Scientific Journal of Biology

Review Article

Supplementation of Nanoparticles During *in vitro* Manipulation of Mammalian Gametes and Embryos

Nasser Ghanem[1,2]*, Romysa Samy[1], Eman Kh Kassab[1], Beshoy SF Khalil[1], Aya Ahmed Kordy[1], Marwa MH Said[1], Nouran S Rashed[1], Md. Fakruzzaman[2] and Kong IK[3]

[1]Animal Production Department, Faculty of Agriculture, Cairo University Research Park, Cairo University, Egypt

[2]Animal Production Department, Faculty of Agriculture, Cairo University Research Park, Cairo University, Egypt

[3]Department of Genetics and Animal Breeding, Faculty of Animal Science and Veterinary Medicine, Patuakhali Science and Technology University, Out Campus, Khanpura, Babuganj, Barishal-8210, Bangladesh

[4]Division of Applied Life Science (BK21), Graduate School of Gyeongsang National University, Jinju 660-701, Republic of Korea

***Address for Correspondence:** Nasser Ghanem, Animal Production Department, Faculty of Agriculture, Cairo University Research Park, Cairo University, Egypt, E-mail: nassergo@agr.cu.edu.eg

Submitted: 09 March 2021; **Approved:** 15 March 2021; **Published:** 19 March 2021

Cite this article: Ghanem N, Samy R, Kassab EK, Khalil BS, Kordy AA, Said MM, Rashed NS, Fakruzzaman M, Kong IK. Supplementation of Nanoparticles During *in vitro* Manipulation of Mammalian Gametes and Embryos. Sci J Biol. 2021 March 19;4(1): 001-004. doi: 10.37871/sjb.id21

Abstract

There is intensive application of biotechnology in the field of animal breeding. For instance, artificial insemination from elite males is applied worldwide as the main tool for genetic improvement of productive traits (milk and meat production) several decades ago. In addition, embryo production both *in vivo* and *in vitro* from selected females is an effective tool to accelerate genetic gain of preferable livestock economic traits. These tools are among the assisted reproductive techniques that have been applied to improve reproductive efficiency and outcomes of human as well as farm animal species. *In vitro* manipulation of gametes and embryos required optimized condition that mimics *in vivo* culture of female reproductive tract. Recently, nanotechnology was introduced to provide chemicals at nanoscale size that have high a wide range of biological activities and beneficial biomedical applications. Indeed, several nanoparticles have antioxidant effect that could be beneficial in reducing or preventing oxidative stress during *in vitro* manipulation of mammalian cells, gametes and embryos. Therefore, the supplementation of nanoparticles could be useful during *in vitro* culture of cells and embryos. Moreover, cryopreservation of oocytes, sperm and embryos can be improved by supplementing nano protectants to freezing medium. Recent studies have evaluated the supplementation of several nanoparticles among them zinc and selenium. However, there is still limitation for supplementation of some nano chemicals due to of cytotoxic effect. The current application and future prospects of nanomaterials is the focus of this review.

