseases of aging	Oxidative metabolism is essential part of life but it has expensive trade-off causing damages to DNA, protein, and lipid. It is a major cause of aging and degenerative diseases	[15]
Oxidative stress and its implications in female infertility – a clinician's perspective	ROS have a role in the modulation of gamete quality and gamete interaction	[9]
Oxidative stress and its role in female infertility and assisted reproduction: Clinical implications	ROS are involved in physiological functions and act as mediators in various signaling processes	[36]
Oxidative stress and living cells	ROS are onslaught causing molecular damages in cells of plants, animals, and man	[20]
Oxidative stress as a mediator of life history trade-offs: Mechanisms, measurements, and interpretation	Oxidative stress is underlying mechanism for understanding the concept of life-history. Managing oxidative stress is likely to be a major determinant of life histories, as virtually all activities generate ROS	[30]
Increased susceptibility to oxidative stress as a proximate cost of reproduction	Investment in current reproduction is usually paid regarding reduced future reproduction and increased mortality; reproduction decreases antioxidant defenses, illustrating that oxidative stress represents a cost of reproduction	[16]
Oxidative stress in an ART setting	Increase in levels of ROS without a concomitant rise in antioxidant defenses leads to oxidative stress causing cellular damages on lipid, protein, and DNA which are all associated with suboptimal ART success rates	[12]
Oxidative stress, antioxidants, and animal function	Reactive oxygen metabolites generated during body metabolism can enter into reactions that, when left uncontrolled, can impair the performance of dairy cows thereby reducing productivity. To optimize performance, oxidative stress in high producing cows must be controlled by supplying all known antioxidant nutrients and by minimizing effects of substance or condition stimulation generations of ROS	[28]
Oxidative stress, prooxidants, and antioxidants: The interplay	Oxidative stress can be viewed as an imbalance between prooxidants and antioxidants in the body. It is an important biochemical process in body growth and development; genomic evidence showed oxidative stress relationship with disease development, incidence of malignancies and autoimmune disorders, increased susceptibility to bacterial, viral, and parasitic diseases	[8]
Oxidative damage increases with reproductive energy expenditure and is reduced by food-supplementation	Life-history theory identified the process of reproduction to negatively affect survival. Costs of reproduction are thought to be physiologically based, but the underlying mechanisms remain poorly understood; meanwhile oxidative stress is implicated as the underlying mechanism	[34]
Role of oxidative stress and antioxidant supplementation in pregnancy disorders	Oxidative stress is widely implicated in failed reproductive performance, including infertility, miscarriage, diabetes-related congenital malformations, and preeclampsia	[25]
The effects of oxidative stress on female reproduction: A review	Oxidative stress adversely affects sperm quality, oocytes production, and functions. Environmental effects of pollution can trigger oxidative stress while antioxidant supplementation may be effective in controlling generation of ROS for improved reproduction	[10]
Fecundity and survival in relation to resistance to oxidative stress in a free-living bird	Resistance to oxidative stress is a major determinant for high reproductive output regarding survival to breeding season and size of egg clutches in free-living birds in the wild	[31]

ROS: Reactive oxygen species, ART: Assisted reproductive techniques

GENETIC EVIDENCE OF OXIDATIVE STRESS EFFECTS ON REPRODUCTIVE PERFORMANCE

During oxidative stress condition, there is usually elevated levels of ROS, and this is reported to cause genomic instability through manipulation of deoxyribonucleic acid coding, and it also reduce activities of protective antioxidants on cells, thereby resulting into cellular destruction and or damage.[2] According to[44] there is cellular destruction and damage on DNA, protein, and lipids molecules as a result of oxidative stress. Also[5,13] reported that there are dysfunctions of structures in spermatozoa of luekocytospermic patients; they justified this observation on overproduction of prooxidants which originally are meant for building defense against infections during spermatogenesis.

High levels of ROS are also reported to induce oxidative damage of DNA in sperm plasma membrane, mitochondrion, and nuclear genome. The danger in this damage is not associated with poor reproductive performance alone but is capable of causing cancer and inherited infertility in the off-springs.[4] This damage impact negatively on life and survival of the spermatozoa, inability of sperm to fertilize and destruction of oocytes in case there was fertilization. Oxidative stress is also implicated in DNA fragmentation - a condition common in subfertile human beings. This fragmentation causes mutation in offspring because the fragmentation is hardly repaired ahead of fertilization. According to the study of[14] oxidative stress affect reproductive performance through damage in different cellular components and biomolecules at all levels of reproduction from fertilization, to maintenance of pregnancy and lactation period in both humans and animals; some of these biomolecules are cellular genetic materials.

