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# Investigating the Uses of ''Nanotechnology'' as an Alternative Approach to Increasing Animal Welfare in Dairy Cattle

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**Abstract:** In the recent years, proper animal welfare practices in dairy farming have become an urgent topic to investigate in the animal sciences fields. Practices made in accordance with the five principles of freedom (hunger, thirst, well-being etc.), which are important for animal welfare, will improve the levels of animal welfare and the level of product (milk yield, fertility etc.) quality. There is a multitude of technologies to be selected to achieve proper animal welfare practices. One of the most complex and newest technologies is nanotechnology. Nanotechnology is used in many different fields such as nanomaterials, nano-bio system, nanomedicine, nanomineral, nanoimaging, nanoencapsulation, nano lubricants, nanocoating, nano paint, nano insulation, etc. Since animal welfare practices in dairy cattle affect yield, research have been carried out to improve animal welfare nowadays. But the limited information available on the use of nanotechnology as an alternative approach to improve animal welfare has made this research necessary. The purpose of this review is to shed light on further research in this area, and to better understand and select useable nanotechnologies for dairy cattle to improve animal welfare.
**Keywords**: Animal welfare, dairy cattle, nanotechnology

**Süt Sığırlarında Hayvan Refahının Artırılmasına Alternatif Bir Yaklaşım Olarak "Nanoteknoloji"nin Kullanım Olanaklarının Araştırılması**

**Öz:** Süt sığırcılığında doğru refah uygulamaları hayvan yetiştiriciliği alanı için son yıllarda çalışılması gereken bir konu haline gelmiştir. Hayvan refahı için önemli olan beş özgürlük ilkesine (açlık, susuzluk sağlıklı olma hali vb.) uygun olarak yapılan uygulamalar, hayvan refahı ve ürün (süt verimi, döl verimi vb.) kalite düzeyini artıracaktır. Hayvan refahı uygulamalarını geliştirebilecek pek çok uygulama vardır. Bunlardan biri de karmaşık ve yeni bir uygulama olan nanoteknolojidir. Nanoteknoloji birçok farklı alanda kullanılmakta örneğin, nanomalzemeler, nano-biyosistem, nanotıp, nanomineral, nanogörüntüleme, nanokapsülasyon, nano yağlayıcılar, nanokaplama, nano boya, nano yalıtım vd. Süt sığırlarında hayvan refahı uygulamaları verimi etkilediğinden nanoteknolojinin hayvan refahını artırmada alternatif bir yaklaşım olarak kullanılması hakkında sınırlı bilgi olması araştırmayı gerekli kılmıştır. Bu derlemenin amacı; hayvan refahının iyileştirilmesi ile ilgili olarak süt sığırları için kullanılabilir nanoteknolojilerin daha iyi anlaşılması ve seçilmesi için bu alanda yapılacak yeni araştırmalara ışık tutmaktır.
**Anahtar kelimeler:** Hayvan refahı, nanoteknoloji, süt sığırcılığı

## Introduction

The term "nanotechnology" was invented at the University of Tokyo in 1971 by Professor Norio Taniguchi (Rajak, 2018). The prefix "nano" is derived from the Greek word "nanos", signifying "dwarf" (Ye et al., 2012). Nanotechnology can be defined as the design, synthesis, and application of materials and devices whose size and shape have been engineered at the nanoscale (Buzea et al., 2007). It exploits unique chemical, physical, electrical, and mechanical properties that emerge when matter is structured at the nanoscale (Buzea et al., 2007). The nanoscopic scale (or nanoscale) usually refers to structures with a length scale applicable to nanotechnology, usually cited as 1-100 nano meters. In more technical terms, the word "nano" means $10^{-9}$, or one billionth of something (Kirdar, 2015). So, nanotechnology is the study of very small structures, having the size of 0.1 to 100 nm (Nikalje, 2015).

