Potential Applications of Non-thermal Plasma in Animal Husbandry to Improve Infrastructure

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Abstract. Infrastructure in animal husbandry refers to fundamental facilities and services necessary for better living conditions of animals and its economy to function through better productivity. Mainly, infrastructure can be divided into two categories: hard infrastructure and soft infrastructure. Physical infrastructure, such as buildings, roads, and water supplying systems, belongs to hard infrastructure. Soft infrastructure includes services which are required to maintain economic, health, cultural and social standards of animal husbandry. Therefore, the proper management of infrastructure in animal husbandry is necessary for animal welfare and its economy. Among various technologies to

improve the quality of infrastructure, non-thermal plasma (NTP) technology is an effectively applicable technology in different stages of animal husbandry. NTP is mainly helpful in maintaining better health conditions of animals in several ways via decontamination from microorganisms present in air, water, food, instruments and surfaces of animal farming systems. Furthermore, NTP is used in the treatment of waste water, vaccine production, wound healing in animals, odor-free ventilation, and packaging of animal food or animal products. This review summarizes the recent studies of NTP which can be related to the infrastructure in animal husbandry.

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Animal husbandry, a component of modern agriculture, concerns with the animals that are raised for commodities such as meat, milk, eggs, fur, leather and wool. The well-being of animals in animal husbandry has ethical, scientific, political and aesthetic components which are required for a better animal management, welfare, handling, care and high productivity (1). Infrastructure is one of the major contributors to well-being of animals which usually associates with management issues regarding nutrition, health, transportation, mustering and handling and other special invasive practices (2). Infrastructure refers to the fundamental facilities in an animal husbandry which can be divided into hard infrastructure and soft infrastructure. Hard infrastructure includes systems such as buildings, roads, and water supplying systems. Soft infrastructure consists of cost-effective, health, social and cultural facilities. Therefore, the better management of infrastructure in animal husbandry leads to well-being of animals and higher financial profit through the higher productivity.

Non-thermal plasma (NTP) has been identified as a potential approach to improve the quality of infrastructure systems and facilities including buildings, medications, food, ventilation, water supply, instruments and other special management practices (3-7). NTP is partially ionized matters in gaseous state at low temperatures and energy is mostly stored in free electrons (8). Different devices have been introduced to generate NTP including dielectric barrier discharges (DBD), atmospheric plasma jets, coronas and, surface and microwave discharges for numerous applications in different fields (9). NTP is environment-friendly, free of toxicity and requires a low temperature. These characteristics of NTP do not put animals and environment in animal husbandry at risk (10, 11). Therefore, NTP can be considered as an effective potential application to improve infrastructure, without disturbing animal well-being.

In this review, we summarized the already known applications of non-thermal plasma in the infrastructure sector of animal husbandry with regard to the well-being of animals and higher productivity which is necessary for its financially profitable function. We also highlighted the studies about the applications of NTP for improving infrastructure in other fields and hypothesized its use in animal husbandry. However, more systematic research is still required to bridge knowledge gaps particularly on NTP and the infrastructure of animal husbandry.

Role of NTP in Bio-decontamination to Provide a Healthy Environment for Farm Animals

The presence of various micro-organisms such as bacteria, biofilms, fungi, spores of fungi and protozoan parasites and their genes and metabolites in the environment increases the health risks to farm animals by causing and spreading numerous diseases (12, 13). Therefore, bio-decontamination of surfaces, instruments and water is necessary in animal husbandry to maintain a healthy environment. Several methods have been introduced for this purpose including oven or autoclave sterilization processes, chemical sterilization such as ethylene oxide sterilization, Gamma irradiation, high hydrostatic pressure technique and microwave sterilization. The limitations of these techniques such as the possibility of chemicals to remain after sterilization, requirement of complex, expensive and high security equipment and the requirement of special conditions for operations have also been discussed (14, 15). Therefore, NTP has been suggested as an effective, less toxic and low-cost method for bio-decontamination by several research groups. Also, none of the destructive effects on decontaminated surfaces were detected following NTP treatment (14, 16, 17). Furthermore, NTP can be used to decontaminate heat-sensitive surfaces and instruments as it is used at room temperature (18).