Keyword: Nanoparticles; Gametes; Embryo; Development

BIOGRAPHY

Dr. Nasser Ghanem is an associated professor at Department of Animal Production, Faculty of Agriculture, Cairo University, Egypt. I have obtained my M.SC in the field of reproductive biology, Cairo University, Faculty of Agriculture, Egypt. And Dr. Nasser Ghanem has got DAAD award for short visit, 2004. I did my Ph.D degree in reproductive genomics at Faculty of Agriculture, Bonn University, Germany. And Dr. Nasser Ghanem got the Faculty of Agriculture Award, Bonn University, in 2009, my major filed of research is animal science with more focus on reproductive biology and genomics of farm animal species. During my Ph.D study, I have contributed to find out molecular markers of bovine oocytes quality selected based on two different well-established models of oocyte selection, which published in outstanding journals. And Dr. Nasser Ghanem got the International Publication Award, Cairo University, in 2009, 2011 and 2019. In addition, I have participated in other research projects that have discovered novel molecular markers of fertility in different tissues and species. Therefore, I have written many manuscripts that already published in outstanding international journals with well-recognized impact factor from 1.5 to 5.2. Furthermore, I have presented my publications in both national and international meetings and conferences. I was research partner in developing new projects ideas that have been successfully got funding from well-known international resources like European Scientific Commission under the frame work of the European project entitled SABRE in addition to DFG in Germany, BK21 in South Korea, Academy of Finland and Science and Technology Development Fund (STDF) in Egypt. Finally, I have a good contact with national and international collaborators all over the world. Dr. Nasser Ghanem is the head of cell culture and embryology lab, Cairo University Research Park, Faculty of Agriculture, Egypt. He is an international reviewer and member of editorial board of several outstanding journals.

METHODOLOGY

Nanotechnology is used to manipulate materials at nanoscale size approximately 1-100 nanometer (nm), which improve its reactivity and solubility. The size and structure of NPs makes it easier to be integrated into a number of biomedical application. The nanoparticles (NPs) have become very attractive for their applications in the fields of food, agricultural production, human health, disease control, veterinary medicine, food and feed science.

BACKGROUND

The research focused on the application of nanoparticles in animal fertility improvement is still limited. For example, an early study has indicated that Zn and is crucial for development and spermatogenesis activity of testis [1–3]. Recently, Jahanbin, et al. [4] have indicated that plasma membrane integrity and live spermatozoa with active mitochondria was increased in bull semen treated with Zn nanoparticles compared to untreated group. Moreover, the profile of Malondialdehyde (MDA) was lower in buck semen supplemented with Zn nanoparticles. On the other hand, progressive motility, sperm total motility, sperm viability, fragmentation of DNA, conception and pregnancy rate of cows inseminated with treated semen were similar in Zn nanoparticles and control groups [4]. Additionally, application of Zn nanoparticles during in vitro maturation has enhanced preimplantation embryo development; however, supplementation of Zn nanoparticles during fertilization step has no effect on development of bovine embryos [4]. This study highlight the importance on clarifying the mode of action of nano form biological particles on embryo development

APPLICATION OF NANOPARTICLES DURING PRE IMPLANTATION DEVELOPMENT

The production of Reactive Oxygen Species (ROS) during *in vitro* culture of animal cells and embryos could exceeded their endogenous antioxidant capacity; which cause oxidative stress that finally lead to cell death [5]. The antioxidant effect of some nanoparticles support the idea of their beneficial use as culture supplement during in vitro manipulation of mammalian cells. For example, administration of cerium dioxide nanoparticles into male rats for 10 days reduced blood lipid peroxidation and elevated superoxide dismutase and catalase activity that subsequently enhanced semen morphological parameters such as sperm count, viability, motility [6]. Indeed, nanoparticles have small size ranged from 1 to100 nm that applied widely in a variety of biological as well as industry fields. In general, nanoparticles can be classified into four groups: metals, natural compounds, nanostructured materials and polymers [7]. Our research group have reported an increase in bovine blastocyst development rate when Zn nanoparticles was supplemented to maturation medium at concentration of 10-6 M [8]. The positive impact of Zn nanoparticles could be due to increased bioavailability of this metal that be able to enhance the activity of antioxidant enzymatic system in cumulus-oocyte complexes that support embryo cleavage [9].

Another study has indicated a higher rate of embryo cleavage and blastocyst formation and reduction in blastocyst apoptotic cells that was linked with decreased level of ROS bovine oocytes supplemented with nanoencapsulated melatonin during *in vitro* maturation [10]. The supplementation of antioxidants in organic form could be useful for preimplantation development however; the efficiency and bioavailability will be affected with *in vitro* condition, which gives the supplementation of nanoparticles a priority to be tested as antioxidant [11]. Noteworthy, the way by which nanoparticles is delivered to animal cell culture have a profound effect on cellular response [12].