There are three methods to synthesize nanomaterials. Top-down manufacturing, bottom-up manufacturing, and convergence of top-down and bottom-up techniques (RSE, 2004). Firstly, top down manufacturing is begun with a pattern generated on a larger scale, then reduced to nanoscale. This method have some weakness there is by nature, aren't cheap and quick to manufacture also slow and not suitable for large scale production (Anonym, 2021). Secondly,

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bottom-up method is start with atoms or molecules and build up to nanostructures. But this method also has weakness, there is for fabrication process much less expensive (Anonym, 2021). Finally, convergence of top-down and bottom-up techniques is a combination between top-down and bottom-up manufacturing (RSE, 2004).

In recent years nanotechnology has been widely used in the many fields since they attract increasing investment from governments and industry around the world (Dowling, 2004). Governments and organizations around the world compete to commercialize nanotechnologies and nanomaterials. Nanotechnology stands to produce scientific and technological advances in diverse fields. For examples, nanotechnology can be applied in the human health, medicine, engineering, food, biosystem, electronics, imaging, fiber, composites, cosmetics, coating, paint, agriculture, and dairy cattle.

***Properties of Nanotechnology***

In practice, the physical, chemical, and biological properties of a substance are determined by the association of physicochemical phenomena that act on the matter (Fesseha et al., 2020). Nanoparticles or nanomaterials show some effects produced by their active ingredients. There are quantum tunneling, quantum phase transition, surface effect, quantum size-effect confinement and nonlinear susceptibility enhancements (Lue, 2007). Thus, the active ingredient of nanoparticles has provided and increased their stability (King et al., 2018). Moreover, they stabilize under high temperature and pressure (Stoimenov et al., 2002).

There are many types of the nanoparticles. The most common ones are polymeric nanoparticles, liposomes, fullerenes, nanotubes, nanoshells, solid lipid nanoparticles (SLNs), micelles, dendrimers, metallic nanomaterials, magnetic nanoparticles, ceramic nanomaterials, quantum dots, nanoemulsion, microbivores, nanobubbles, and respirocytes (Meena et al., 2018). Furthermore, nanomaterials can be categorized in two types as organic nanomaterials and inorganic nanomaterials (Fesseha et al., 2020). Organic nanomaterials can be produced from organic materials, such as proteins, lipid, sugar and the other. For instance, nanocapsules with lipid formulations are possible with improved solubility, high bioavailability and establishment of sustained liberation of the nanoencapsulated food constituents (Akhavan et al., 2018). Nanomaterials can be produced from minerals such as silicon dioxide, calcium and magnesium, silver nanoparticles, and the other. The example is the nano-ZnO promoted the proliferation of the cells and did not injury the cells at lower concentrations (Feng et al., 2009).

***The Significance of Nanotechnology in Dairy Cattle***

Challenges in the dairy farming sector are getting more complex year by year, because livestock production will face some problems in the future as well as today. The problems are covering at all production system stage. The upstream includes the dairy farming system and the downstream includes the dairy product processing system. The main goal of breeders was to increase productivity and efficiency in the past. However, this discussion will be focused only in the upstream area or on-farming. Key drivers for future innovation are basically genomics, information & communication technology (ICT), microsystem and nanotechnology (Den Hartog and Sijtsma, 2013). The most challenges in the dairy cattle can be divided into some areas. There is feed quality, metabolic and reproduction disorders, infectious diseases, barn facilities, and pollutants. Some examples of the application of nanotechnology to solve those dairy challenges are Ag nanoparticles at concentrations lower than the MIC drastically inhibited production of aflatoxin by A. parasiticus (Mousavi and Pourtalebi, 2015), carboxymethyl chitosan-loaded reduced glutathione treatment might alleviate SCK by enhancing gluconeogenesis and reducing ketogenesis in amino acids (Zhao et al., 2020), nanotube implanted under the skin to provide real time measurement of changes in the level of estradiol in the blood (Patil et al., 2009), Ag nanoparticles had marked antibacterial effect against bacteria isolated from calf diarrhoea (Zeedan et al., 2018), $TiO_2$ nanocoating system filled with hollow microspheres reflects solar radiation of all incoming wavelengths (Sandin et al., 2017), and the addition of zinc oxide nanoparticles into the manure were reduced significantly (Alvarado et al., 2015). Because of that, nanotechnology is an alternative instrument that can be selected to solve dairy farming challenges in the future. As far as we know that esteem for animals within the food chain is considered within the context of an ethical matrix that affords respect according to the principles of well-being, farmers and the living environment, farm animals, autonomy and justice to consumers (Webster, 2001). Because the five principles of freedom have had major impact on animal welfare thinking internationally (Mellor, 2016). The five principles of freedom are:

Freedom from discomfort,

Freedom from hunger, thirst and malnutrition,

Freedom from fear and distress

Freedom to express normal behavior

Freedom from injury, pain and disease (Gill, 2012).

Although in the recent years, the five principles of freedom to evaluate animal welfare levels has expanded to more than five criteria. For example, according Kjærnes and Keeling (2002) there are 12 criteria to evaluate animal welfare levels, but the expansion of the criteria is also based on the five principles of freedom. So, there is a connection among nanotechnology, animal welfare, and dairy cattle. Moreover, nanotechnology can be used as an alternative solution to solve the problem in dairy cattle welfare.

***Compatibility of Nanotechnology in Dairy Cattle***

It is generally known that every system has limited factors, including nanotechnologies. Although nanotechnology is a new invented technology, it cannot cover all of the fields. Nanotechnology also has some disadvantages; the potential danger to humans, the environment, and an economic market crash related to a potential lower value (Lauterwasser, 2008). However, it is only needed to identify which nanotechnologies are applicable in dairy farming.

***The Application of Nanotechnology in Dairy Cattle Welfare Improvement***

**Freedom from discomfort**

The animal welfare in the dairy farms should be possible in shelters with a comfortable rest area (Gill, 2012). Specific areas in this aspect include; thermal comfort, comfort around resting, and ease of movement of all the cows (EFSA, 2009). Some areas in the dairy farms can be improved with the nanotechnology approach. But in general, it is connected with construction and facilities in the barn. For example, cow bedding, milking grease, milking machine, feeder, cubicles, and the other facilities. However, the discomfort aspect is also related with pollutants in the barn, and the nanotechnology is also able to solve the problems in this field. Mat-stall (bedding) improves the productive and reproductive performance (Singh et al., 2020). Mat-stall (bedding) materials are related with odds ratio of lameness. If the bedding is made from hard materials, it will improve the odds ratio of lameness. The bedding is also affected by the overall gaseous emissions (Hartung and Phillips, 1994). Using mat-stall for the bedding for the cows will improve comfort levels in the barn. Nanotechnology might apply for mat-stall materials.

Se, NPs is proven to increase the activity of anti-oxidative enzyme in serum also relieve and improve oxidative damage in dairy cows caused by heat stress (Weixing et al., 2009). To decrease the heat stress effect in the tropic and hot climates, construction manipulation is one of the solutions. Construction manipulation is always correlated with materials used to building the barn especially roof materials to decrease the heat radiation. Nanoparticle $TiO_2$ has the capability of photocatalytic activities, so this material is good for heat insulation. Furthermore, using $TiO_2$ nanoparticle in the feeder can improve the comfort level of the cattle because this material has self-cleaning coating which will reduce the contaminant agents in the feed. Another discomfort factor is gas emissions in the barn that causes odours. There are two approaches to reduce the emission of gas in dairy farms; reduced gas emissions inside of the body metabolic system and reduce the emissions in the slurry degradation processes. Applicable nanotechnology approach can be used to solve gas emission problems with some nanomaterials. For instance, using $SiO_2$ as a feed additive can reduce ammonia emission in the body metabolic system (Pieszka et al., 2018). Another example is an approach to animal waste management involving adding nanoparticles to manure to enhance biogas production from anaerobic digesters or to reduce odours (Scott, 2007).