Commonly, most decontamination techniques target the membrane of a cell as it separates its inner compartments from the environment (14). NTP has general and specific effects on the cell surface of living organisms (14, 19-21). In addition to cell membranes (14, 22-26), NTP targets DNA (14, 24, 26, 27) and proteins (14, 26, 28) to destroy living organisms (Table I).

High-touch and Frequently-touched Surfaces and Instruments Can Be Decontaminated by NTP in Animal Farms

Poor health conditions of farm animals disturb animal well-being and result in poor productivity and economic losses. Therefore, health and hygiene of farm animals, which comes under the category of soft infrastructure, must be maintained properly. "High-touch" or frequently touched surfaces and instruments are easily contaminated and should be decontaminated for a pathogen-free environment (15, 16).

To date, NTP has been identified as an effective, low-cost and non-toxic way to decontaminate surfaces, instruments and confined environments (15, 16, 29). It has been shown that NTP produced from single-jet system eradicates vegetative bacteria from different surfaces (16, 30) and NTP from multi-jet system is capable of reducing surface pathogens such as methicillin-resistant *staphylococcus aureus*, *Clostridium difficile*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae* and *Acinetobacter baumannii* (16). Furthermore, other studies have also demonstrated the successful decontamination of surfaces and instruments from these pathogenic organisms by NTP treatment (6, 15). Therefore, NTP can be used in the decontamination of animal farm environments as these pathogens are breeding health risks for animals (13, 31-35). It has also been reported that exposure to NTP over a short period inactivates micro-organisms in confined environments such as airtight boxes and refrigerators, suggesting that NTP can be used to keep stored agricultural products fresh (29). Another study has suggested that NTP generated from pure oxygen is more effective for decontamination than that generated from oxygen-hydrogen gas mixture (18).

Moreover, NTP is able to inactivate micromycete species such as *Cladosporium sphaerospermum*, *Aspergillus oryzae*, *Alternaria* species and *Byssoschlamys mivea* and micromycete spores (36, 37). This fungicidal property of NTP also suggests its usefulness in decontaminating animal farms. The antibacterial efficacy of NTP has been further confirmed by several groups (4, 30, 38-40). NTP has been found to have antibacterial effects on a variety of bacteria (41, 42), on ESKAPE pathogens in the environment (17), on multi-drug-resistant bacteria in surface environments (43). Moreover, NTP has been shown to suppress host-cell invasion and to deactivate cell motility of *Salmonella Typhimurium* (44).

Table I. *Effects of NTP on microbial constituents to destroy micro-organisms.*

Constituent of micro-organism	Action of plasma	Effects on micro organism	Ref.
Cell surface	Intense bombardment by radicals	Provoke surface lesions that micro-organisms cannot repair sufficiently	(14, 19-21)
	“Etching” process	Form volatile compounds by adsorbing plasma components Destroy spores	
Cell membrane	Induce perforation	Increase the number of pores formed in cell membrane	(14, 22-26)
	Increase transmembrane permeability	Affect the transmembrane potential and destroy the intracellular pH regulation	
DNA	Breakdown of the interaction between membrane protein and DNA	Increase the release of DNA	(14, 24, 26, 27)
		Leakage of DNA from the cell through plasma-formed pores in membrane Partial hydrolysis of DNA	
Proteins	Oxidative processes	Affect the enzyme system	(14, 26, 28)

Other than vegetative cells, NTP has the ability to decontaminate surfaces from biofilms which are responsible for undesirable effects such as equipment damages and pipe plugging and cannot be destroyed by conventional sterilization methods. Moreover, NTP can destroy endotoxins, lipids and prions of microorganisms (45-50).

