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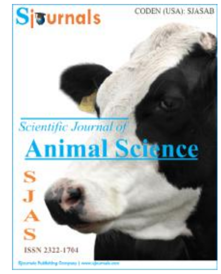

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Review article

Impact of antioxidants, oxidative stress on gametogenesis, embryogenesis, and fertility in livestock production

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A B S T R A C T

Gametogenesis is a fundamental aspect in sexual reproduction. Successful gametogenesis transcends to high fertility in any breeding herd when all other production factors are held optimum. The interaction amongst gametogenesis, embryogenesis, antioxidants and oxidative stress should be considered a key component of livestock fertility which has the potential to improve efficiency. This discussion looks at the influence of antioxidants and oxidative stress on gametogenesis, embryogenesis and livestock fertility in broad. Any disorders during gametogenesis and embryogenesis result in reduced fertility in livestock. Infertility is one of the major bottlenecks hampering livestock production. Livestock fertility is a multi-factorial trait as its decline is attributed to physiological, genetic, and environmental as well as husbandry factors. Furthermore, the discussion will spell out how antioxidants can be exploited as a remedy to tackle negative effects of reactive oxygen species in *in vivo*.

1. Introduction

Antioxidants are recognized as feed additives for elongating shelf life of feedstuffs based on their ability of preventing lipid peroxidation. Antioxidants' role exceeds this notion of being simple additives to animal rations. Dietary antioxidants and those circulating *in vivo* have been noticed for scavenging free radicals and preventing the formation of ROS, hence combating oxidative stress in livestock production. This helps promote livestock health, wellbeing and efficiency per each livestock unit. The food industry has acknowledged the significance of antioxidant supplementation in livestock. Nutritional, organoleptic properties and shelf life qualities of animal products from animals subjected to antioxidant supplementation showed an improvement compared to none antioxidant beneficiaries (Salami et al., 2016).

Oxidative stress results from a variance between the generation of ROS and antioxidant strategies *in vivo*. Reactive oxygen species are inevitable as they are formed during normal aerobic metabolic reactions within the mitochondrion. In this regard, spermatozoa, oocytes and embryos depend on mitochondrial oxidative phosphorylation for energy with ROS being a byproduct. Excess ROS distort the antioxidant capacity of the spermatozoa and seminal plasma leading to oxidative stress. Oxidative stress is associated with detrimental effects of infertility in livestock. ROS have a positive correlation to any form of stress exerted on the animal. Stress has been implicated with the increase of ROS in the male reproductive tract. An increase on the ROS translates to hypo spermatogenesis, poor sperm quality resulting in sire infertility. Sperm quality determines the ability of the male gamete to successfully fertilize an ova henceforth support the development of a normal embryo. Defective sperm function is a major cause of sire infertility. There is need for the development of viable antioxidant therapies to help solve problems of hypospermatogenesis in livestock production (Agarwal et al., 2014; Tsunoda et al., 2014; Migaud et al., 2013; Turner and Lysiak, 2008; Koksal et al., 2003).

Hypospermatogenesis may be encountered by strengthening the antioxidant testicular defense system. Testicular lipid peroxidation has been controlled by optimum zinc supplementations in male rates. Similarly, vitamin E and selenium supplementations have been used to protect avian spermatozoa tastes and liver form lipid peroxidation. Malnutrition, vitamin E, selenium and zinc deficiency may result in testicular oxidative stress. Optimum supplementations of vitamins and essential trace elements is commendable and it lowers susceptibility of sires to testicular lipid peroxidation.

An impairment of the antioxidant systems due to excess ROS enhance testicular lipid peroxidation leading to testicular malfunction. Spermatozoa are rich in polyunsaturated fatty acids, this makes them more exposed to oxidative induced damage and lipid peroxidation. This translates to hypospermatogenesis, impacting negatively on the sperm's viability and fertilization potential. Essential trace elements such as zinc should be maintained optimum as it elongates the sperm's functional lifespan (Agarwal et al., 2014; Surai et al., 1998; Oteiza et al., 1996; Ahotupa and Huhtaniemi, 1992; Bedwal and Bahuguna, 1994).