**Freedom from thirst, hunger and malnutrition**

This principle of freedom in process evaluation can be measured by access to clean, fresh water and a diet to maintain full health and vigor (Gill, 2012). Some food and nutrition products containing nanoscale additives are already commercially available, and nanotechnology has begun to be widely used in different fields (Brunori et al., 2009). For example, in the application of nanotechnology, various compounds are used as a supplemental source of trace minerals (MgO, $Na_2O$, $SiO_2$, CaO, $K_2O$, $TiO_2$, $Al_2O_3$, and $Fe_2O_3$) nanoparticles (NPs) in diets (Meena et al., 2018).

Each nanomaterial has a specific function in the metabolism system. For example, ZnO nanoparticles as feed additives can improve the growth of rumen microorganisms and ruminal microbial protein synthesis (Huang et al., 2015) and raise the energy utilization efficiency (Riazi et al., 2019). Then, Se NPs can stimulate rumen microbial activity, digestive microorganisms or enzyme activity (Shi et al., 2011) and Se NPs exhibit lower toxicity than selenite (Çiçek et al., 2021). Moreover, $CuSO_4$ can significantly improve the digestibility of crude fat and energy, levels of IgG, γ-globulin and total globulin protein, and SOD activity (Gonzales-Eguia et al., 2009). Further, $SiO_2$ can significantly increase the number of lactic acid bacteria and decrease in the number of bacterial pathogens (Pieszka et al., 2018). Technique nanoencapsulation can be applied for rumen protection for some amino acids. Because some researches have reported that rumen protected methionine (RPM) plus rumen protected lysine (RPL) can improve milk yield and protein contents of dairy cows (Awawdeh, 2016).

From the examples that are mentioned above, we can conclude that nanoparticles can become an alternative solution to improve the dairy cattle welfare quality level in the aspect of freedom from thirst, hunger, and malnutrition. Because the data shows that the usage of nanoparticles in the feed can improve digestibility, enzyme activity in the digestive system, and inhibit pathogen bacteria growth (Huang et al., 2015, Riazi et al., 2019). As a result, the evaluation of dairy cattle welfare improvement in this aspect can be done with body condition score (BCS) method (Spigarelli et al., 2020). After nanotechnology application, the BCS of cows can be tested to see if they are in the normal range and are not over-conditioned or under-conditioned. It can be concluded that animal welfare levels in this aspect have been improved.

**Freedom from fear and distress**

The last aspect to evaluate animal welfare is freedom from fear and distress. This aspect can be achieved by ensuring conditions that avoid mental suffering (Gill, 2012). Some production management methods that are applied in the farm might cause fear and distress to the cattle. For example, not normal parity process (dystocia) and the need of human assistance might cause trauma to the cattle. The nanoparticle MgO has preventive capability in the memory impairment induced by postpartum depression (Zadedarvish et al., 2020). Furthermore, the milking process also has potency for trauma if the process is not properly done. Therefore, nanotechnology can be applied in this area. To improve the comfort levels in the milking process, generally some dairy farms use milk grease. Nanoparticles can be applied in this area, especially nano-lubricants fields. Thin and short multi-walled carbon nanotubes could improve the friction-reduction and anti-wear properties of vegetable-based oil more effectively than thick and long multi-walled carbon nanotubes (Su et al., 2018). Furthermore, some part in the milking machine uses rubber, so nanotechnology can also take a part in this area to improve the comfort quality while the milking process is carried out. For example, the tensile strength, tensile stress, and elongation at break of rubber nanocomposites were found to increase with addition of CNC regardless of cellulose sources (Dittanet et al., 2019).