As ROS increases in the body of animal models and human subject more than the natural balance of antioxidants, body system naturally increases effort to overcome this situation, and this has been reported to lead to aging because of damages inflicted on vital biological components which naturally supports and promote structural integrity of the body. This damages include damage on DNA by destruction of purine and pyrimidine bases, destruction of protein, and lipids biomolecules through fast reactions between the reactive species and the biomolecules such as proteins, carbohydrates, and lipids. This is an indication again that reproduction is a trade-off for aging. To inhibit aging as result of reproduction, there is need for reducing rates of oxidative stress in food-producing animals such as for sustainable production of meat that is safer for human consumption and public health friendliness.

INFLUENCE OF OXIDATIVE STRESS ON LIVESTOCK PRODUCTIVITY

Suboptimal livestock productivity is closely linked to oxidative stress because oxidative stress promotes a decrease in residual reproductive value of animals with age advancement. In livestock production, optimal productivity is a complex of reproductive efforts as it involves animal physiological maturity or aged before the animal can be productive.[33] In dairy production for example, cows' ability to produce the right quantity and quality of milk depend on reproduction because the animal is required to get fertilized and calve before it can produce milk during lactation. Similarly, in poultry production, hen day production capacity of laying birds depends on reproductive maturity of the birds. In rabbit and pig production, frequency and number of off-spring which are major factors determining productivity depends on reproductive maturity and optimum performance of animals.

All the indicators listed above require huge biological investment from animals for them to be productive. However, as animals attempt to invest for future reproductive output; oxidative stress presents itself as a limiting factor because it mediates between reproductive output and resources allocation for reproduction, especially energy. Animal species based on resources allocation for reproduction are categorized to be short live with high reproductive rates and long live with low reproductive rates. This phenomenon is termed livelihood trade-off for reproduction. Studies supporting this hypothesis was demonstrated to be scientific through the work of[33] in Zebra finches whereby increased oxidative stress was reported with increase brood size and vice-versa. Oxidative stress will definitely occur as animals increase effort to reproduce because since reproduction is an energy focus activity; continuous demand for increasing energy for metabolic activities will result into development of oxidative stress through accumulation of

non-reduced oxygen from cellular oxidative phosphorylation.

In actively producing animals, oxidative stress limits reproductive and productive output through reproductive failures. An example of reproductive failure causing loss due to oxidative stress is impaired uterine contractibility. Uterine contraction which is an important process for embryo implantation in animals when impaired, inhibit the process of parturition because the normal process of uterine smooth muscle contraction becomes hampered. In ewe and cows, impaired uterine contraction was reported to decrease transportation of sperm for fertilization process, and in a condition of poor sperm transportation, conception rates decrease is a common condition.

ANTIOXIDANT TREATMENT EFFECTS ON OXIDATIVE STRESS

In both animals and humans, there is an internal system of antioxidants defense which put oxidative stress under check at all times. This system is composed of bioactive compounds internally produced by animals or man *in vivo* or supplied externally to the animals. These antioxidants are categorized broadly as enzymatic or non-enzymatic antioxidants. Enzymatic antioxidants include catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GPx) while nonenzymatic include malondialdehyde, glutathione, tocopherol, astaxanthin, carotenoids, fucoxanthin, and vitamins. Antioxidants either enzymatic or nonenzymatic can be from natural or synthetic sources and can be applied to suppress activities of ROS in natural reproductive or assisted reproductive activities.[17,21,39]

Exogenous antioxidant supplementation is a common practice for fertility treatment in man and it improves reproductive performance. In male human fertility patients; using of Vitamin E was reported for improvement of post-thaw sperm motility and improvement of DNA integrity. Also[40] reported the use of Vitamin E infertility patient and in cryopreservation of sperm of male fertility patients.[19] Reported Vitamin C for reduction of malondialdehyde level – an indication of a reduction in sperm lipids peroxidation, reduction of DNA structural damage, and improved sperm progressive motility as well as viability of sperm all resulting into improved fertility in human fertility patients. These researchers concluded that exogenous supplementation of antioxidants is a proven means of reducing oxidative stress associated with reproductive performance and the need to discover different sources of antioxidants capable of improving reproductive performance.