APPLICATION OF NANOPARTICLES DURING CRYOPRESERVATION

Cryopreservation of sperm collected from genetically selected bulls is a prerequisite for worldwide application of Artificial Insemination (AI) in cattle breeding [13]. While, cryopreservation of oocyte is a key process in propagating the genetic merit of female farm animals with desired economic traits and conservation of local endangered species. The routine procedure of assisted reproduction in human require freezing of sperms, oocytes, embryos and ovarian tissue. Mammalian gametes have a high content of lipids either in their membranes or in the cytoplasm. Spermatozoa have high lipid content in their membranes in a form of polyunsaturated fatty acids that reduced membrane integrity and viability when oxidized with ROS [14-20]. Indeed, the high cytoplasmic lipid content of oocytes could be target of oxidative stress induced by ROS, which compromised early preimplantation development under in vitro environment [17-19]. Therefore, several research groups have recommended supplementation of antioxidant during cryopreservation of spermatozoa of bull [13], ram [20], boar [21] and human [22]. Antioxidant supplementation after freezing and thawing process has restored the developmental competence of mice COCs [23]. While, addition of antioxidants in freezing medium has improved quality and of vitrified mice embryos [24] Viability of mammalian gametes after freezing can be improved by supplementation of Nano protectants in cryopreservation medium. Used to dilute sperm, extenders are buffering agents and provide sperm with nutrients required for prolonged storage. Nanoparticles could contain antibiotics that inhibit microbial growth and enhance their viability after freezing of boar sperm [25] addition of selenium nanoparticles at concentration of 1.0 µg/ml has enhanced the post-thaw physical, biochemical quality and in vivo fertilizing capacity of cryopreserved bull semen [26]. On contrast, there was a reduction of human sperm motility when mixed with gold nanoparticles [27].

CONCLUSION

Research done in the application of nanoparticles on assisted reproduction is still in the early phase of practice. However, several studies have indicated the beneficial and side effects of nanoparticle application on assisted reproductive techniques of different mammalian species. This make the research in this area of great interest to optimize the size, concentration and the way of supplementation.