**Freedom to express normal behavior**

Providing sufficient space, proper facilities and company for animals is a procedure to improve the animal welfare level in the aspect of freedom to express normal behaviour (Gill, 2012). Appropriate or normal behaviour can be evaluated from four areas; expression of social behaviours, expression of other behaviours, good human-animal relationship, and absence of general fear (EFSA, 2009). Social behaviour expression in dairy cattle is usually related with social dominance. Social dominance can be defined as a relationship where an animal through threat, force, or mere pleasure causes a subordinate animal to yield space (Lamb, 1976). The expression of other behaviours in dairy cattle can be divided into eating time, lying time, ruminating time, standing time, and idle time (Nikkhah and Kowsar, 2012). Space of the facilities in the barn and pasture for dairy cattle have big impact for comfort levels. Because of that, to make a connection between cattle behaviour and nanotechnology is very limited. However, nanotechnology can apply in the pasture to improve the quality of grass. Encouraging nitrogen use efficiency (NUE) results have been found when using nano-fertilizers (Mejías et al., 2021). Moreover, the release pattern demonstrated that the nanocomposite had a slow release behaviour for urea dissolution (Golbashy et al., 2017). Nanocomposite coating has a compact and non-porous microstructure; therefore, it prevents the penetration of chloride ions (Lekka et al., 2010). Another application of nanotechnology in the area of good human-animal relationship and the absence of general fear. Many studies that reported the effect of colours in the dairy farm. For instance, cows learn to discriminate among handlers partially based on the colours of their clothes (Munksgaard et al., 1997).

**Freedom from injury, pain and diseases**

Improvement process in the aspect of freedom from injury, pain and diseases can be done by prevention or rapid diagnosis and treatment (Gill, 2012). Absence of injuries, pain and disease induced by management procedures are the scope in this aspect (EFSA, 2009). Nanotechnologies are widely used for rapid detection and diagnosis, notably for clinical examination, food safety testing, and animal epidemic surveillance (Huang et al., 2015). One of the biggest diseases prevalent in the dairy farming is mastitis. Mastitis is caused by infectious bacteria in the milking process. Teat dip is always applied in the dairy farm to reduce the prevalence of mastitis. In usual Iodine and Chlorine are used in this dip process. Because of that nanotechnology can take a part in the process. Teat dip containing 4% povidone-iodine and 1% chitosan was more effective than 10% povidone-iodine in preventing subclinical mastitis (Hui-min et al., 2020).

Diseases seen in calves is mostly diarrhoea. In general, this disease is also caused by bacteria. Some nanoparticles are proven to reduce the odds ratio of this disease. There is $SiO_2$ and $TiO_2$. The literatures show $TiO_2$ has antimicrobial effect reaction Gram-positive bacteria (*Lactobacillus acidophilus*), yeast (*Saccharomyces cerevisiae*), Gram-negative bacteria (*Escherichia coli*) and green algae (*Chlorella vulgaris*) (Haider et al., 2019). Moreover, $SiO_2$ has the capability to reduce the prevalence of diarrhoea (Pieszka et al., 2018). Some incidences of disease in the dairy farms are caused by viruses. For instance, foot-and-mouth disease virus (FMDV), bovine virus diarrhoea (BVD), bovine herpes virus (BHV-1), and brucellosis. The research resulted those nanotechnologies are applicable to fight virus attack in dairy cattle. Nanoparticle of MgO NPs can inhibit foot-and-mouth disease (FMDV) by more than 90% at the early stages of infection (Rafiei et al., 2015a). Then, nanoparticle of Au NPs can inhibit post-entry stages of viral replication concomitant with the onset of intracellular viral RNA synthesis (Rafiei et al., 2015b). Another area of application of nanotechnology for dairy cattle is nanoencapsulation. One of the nanoencapsulations that is usually used is synthesized from chitosan nanoparticle. Chitosan nanoparticle of hCG (*Human Chorionic Gonadotrophin*) hormone or CS-NPh as a nasal spray can be used in enhancing the induction of ovulation in dairy cattle (Pamungkas et al., 2016).