In their study reported potency of micronutrients supplementation for control of oxidative stress in female human subjects as highly successful.[26] The study concluded that additional treatment with micronutrients, starting 3 months before *in vitro* fertilization cycles, protects the follicular microenvironment from oxidative stress, thus increasing the number of good quality oocytes recovered at the pickup. Common micronutrients reported as antioxidants include selenium, manganese, and zinc.

While exploring phytochemical sources for antioxidants capable of reducing oxidative stress, reported that *Telfairia occidentalis* aqueous extract ameliorates oxidative stress in brain of rats exposed to gamma rays.[2] The study reported better levels of both enzymatic and nonenzymatic antioxidants in the brain of rats treated with the aqueous extracts after different durations of exposure to gamma rays (source of oxidative stress).

Turmeric powder for preservation of rabbit meat; the turmeric powder proved to be a strong antioxidant source because it prevented lipids peroxidation in rabbit meat even more than synthetic antioxidant source-like ascorbic acid used in the preservation of rabbit meat. This work contributed turmeric as a natural source of antioxidants in widely consume products such as meat burger as alternative for synthetic preservatives which have in them potential toxic compounds.[47] Supplementation of pomegranate peel in rabbit diet is a source of natural antioxidant and concluded that it improved reproductive performance of rabbit due to protective action of antioxidants against lipid oxidation in the cell membrane of the pomegranate.[24,45] The studies recommended using pomegranate peel for newborns, which exhibit a greater sensitivity to oxidative damage than adults, and for the development of the immune system in young animals.

MICROALGAE AS SOURCE OF DIETS AND ANTIOXIDANTS FOR LIVESTOCK PRODUCTION

Exploration of natural antioxidant sources against oxidative damages in animals can serve as livestock production system to beat because it is capable of raising animal's productivity above suboptimal levels, especially at critical physiological states of pre-pubertal, gestation and lactation periods. Natural antioxidants in animal nutrition will be playing similar roles antioxidant-rich foods including onions, garlic, tomatoes, pepper, and orange are playing in human nutrition. In human nutrition, these foods in addition to their regular supply of nutrients are playing roles of protection against microbial damage and supply of bioactive compound preventing oxidative damages in human body system.

Microalgae including *Chlorella vulgaris*, *Dunaliella,* and *Spirulina* have been explored for production of functional bioactive compounds including vitamins, carotenoids, phycocyanin, astaxanthin, and other photosynthetic pigments. Inclusion of microalgae at <10% showed positive effects on growth performance and feed utilization efficiency in broiler chickens. Inclusion of algae at 2.5% and 10% resulted in positive effects on growth performance by increasing weight gain, nutrient utilization, feed digestibility, carcass quality, physiological functions, and intestinal microbial environment.[48]

Chemical composition of microalgae can be efficiently use for improvement of animal product quality and can as well partially replace conventional dietary protein sources in animal diets because in a study, researchers replaced soybean at 0%, 20%, 40%, 60%, and 80% with *C. vulgaris* for production of diets fed to broilers chicken. It was proved that inclusion of the algae as a replacement for soybean is feasible since it contains approximately 60% crude protein with balanced amino acids as well as vitamins, minerals, and antioxidants. Inclusion at 20% in the study was reported tolerable by the chicken and improved the chicken performance.[49]

In a similar study, *C. vulgaris* a microalgae was also explored as a source of nonchemical antibiotics and growth promoter; the researchers reported that the algae is an alternative antibiotic source and growth promoter in chicken because it promoted production performance, immune system, and intestinal microflora of the chicken. It was also reported that even at very small quantity, *C. vulgaris* significantly influence performance and improved physiological activities in chicken because it increases weight gain and phagocytic activity of white blood cells as well as lymphatic tissue development.[22,23] Influence of selenium-enriched with *C. vulgaris* on performance of broiler chickens was also investigated, and the study showed positive effect of the preparations (0.3 mg of *Chlorella* enriched selenium per Kg of diets) on body weight gain and activity of antioxidant enzyme GPx.[18] In addition, inclusion of *C. vulgaris* at 0.07%, 0.14%, and 0.21% in Broiler chickens diets from starter till 42 days improved the performance of the chicken through better feed conversion ratio and better immune system.[35] *C. vulgaris* inclusion at 1.25% of laying birds diets positively affected oxidative stability of the egg yolk lipids and stored eggs this was evaluated by replacement of microalgae with fishmeal, it was concluded that microalgae have potential replacement capability due to its nutritional compositions.[38]