Even though, most of these studies were conducted in hospital environments and on medical devices, their results are applicable for all environments and instruments contaminated with above mentioned pathogenic microorganisms. Therefore, NTP is an effective and low-cost technology for surface and equipment decontamination in animal farms without any adverse effects to animals or farm environment.

NTP Increases the Microbiological, Physical and Chemical Quality of Water via Inactivating Micro-organisms

The quality of water can affect animal health and productivity directly and indirectly. Therefore, ensuring the microbiological, chemical and physical quality of water which is used for any purpose in a farm is an important management practice under the infrastructure section of animal farming (51).

As an effective method of water sterilization, NTP has been shown to successfully inactivate *E. coli* as a model bacterium in water (52). The same study has shown that bacteria cells enter to an active-but-nonculturable state after exposure to argon plasma jet-generated NTP. Membrane damages were also observed, suggesting that bacterial inactivation may be due to the peroxidation of cell membrane lipids by NTP-produced ROS (52). Another study has found that NTP is a cost-effective, environmentally friendly, sustainable and non-chemical-based promising candidate to destroy microcystins in water which cannot be

destroyed by conventional methods. Microcystins are toxins produced by cyanobacteria, and can cause detrimental effects on farm animal health (53). Moreover, DBD-generate -NTP has been shown to inactivate residues of cyanobacteria which cause algal bloom in water (54). Another study has reported that pulsed plasma gas discharge destroys waterborn enteroparasites which infect both farm animals and humans. According to that study plasma treated water kills the parasite at the thick-walled oocyst stage which is highly resistant to chlorine (55). It has been reported from another research group that plasma has a selective impact on bacterial populations at lower doses and potent bactericidal effects at high doses (56).

Altogether, these studies have shown that NTP is an effective method to keep water quality in a standard level to maintain animal health in animal husbandry.

NTP Degrades the Organic Contaminants in Waste Water Effluents

Waste management is one of the key infrastructure facilities in the field of livestock. The release of waste water effluents without proper management from industries, agricultural systems and animal farms has gained attention as a major cause of aquatic environment pollution. Waste water effluents from animal farms contain animal slurry, milk, hormones, medication drugs, pharmaceutical compounds and food wastes (57). Even though, the conventional water treatment methods destroy some of these pollutants, fail to degrade most of persistent substances and micro pollutants in waste water (58).

Therefore, various advanced oxidation processes were introduced during the last decades for the treatment of waste water including electric discharge NTP technology (59). According to previous studies, active species of NTP such as

ions, radicals, molecular species, atoms, UV light and shock waves are contributing to the removal of pollutants without requiring any additional chemicals. The efficiency of NTP treatment on waste water depends on the gas composition used to generate NTP, the power applied and the temperature of the solution (60-64). A study has shown that the application of NTP to degrade antibiotics of the penicillin class such as amoxicillin, oxacillin and ampicillin which are widely used in veterinary medicine for the treatment of bacterial infections in animals (65). NTP has also shown synergistic effects with micro pollutant adsorption in the decomposition of pesticides in waste water such as atrazine, which can be released from animal husbandry (58).

Moreover, NTP can be used to degrade sulfonamide antibiotics in waste water (66). Sulfonamides are widely used in veterinary medicine practices as effective chemotherapeutics for protozoan and bacterial infections. But, it has a maximum residue limit due to the carcinogenic potency of sulfonamide residues (67). Also, animal antibiotics are considered as non-biodegradable pollutants due to their adverse effects and toxicity to ecosystems (65). Therefore, it is necessary to degrade the sulfonamides in waste water. A previous study has introduced an aeration-assisted NTP to degrade these non-biodegradable sulfonamides (66). According to another study, NTP mineralizes organic pollutants in waste water such as Irgarol 1051 which is an algicide found in antifouling paints (68). An NTP-ozonation system has been successfully tested for the degradation of herbicides and pesticides in waste water. Herbicides and pesticides are used to destroy unwanted vegetation and pests in farming systems (69). Farm waste water effluents may include significant amounts of palm oil, used in animal nutrition, and of its derivatives (70, 71). Gliding arc discharge NTP has been shown to degrade palm oil pollutants in waste water (59) and to reduce more than 50% of total organic carbon (TOC) (59). Post-treatment of plasma to aryl containing water increased the effectiveness of biological removal (72).