**Conclusion**

Animal welfare is an essential management practice in dairy farms. Improvement in the five aspects of animal welfare will impact to the performance and productivity of the cattle because all the environment conditions are supported to express maximum potency. The new technology can be used as an approach to achieve that purpose. Nanotechnology is one of the most advanced technological inventions of the $20^{th}$ centuries. In general, nanotechnology can be applied in dairy cattle for animal welfare improvement. The management only needs to select the correct nanotechnology that would be applied in the dairy farm to solve the challenges. In some specific areas related with animal welfare improvement, there are some potential nanotechnologies that can be applied. However, compatibility of nanotechnologies in the dairy animal welfare can still be elaborated in a more detailed aspect depending on the challenges in the farm. As a result of the study, it can be stated that nanotechnology should be used to improve the welfare standards of dairy cows.

**References**

Akhavan S, Assadpour E, Katouzian I, Jafari SM. Lipid nano scale cargos for the protection and delivery of food bioactive ingredients and nutraceuticals. Trends Food Sci Technol 2018; 74: 132-46.

Alvarado AC, Predicala BZ, Asis DA. Mixing nanoparticles with swine manure to reduce hydrogen sulfide and ammonia emissions. Int J Environ Sci Technol 2015; 12(3): 893-904.

Anonymous. Techniques for synthesis of nanomaterials. In: 40. Lahore College for Women University, LCWU. Accesed Adress: https://www.slideshare.net/Krishanyadav28/synthesis-of-nanomaterials, Accesed Date: 13.04 2021.

Awawdeh MS. Rumen-protected methionine and lysine: effects on milk production and plasma amino acids of dairy cows with reference to metabolisable protein status. J Dairy Res 2016; 83: 151-5.

Brunori, G., L. Jiggens, R. Gallardo, and O. Schmidt. New Challenges for Agricultural Research: Climate Change, Food Security, Rural Development, Agricultural Knowledge Systems. Second SCAR Foresight Report. EU Commission, SCAR, Brussels 2009.

Buzea C, Pacheco , Robbie K. Nanomaterials and nanoparticles: sources and toxicity, Biointerphases, 2(4): MR17-MR71 2007.

Çiçek S, Turhan S, Işık S. Application of selenium nanoparticles diets in ruminants. Atatürk Uni Agri Fac 2021; 52: 98-107.

Den Hartog LA, Sijtsma R. Challenges and opportunities in animal feed and nutrition. Eleventh World Conference on Animal Production. October, 15-20, 2013; Beijing-China.

Dittanet P, Somphol W, Lampang N, Prapainainar P, Loykulnan S. Natural rubber reinforced by nanocellulose extracted from dried rubber leaves. Seventh International Conference on Nano and Materials Science (ICNMS 2019) AIP Conf Proc 2019; 2083 (030008): 1-5.

Dowling AP. Development of nanotechnologies. Materials Today 2004; 7 (12): 30-5.

EFSA. Scientific report of EFSA prepared by the Animal Health and Animal Welfare Unit on the effects of farming systems on dairy cow welfare and disease. Annex to the EFSA 2009; 1143: 1-38.

El-Hammadi MM, Arias JL. Nanomedicine for vaginal drug delivery. In: Theory and Applications of Nonparenteral Nanomedicines. Academic Press, 2021; pp. 235-57.

Feng M, Wang ZS, Zhou AG, Ai DW. The effects of different sizes of nanometer zinc oxide on the proliferation and cell integrity of mice duodenum-epithelial cells in primary culture. Pak J Nutr 2009; 8(8): 1164-6.

Fesseha H, Degu T, Getachew Y. Nanotechnology and its aplication in animal production: A review. Vet Med 2020; 5(2): 43-50.

Gill R. Animal Welfare and the “Five Freedoms”. https://animalscience.tamu.edu/wp-content/uploads/sites/14/2012/04/Five-Freedoms-Long-vers.pdf; Accessed Date : 16.08.2021.

Golbashy M, Sabahi H, Allahdadi I, Nazokdast H, Hosseini M. Synthesis of highly intercalated urea-clay nanocomposite via domestic montmorillonite as eco-friendly slow-release fertilizer. Arch Agro Soil Sci 2017; 63(1): 84-95.