2. Benefits of antioxidants on gametogenesis and livestock fertility

Gametogenesis and embryogenesis occur successfully when the antioxidant systems are higher. Antioxidant defense systems harness excess ROS being a cause of oxidative stress. Vulnerability of productive animals to oxidative stress lead to infertility, a reproductive abnormality in both males and females. Optimum antioxidant defense systems promote super ovulation and are an important factor in sheep and goat production as they give rise to multiple births. Ewes and does that have multiple births are associated with pregnancy toxemia during late gestation. A failure of gluconeogenesis during this period of high glucose demand exposes ewes and does to pregnancy toxemia (ketosis). Oxidative stress is extremely pathogenic. It is associated with numerous reproductive and metabolic disorders in livestock. Polycystic ovary syndrome, retained placenta, uterine prolapse, endometritis, cystic ovaries, low conception rates, pregnancy complications, spontaneous abortion sare interlinked conditions affecting reproductive livestock efficacy and are as a result of oxidative stress as enhanced by ROS (Agarwal and Allamaneni, 2004; Hemingway, 2003; Marteniuk and Herdt, 1988).

Antioxidant defense exploits both, enzymatic and non-enzymatic strategies. Enzymatic antioxidant such as superoxide dismutase, glutathione peroxidase, glutathione reductase and catalase are there to strengthen the antioxidant defense system. Vitamin E and A have proved to be vital non-enzymatic antioxidants that protect cell integrity and supporting livestock reproductive function and efficacy.

An optimum total antioxidantstatus *in vivo* prevents the formation of defective gametes and poorly developing embryos. Selenium is an essential trace element for good testicular development, spermatogenesis, spermatozoa motility, capacitation and function. Enzyme glutamine peroxidase is powered by selenium to protect cellular membranes from peroxidative induced damage. Perfect combinations of vitamin E and selenium are a useful tool of improving spermatogenesis, semen quality and conception rates in infertile bovines. In contrary antioxidant supplemented in excess tend to overwhelm the signaling function of ROS and impede the reproductive potential. There are more chances of higher ROS generation during assisted reproduction techniques *in vitro*. The risk of oxidative stress generation *in vitro* is even higher compared to *in vivo* during artificial reproductive technology (ART) due to limitations of natural antioxidants systems against a range of potential ROS sources. Higher levels of ROS during *in vitro* fertilization (IVF) may translate to cytotoxic damage to gametes. Antioxidant systems have been used successfully *in vitro* to neutralize the effects of ROS by maintaining an equilibrium between antioxidants and pro oxidants. Detoxification of lipid peroxidation products enhances sperm function. This supports sperm capacitation, activation and render it competent to fertilize an oocyte (Luddi et al., 2016; Tsunoda et al., 2014; Moslemi and Tavanbakhsh, 2011; Al-Qudah, 2011; Gonçalves et al., 2010; Sies, 1997).

3. Effects of oxidative stress on gametogenesis and livestock fertility

Oxidative stress is a result of intense accumulation of ROS. Reactive oxygen species somehow have a dual purpose *in vivo* as they serve as key signal molecules in physiological processes but also have a great influence in pathological processes. There is evidence that ROS are a predominant cause of livestock infertility. Higher concentrations of ROS cause cell degeneration and premature senescence of the reproductive tract cells. Excess ROS have an influence on gamete quality and gamete interaction. This implies that ROS form part of the determinants of fertilization rates. Oxidative stress may as well lead to depletion of testosterone and inhibition of spermatogenesis. This leads to defects in spermatozoa. Sperm function is also affected by oxidative stress assaults. In females oxidative stress may lead problems such as impaired synthesis or secretion of follicle stimulating hormone and luteinizing hormone, abnormal ovarian development and maturation, disruption of the estrous cycle, fertilization, poor embryogenesis, frequent spontaneous abortions, prolonged gestation periods, teratogenicity, still births, difficulty in parturition, pre-eclampsia, toxemia and low birth weights of progeny. Offspring of antioxidant weak ewes, does and dams suffer from white muscle. This can be addressed by providing dietary antioxidants to gestating and lactating females (Tsunoda et al., 2014; Agarwal et al., 2012; Agarwal et al., 2005; Cohen-Kerem and Koren, 2003).