All these studies provided great evidence showing that NTP alone or in combination with other operation systems has the ability to degrade organic contaminants in waste water effluents from indoor or outdoor animal farming systems.

NTP Abates the Emission of Harmful Volatile Organic Compounds (VOC) and Offensive Odors from Indoor and Outdoor Animal Farming Systems

Volatile organic compounds (VOCs), organic chemicals which produce vapors at room temperature, are not acutely toxic. However, they cause short- or long-term adverse health effects to animals and humans (73). Many types of VOCs including carboxylic acids, alcohols, carbonyls,

phenolic compounds and sulfur and nitrogen-containing compounds are emitted to the environment in animal husbandry mainly due to feeding operations such as storage and handling, animal wastes and exhalation (74-76).

Few technologies have been introduced to control the emission of VOCs and odors such as adsorption, absorption, condensation, thermal and catalytic incineration and biological oxidative filtering (77). Recent studies have suggested that NTP is a better treatment technology for VOC emission abatement (78-80) due to the advantages of requiring relatively low energy, having moderate cost, being easily operated, having short residence time and the ability to treat relatively low concentrations of VOCs at low operating temperatures (81, 82). Furthermore, previous studies have tested the application of NTP for abatement of numerous hazardous air pollutants such as sulfur dioxide (SO₂) (83), Nitrogen dioxide and nitric oxide (NO), odors (H₂S, NH₃) (84-86), chlorofluorocarbons (CFCs) and Mercury (87, 88).

NTP generates strong oxidants in the gas phase and therefore, is a source of gas-phase reactive species and free radicals such as O⁻, OH⁻ and H⁺ which are contributing to the elimination of air pollutants. These reactive species and radicals are able to react with odors, vapors and toxic gases and convert them into non-toxic molecules (89, 90). Furthermore, some studies have introduced synergistic methods to abate VOCs like NTP coupled with F-TiO₂/gamma-Al₂O₃ for the removal of toluene odor (91) and NTP combined with bio trickling filters (BTF) for the removal of dimethyl sulfide (DMS) (92).

Taken together, it has been demonstrated that NTP is an effective technology of care for the health of animals in confined indoor environments by abating VOC and offensive odors. It also controls the air pollution in outdoor environments. Therefore, it can be concluded that NTP is a helpful technology to manage animal health as one component of soft infrastructure and ventilation in buildings as a component of hard infrastructure.

NTP Is an Effective Inactivating Agent for Preparation of Conventional Inactivated Vaccines

Vaccines can be categorized under the section of health in soft infrastructure. Vaccines are considered a predominant method of controlling various diseases in livestock industry. Conventional inactivated vaccines, live attenuated vaccines and gene-mutated vaccines are the three types of vaccines used in animals (93, 94). Among these vaccines, inactivated vaccines are considered the most popular vaccines in animal husbandry (95). Usually, the inactivated vaccines rely on inactivating agents. However, the deleterious effects of those agents such as formaldehyde and beta-propiolactone

compromise safety and effectiveness of vaccines (11, 96). Therefore, NTP has introduced as an effective and safe agent to produce inactivated vaccines (11).

It has already been reported the preparation of vaccines against Newcastle disease virus (NDV) and Avian influenza virus (AIV) using NTP as inactivating agent (11). Newcastle disease and Avian influenza are two common diseases which affect a variety of animal species and cause 100% mortality (97). A previous study has shown that treatment for a certain time period with NTP is suitable for these vaccine preparations (11). The same study has reported that overdose of NTP destroys virus morphology, decreases virulence, and causes loss of immunogenicity. Therefore, determination of the specific dose and time of NTP treatment is necessary for the preparation of inactivated vaccines (11). According to the above study, inactivation of virus by NTP treatment is due to increased oxidation reduction potential (ORP) through a series of chemical reactions among ROS and RNS in the allantoic fluid system of virus (11).