Gonzales-Eguia A, Fu CM, Lu FY, Lien TF. Effects of nanocopper on copper availability and nutrients digestibility, growth performance and serum traits of piglets. Livest Sci 2009; 126(1-3): 122-9.

Haider AJ, Jameel ZN, Al-Hussaini IHM. Review on: titanium dioxide applications. Energy Procedia 2019; 157: 17-29.

Hartung J, Phillips VR. Control of gaseous emissions from livestock buildings and manure stores. Agri Engineering Res 1994; 57: 173-89.

Huang S, Wang L, Liu L, Hou Y, Li L. Nanotechnology in agriculture, livestock, and aquaculture in China. A review. Agron Sustain Dev 2015; 35: 369-400.

Hui-min Z, Hong-rui J, Dai-jie C, Zi-lian S, Yong-jiang M, Yu-sheng L, Loor JJ, Zhang-ping YY. Evaluation of a povidone-iodine and chitosan-based barrier teat dip in the prevention of mastitis in dairy cows. Integrative Agri 2020; 19: 2-12.

King T, Osmond-McLeod MJ, Duffy LL. Nanotechnology in the food sector and potential applications for the poultry industry. Trends Food Sci Technol 2018; 72: 62-73.

Kirdar SS. Current and future applications of nanotechnology in the food industry. In: ISITES2015 Valencia-Spain: Akademik Platform 2015; pp.1517-27.

Kjærnes U, Keeling L. Principles and criteria of good animal welfare. In: 2. Lelystad, The Netherlands: Animal Sciences Group of Wageningen UR 2002.

Lamb RC. Relationship between cow behavior patterns and management systems to reduce stress. Dairy Sci 1976; 59: 1630-6.

Lauterwasser C. Opportunities and risks of Nanotechnologies: Report in co-operation with the OECD International Futures Programme. In: München, Germany: Allianz Center for Technology & The OECD International Futures Programme 2008; pp. 44-6.

Lekka M, Zanella C, Klorikowska A, Bonora PL. Scaling-up of the electrodeposition process of nanocomposite coating for corrosion and wear protection. Electrochimica Acta 2010; 55 (27): 7876-83.

Lue JT. Physical properties of nanomaterials. Encyclopedia of nanosci nanotechnol 2007; 10: 1-46.

Meena N, Sahni Y, Thakur D, Singh R. Applications of nanotechnology in veterinary. Vet World 2018; 3: 477-80.

Mejías JH, Salazar FJ, Pérez L, Hube S, Rodriguez M, Alfaro MA. Nanofertilizers: A cutting-edge approach to increase nitrogen use efficiency in grasslands. Front Environ Sci 2021; 9: 52.

Mellor DJ. Updating animal welfare thinking: Moving beyond the “Five Freedoms” towards “a Life Worth Living”. Animals 2016; 6(3): 21.

Munksgaard L, De Passillé AM,Rushen J, Thodberg K, Jensen MB. Discrimination of people by dairy cows based on handling. Dairy Sci 1997; 80(6): 1106-12.

Mousavi SAA, Pourtalebi S. Inhibitory effects of silver nanoparticles on growth and aflatoxin B1 production by Aspergillus Parasiticus. Iran J Med Sci 2015; 40(6): 501-6.

Nikalje AP. Nanotechnology and its applications in medicine. Med Chem 2015; 5(2): 81-9.

Nikkhah A, Kowsar R. Seasonal and group effects on dairy cow behavior in large yards. Turk Vet Anim Sci 2012; 36(2): 123-9.

Pamungkas FA, Sianturi RG, Wina E, Kusumaningrum DA. Chitosan nanoparticle of hCG (human chorionic gonadotrophin) hormone in increasing induction of dairy cattle ovulation. JITV 2016; 21 (1): 34-40.

Patil SS, Kore KB, Kumar P. Nanotechnology and its applications in veterinary and animal science. Vet World 2009; 2: 475-7.