REFERENCES

1. Agarwal A, Gupta S, Sharma RK. Role of oxidative stress in female reproduction. Reprod Biol Endocrinol. 2005 Jul 14;3:28. doi: 10.1186/1477-7827-3-28. PMID: 16018814; PMCID: PMC1215514.
2. Kobyliak NM, Falalyeyeva TM, Kuryk OG, Beregova TV, Bodnar PM, Zholobak NM, Shcherbakov OB, Bubnov RV, Spivak MY. Antioxidative effects of cerium dioxide nanoparticles ameliorate age-related male infertility: optimistic results in rats and the review of clinical clues for integrative concept of men health and fertility. EPMA J. 2015 Jun 10;6(1):12. doi: 10.1186/s13167-015-0034-2. PMID: 26097523; PMCID: PMC4475301.
3. Hill EK, Li J. Current and future prospects for nanotechnology in animal production. J Anim Sci Biotechnol. 2017 Mar 14;8:26. doi: 10.1186/s40104-017-0157-5. PMID: 28316783; PMCID: PMC5351054.
4. Jahanbin R, Yazdanshenas P, Rahimi M, Hajarizadeh A, Tvrda E, Nazari SA, Mohammadi-Sangcheshmeh A, Ghanem N. In Vivo and In Vitro Evaluation of Bull Semen Processed with Zinc (Zn) Nanoparticles. Biol Trace Elem Res. 2021 Jan;199(1):126-135. doi: 10.1007/s12011-020-02153-4. Epub 2020 Jun 3. PMID: 32495179.
5. Farin PW, Piedrahita JA, Farin CE. Errors in development of fetuses and placentas from in vitro-produced bovine embryos. Theriogenology. 2006 Jan 7;65(1):178-91. doi: 10.1016/j.theriogenology.2005.09.022. Epub 2005 Nov 2. PMID: 16266745.
6. Remião MH, Lucas CG, Domingues WB, Silveira T, Barther NN, Komninou ER, Basso AC, Jornada DS, Beck RC, Pohlmann AR, Junior AS, Seixas FK, Campos VF, Guterres SS, Collares T. Melatonin delivery by nanocapsules during in vitro bovine oocyte maturation decreased the reactive oxygen species of oocytes and embryos. Reprod Toxicol. 2016 Aug;63:70-81. doi: 10.1016/j.reprotox.2016.05.016. Epub 2016 May 24. PMID: 27233482.
7. Lucas CG, Remião MH, Komninou ER, Domingues WB, Haas C, Leon PM, Campos VF, Ourique A, Guterres SS, Pohlmann AR, Basso AC, Seixas FK, Beck RC, Collares T. Tretinoin-loaded lipid-core nanocapsules decrease reactive oxygen species levels and improve bovine embryonic development during in vitro oocyte maturation. Reprod Toxicol. 2015 Dec;58:131-9. doi: 10.1016/j.reprotox.2015.10.004. Epub 2015 Oct 22. PMID: 26476360.
8. Moore TL, Urban DA, Rodriguez-Lorenzo L, Milosevic A, Crippa F, Spuch-Calvar M, Balog S, Rothen-Rutishauser B, Lattuada M, Petri-Fink A. Nanoparticle administration method in cell culture alters particle-cell interaction. Sci Rep. 2019 Jan 29;9(1):900. doi: 10.1038/s41598-018-36954-4. PMID: 30696847; PMCID: PMC6351679.
9. Olfati Karaji R, Daghigh Kia H, Ashrafi I. Effects of in combination antioxidant supplementation on microscopic and oxidative parameters of freeze-thaw bull sperm. Cell Tissue Bank. 2014 Sep;15(3):461-70. doi: 10.1007/s10561-013-9412-y. Epub 2013 Nov 29. PMID: 24292238.
10. Agarwal A, Virk G, Ong C, du Plessis SS. Effect of oxidative stress on male reproduction. World J Mens Health. 2014 Apr;32(1):1-17. doi: 10.5534/wjmh.2014.32.1.1. Epub 2014 Apr 25. PMID: 24872947; PMCID: PMC4026229.
11. Baumber J, Ball BA, Linfor JJ, Meyers SA. Reactive oxygen species and cryopreservation promote DNA fragmentation in equine spermatozoa. J Androl. 2003 Jul-Aug;24(4):621-8. doi: 10.1002/j.1939-4640.2003.tb02714.x. PMID: 12826702.
12. Kao SH, Chao HT, Chen HW, Hwang TIS, Liao TL, Wei YH. Increase of oxidative stress in human sperm with lower motility. Fertil Steril. 2008 May;89(5):1183-1190. doi: 10.1016/j.fertnstert.2007.05.029. Epub 2007 Jul 31. PMID: 17669405.
13. Boni R, Santella L, Dale B, Roviello S, Palo DR, et al. An ultrastructural study of maturation in buffalo oocytes. Acta Medica Veterinaria 1992; 38:153-l61.
14. Halliwell B. Free radicals, reactive oxygen species and human disease: a critical evaluation with special reference to atherosclerosis. Br J Exp Pathol. 1989 Dec;70(6):737-57. PMID: 2557883; PMCID: PMC2040729.
15. Nasr-Esfahani MH, Aitken JR, Johnson MH. Hydrogen peroxide levels in mouse oocytes and early cleavage stage embryos developed in vitro or in vivo. Development. 1990 Jun;109(2):501-7. PMID: 2401209.
16. Sánchez-Partida LG, Setchell BP, Maxwell WM. Epididymal compounds and antioxidants in diluents for the frozen storage of ram spermatozoa. Reprod Fertil Dev. 1997;9(7):689-96. doi: 10.1071/r97045. PMID: 9623488.
17. Malo C, Gil L, Gonzalez N, Martínez F, Cano R, de Blas I, Espinosa E. Anti-oxidant supplementation improves boar sperm characteristics and