OXIDATIVE STRESS BIOMARKERS OF PHYSIOLOGICAL REPRODUCTIVE SIGNIFICANCE

Cells contain a large number of antioxidants that naturally prevent or repair the damage caused by prooxidants and also regulate redox-sensitive signaling pathways; these antioxidant enzymes include SODs, CAT, and GPx. Shortfall of these internal body antioxidant systems are an indication of oxidative stress and this occurs time-to-time in animals hence feeding antioxidant-rich feedstuff such as algae can contribute to improve internal antioxidant system in animals whereby all these enzymes will be available at optimum levels. As biological markers, poor or low activities of these antioxidant enzymes can serve as indicators of levels of oxidative stress damage at different reproductive stages.

SODs are metalloenzymes that catalyze the dismutation of superoxide anion to molecular oxygen and hydrogen peroxide which is a strong mechanism for development of cellular antioxidant in the body. Poor or low activities of SODs results into increased oxidative stress. SOD work in complementation with another antioxidant enzyme called CAT. SOD converts superoxide radicals by dismutation into hydrogen peroxide

while CAT convert hydrogen peroxide into water in order to become harmless in the body. This is the mechanisms of action of SODs. SODs type depend on associated metals either Manganese SOD or Copper-Zinc SOD. Manganese SOD is located in the mitochondria while Copper-Zinc SOD is located in the cytoplasm.[48]

CAT is antioxidant enzymes which convert hydrogen peroxide – a very strong oxidative damaging compound into water which is a harmless compound in the body. Activities of CAT enzyme are largely located in subcellular organelles called peroxisome in the cell. Measuring of the CAT can be done using CAT ELISA kit where CAT activity is measured by a spectrophotometric procedure evaluating peroxide removal.[49] GPx is an enzyme that catalyzes the reaction which reduces peroxides such as hydrogen peroxides to protect cell from oxidative damage. GPx is an enzyme that catalyzes the reaction which reduces peroxides such as hydrogen peroxides to protect cell from oxidative damage. Higher concentration of this antioxidant can reduce oxidative stress effects in animals.

Mitochondria respiration at cellular level is a process of oxidative phosphorylation leading to the production of by-products which are free radicals that cause cellular damages. Natural process of cellular protection against these free radicals was identified as physiological roles of uncoupling proteins (UCPs) family. It can, therefore, be hypothesized that UCPs are potential part of cellular antioxidant defense system because of its inhibition of oxidative damage on mitochondrion as well as elevated levels of ROS due to its absence. UCPs are group of molecular compounds associated with protection of mitochondria during the process of thermogenesis. They uncouple respiration (oxidation) from adenosine triphosphate (ATP) synthesis in mitochondria. In a situation whereby oxidation is uncoupled from production of energy in the form of ATP; generation of ROS is inhibited in the cell and hence these proteins (UCPs) can, therefore, be categorized as part of cellular antioxidant defense system. These proteins are categorized as UCPs 1, 2 and 3; they are anion carrier proteins found in the mitochondria and distributed in cells of different parts of the body including spleen, lungs, stomach, and white adipose tissue.[50]

Mitochondria as the focal point for cellular thermogenesis and heat dissipation exerts its metabolic responsibilities through passive exchange of small metabolites between cytoplasm and the intermembrane space with the aid of transporter proteins known as UCPs. Structurally their amino acids is hundred and contain two domains of transmembrane while their molecular weight is between 28 KDa and 34 KDa.[51] Members of this protein family include UCPs 1, 2, 3, 4, and 5 and are generally anion carriers. UCP-1 is associated with metabolic protection against cold stress. It is found in the brown adipose tissue which is responsible for mediation of internal heat generation for survival of external cold environments. Another pointer to roles of these protein in energy generation and balance is the effects of thyroid hormone, leptin and noradrenalin hormone on its levels. These hormones are all involved in the process of energy generations and balance, and they also increase levels of UCP-1; therefore, it can be deduced that the protein is an important carrier in mitochondria physiological role of energy production and dissipation.[51]

CONCLUSION

Oxidative stress is a biochemical process that it naturally inevitable for normal body functions; however, it can turn-out to become a biochemical process negatively affecting reproduction hence it can be hypothesized that oxidative stress is a nexus between functional biochemical process and improved productivity. Therefore, the study concluded that abatement of oxidative stress is highly important for promotion of reproduction and dietary supplementation of microalgae can serve as natural sources of antioxidants for reducing negative effects of oxidative stress.

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