Pieszka M, Szczurek P, Pietras M. $SiO_2$ nanostructures as a feed additive to prevent bacterial infections in piglets. J Annals of Warsaw Uni Life Sci-SGGW Anim Sci 2018; 57.

Rafiei S, Rezatofighi SE, Ardakani MR, Madadgar O. In vitro anti-foot-and-mouth disease virus activity of magnesium oxide nanoparticles. IET Nanobiotechnol 2015a; 9(5): 247-51.

Rafiei S, Rezatofighi SE, Ardakani MR,Rastegarzadeh S. Gold nanoparticles impair foot-and-mouth disease virus replication. IEEE transactions on nanobiosci 2015b; 15(1): 34-40.

Rajak A. Nanotechnology and its application. J Nanomed Nanotechnol 2018; 9: 3.

Riazi H, Rezaei J, Rouzbehan Y. Effects of supplementary nano-ZnO on in vitro ruminal fermentation, methane release, antioxidants, and microbial biomass. Turk Vet J Anim Sci 2019; 43: 737-46.

Sandin O , Nordin J, Jonsson M. Reflective properties of hollow microspheres in cool roof coatings. Coatings Technol Res 2017; 14(4): 817-21

Scott NR. Impact of nanoscale technologies in animal management. Anim Pro Anim Sci Worldwide 2007; 1: 283-91.

Shi L, Xun W, Yue W, Zhang C, Ren Y, Liu Q, Wang Q, Shi L. Effect of elemental nano-selenium on feed digestibility, rumen fermentation, and purine derivatives in sheep. Anim Feed Sci Technol 2011; 163: 136-42.

Singh AK, Kumari T, Rajput MS, Baishya A, Bhatt N, Roy S. A review: Effect of bedding material on production, reproduction and health and behavior of dairy animals. Int J Livest Res 2020; 10(7): 11-20.

Spigarelli C, Zuliani A, Battini M, Mattiello S, Bovolenta S. Welfare assessment on pasture: A review on animal-based measures for ruminants. J Anim 2020; 10(4): 609.

Stoimenov PK, Klinger RL, Marchin GL, Klabunde KJ. Metal oxide nanoparticles as bactericidal agents. J Langmuir 2002; 18 (17): 6679-86.

Su Y, Tang Z, Wang G, Wan R. Influence of carbon nanotube on the tribological properties of vegetable -based oil. Adv Mech Eng 2018; 10 (5): 1-11.

The Royal Society, and The Royal Academy of Engineering (RSE). In: Nanomanufactoring Nanoscience and nanotechnology Clyvedon Press: Cardiff, UK 2004; pp. 25-30.

Webster AJF. Farm Animal Welfare: The five freedoms and the free market. The Vet J 2001; 161: 229-37.

Weixing D, Dongmei W, Zheng L, Cheng M, Depo Y, Chaoliang L, Shaobao L. Effects of nano-Se and vitamin E on anti-oxidative capability of dairy cows in heat stress. China Dairy Cattle 2009; 9: 21-4.

Ye BC, Zhang M, Yin BC. Nano-bio probe design and its application for biochemical analysis Springer Science & Business Media 2012; 1: pp. 1.

Zadedarvish F, Kesmati M, Khajepour L, Torabi M. Effects of magnesium oxide nanoparticles on memory impairment induced by postpartum depression model. Physiol Pharmacol 2020; 24 (1): 63-73.

Zeedan GSG, Abdalhamed AM, Ibrahim ES, El-Sadawy HAF. Antibacterial efficacy of green silver nanoparticles against bacteria isolated from calf diarrhoea. Asian J Epidemiol 2018; 11(2): 65-73.

Zhao C, Bai Y, Fu S, Wu L, Xia C, Xu C. Metabolic alterations in dairy cows with subclinical ketosis after treatment with carboxymethyl chitosan□ loaded, reduced glutathione nanoparticles. Vet Int Med 2020; 34(6): 2787-99.