fertility after cryopreservation: comparison between cysteine and rosemary (Rosmarinus officinalis). Cryobiology. 2010 Aug;61(1):142-7. doi: 10.1016/j.cryobiol.2010.06.009. Epub 2010 Jun 30. PMID: 20599883.

18. Shaaban AA, Shaker ME, Zalata KR, El-kashef HA, Ibrahim TM. Modulation of carbon tetrachloride-induced hepatic oxidative stress, injury and fibrosis by olmesartan and omega-3. Chem Biol Interact. 2014 Jan 25;207:81-91. doi: 10.1016/j.cbi.2013.10.008. Epub 2013 Oct 18. PMID: 24144775.

19. Mukunoki A, Takeo T, Nakagata N. N-acetyl cysteine restores the fertility of vitrified-warmed mouse oocytes derived through ultrasuperovulation. PLoS One. 2019 Oct 22;14(10):e0224087. doi: 10.1371/journal.pone.0224087. PMID: 31639156; PMCID: PMC6804996.

20. Truong TT, Gardner DK. Antioxidants increase blastocyst cryosurvival and viability post-vitrification. Hum Reprod. 2020 Jan 1;35(1):12-23. doi: 10.1093/humrep/dez243. PMID: 31916568.

21. Bryła M, Trzcińska M. Quality and fertilizing capacity of boar spermatozoa during liquid storage in extender supplemented with different antibiotics. Anim Reprod Sci. 2015 Dec;163:157-63. doi: 10.1016/j.anireprosci.2015.11.005. Epub 2015 Nov 10. PMID: 26586542.

22. Khalil WA, El-Harairy MA, Zeidan AEB, Hassan MAE. Impact of selenium nano-particles in semen extender on bull sperm quality after cryopreservation. Theriogenology. 2019 Mar 1;126:121-127. doi: 10.1016/j.theriogenology.2018.12.017. Epub 2018 Dec 5. PMID: 30551018.

23. Xu Y, Wang N, Yu Y, Li Y, Li YB, Yu YB, Zhou XQ, Sun ZW. Exposure to silica nanoparticles causes reversible damage of the spermatogenic process in mice. PLoS One. 2014 Jul 8;9(7):e101572. doi: 10.1371/journal.pone.0101572. PMID: 25003337; PMCID: PMC4086902.

24. Caldamone AA, Freytag MK, Cockett AT. Seminal zinc and male infertility. Urology. 1979 Mar;13(3):280-1. doi: 10.1016/0090-4295(79)90421-7. PMID: 442346.

25. Chia SE, Ong CN, Chua LH, Ho LM, Tay SK. Comparison of zinc concentrations in blood and seminal plasma and the various sperm parameters between fertile and infertile men. J Androl. 2000 Jan-Feb;21(1):53-7. PMID: 10670519.

26. Colagar AH, Marzony ET, Chaichi MJ. Zinc levels in seminal plasma are associated with sperm quality in fertile and infertile men. Nutr Res. 2009 Feb;29(2):82-8. doi: 10.1016/j.nutres.2008.11.007. PMID: 19285597.

27. Jahanbin R, Yazdanshenas P, Rahimi M, Hajarizadeh A, Tvrda E, Nazari SA, Mohammadi-Sangcheshmeh A, Ghanem N. In Vivo and In Vitro Evaluation of Bull Semen Processed with Zinc (Zn) Nanoparticles. Biol Trace Elem Res. 2021 Jan;199(1):126-135. doi: 10.1007/s12011-020-02153-4. Epub 2020 Jun 3. PMID: 32495179.