4. Fertilization and embryogenesis

Gametes viability is the main proponent to successful fertilization. Gametes quality and function ensure that a sperm can fertilize an ova and form a normal embryo. Both gametes affect the fertilization process and the subsequent embryogenesis and embryo survival. The sperm should be active, capacitated and motile so that it swims towards the over and undertakes the process of fertilization. Oxidative stress plays a role during spermatogenesis and it leads to hypospermatogenesis through testicular lipid peroxidation. Hypospermatogenesis lowers sperm motility, a key prerequisite for fertilization. Defected sperm results to lower fertilization rates. In fish production sperm motility presents a positive correlation with fertilization success. Sperm motility can be enhanced by exploiting antioxidant therapies such as vitamin E, selenium and zinc supplementations at optimum levels. An elevation of ROS during ART particularly in IVF enhance cytotoxic damage to gametes. It is very much associated with poor fertilization rates. Therefore, it is suffice to advocate for proper antioxidant defense systems to regulate ROS to optimum levels. This ensures sperm capacitation, motility and oocyte penetrability by the spermatozoa leading to successful fertilization. The balance between antioxidants and pro oxidants is also a determinant of successful embryogenesis as well as embryo survival (Tsunoda et al., 2014; Bobe and Labbé, 2010; Gonçalves et al., 2010; Rurangwa et al., 2004).

5. Implantation and gestation

Antioxidants and ROS have a role in regulating reproductive processes such as embryo implantation, and gestation. There should be an equilibrium between antioxidants and ROS. A deviation from this mean in favor of ROS subjects the reproductive tract and the entire body to oxidative stress which distorts the reproductive process as well as lowering the reproductive function. An elevation of ROS is a common phenomenon and they are unavoidable during embryo metabolism and enzymatic mechanisms. If left uncontrolled oxidative stress may lead to embryonic mortality hence implantation rate will be reduced per each given time. Thus ROS are required for cellular functioning and are regulated by antioxidant systems.

Fetal growth restrictions, defective embryo development as well as spontaneous abortions contribute to the lower reproductive function in females leading to terminated gestation and this is as a result of oxidative stress. The third trimester in dairy cows is associated with an increase in ROS production due to a high metabolic activity. This is complemented by oxidative stress assaults such as increased lipid peroxidation and ketosis. It is therefore a noble idea to maintain the antioxidant and pro-oxidant balance to reduce reproductive failure. This can be achieved through oral non-enzymatic and enzymatic antioxidant supplementations and by maintaining good husbandry practices throughout the animals' life cycle (Al-Gubory et al., 2010; Castillo et al., 2005; Guérin et al., 2001).

6. Interaction of antioxidants and pro-oxidants during the peripariturient period

Physiological changes and increased metabolic demands are common during the perparituríent period in livestock production. Nutritional stress and poor antioxidant defense system affect the neutrophil function during the perparituríent period. This affects the innate immune system of the reproductive female. In this regard, deficiencies of dietary vitamin E and selenium expose reproductive females to retained placenta, uterine prolapse and vaginal prolapse as well as still births. Melondyaldeyde (MDA) is one of the end products of lipid peroxidation during oxidative stress. High levels of MDA have been noticed during the peripariturient period and particularly when the antioxidant mechanisms are low. This trend seem to decrease from early lactation going onwards. Besides this natural decrease balanced nutrition rations including essential antioxidant supplements may help control the effects of MDA during this period (Spears and Weiss, 2008; Pintea and Zinveliu, 2006; Gaweł et al., 2004).

7. Conclusion

Antioxidants are a necessity, they scavenge and prevent the further formation of ROS. Products of lipid peroxidation such as MDA are detoxified by antioxidants. Antioxidants play a key role in ensuring a positive animal reproductive function and efficacy. Use of enzymatic and non-enzymatic antioxidants in animal production has seen a positive increase in livestock fertility. There is evidence that ROS are a predominant cause of oxidative stress a challenging condition which is implicated in lowering a range of reproductive processes, they have some important roles that they play.

Reactive oxygen species serve as key signal molecules in physiological processes up to a certain point beyond which they become toxic in the body hence commence pathological processes. It is therefore commended to optimally supplement antioxidants to control ROS as over supplementation tends to impair ROS positive functionality. To realize the full benefits of antioxidants in animal production, antioxidant dosage and timing of supplementation should be taken into consideration. For instance in reproductive females, antioxidant defense demands differ from gametogenesis up to the peripariturient period. Therefore antioxidant supplementation is determined by a thread of genetic and non-genetic factors which influence the total antioxidant status in an animal system.

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