Taken together, these findings suggest that NTP can be used as a successful, effective and safe inactivating agent for inactivated vaccine preparation against viruses affecting animal husbandry. Therefore, NTP indirectly contributes to management of animal health which is a component of soft infrastructure.

NTP Is a Promising Approach to Preserve Fresh and Minimally Processed Animal Feed

Most of fresh or partially processed food products are perishable due to the higher concentration of moisture and ease to spoil specially during storage due to contamination with microorganisms or due to higher chemical/biochemical reactions (98). Most of the times, fresh and partially processed food is given to farm animals which consume it raw. Therefore, it is necessary to preserve the quality of the food and prevent food-borne diseases within animal herds. NTP has been introduced as an effective treatment for this purpose by previous studies. They have shown the ability of NTP to decontaminate food and extend the shelf-life of food (98-102). NTP also inactivates thermophilic bacteria which cannot be destroyed by conventional methods. NTP achieves this by modifying the structure of thermophilic proteins (103). Few studies have shown that NTP inactivates bacteria on fresh food, with special focus on *Salmonella* species which can adversely affect farm animals and humans (104, 105). Another study has specially shown the favorable effects of NTP on raw milk. Milk is a product which can easily get contaminated due to its fresh nature and high nutritious value. Therefore, the elimination of bacteria from milk is a serious problem for decades. However, NTP has been shown to be able to reduce bacteria in milk, using *E. coli* as model bacteria (106). This study demonstrated the

applicability of NTP in animal husbandry as milk is used to feed new born and young animals such as cattle, goats, and humans. Thus, low-cost NTP can be used to produce good quality milk and provide financial benefits for animal husbandry. NTP also inactivates the spores including chemical and heat-resistant spores which are produced by spore-forming microorganisms (107).

Contamination of animal feed and feed raw materials by fungi, especially, during storage is also common in animal husbandry (108). A previous study has shown that NTP prolongs the shelf life of food by reducing the deterioration of food through inactivation of fungi (109, 110). In addition to the inactivation of microorganisms, NTP also preserves food by removing pesticides and insecticides from food surfaces without harming it (111). Thus, NTP plays another important role in animal husbandry by removing toxic materials from raw plant materials which are consumed by farm animals.

Taken together, all studies have demonstrated that NTP treatment is an effective technology to preserve animal feed by increasing its quality, inactivating microbes, preventing spoilage and removing toxic materials. Therefore, NTP contributes to soft infrastructure indirectly *via* food preservation.

Roles of NTP in Skin Decontamination, Skin Renewal and Skin Wound Healing in Animals

NTP has a greater potential in efficient painless disinfection of skins, sterilization even in microscopic openings of the skin, wound healing, therapy of skin infections and tissue regeneration without damaging healthy tissues (112, 113). Gaseous stage NTP allows it to penetrate even inhomogeneous surfaces, civilities and fissures up to micro scale. Therefore, NTP provides advantage over traditional fluids or chemicals used for the same purpose (113).

It has been reported that NTP generated from atmospheric pressure plasma jet and DBD has the ability to decontaminate skins (114) and to inactivate *Chlamydia trachomatis*, which causes different diseases in farm animals, especially in cattle (115). Moreover, several studies have demonstrated the wound healing ability of NTP. According to those studies, NTP supports wound healing by its antiseptic effects, by regulating integrin receptors on the surface of skin cells, by its pro-angiogenic effects, by promoting vascularization, by controlling blood coagulation, by boosting and prolonging the cutaneous microcirculation and by sterilizing the wounds without any observable side effects (116-122). Some of these studies have used skins from animals such as porcine and rat to show that NTP decontaminates animal skins or supports wound healing (120, 122).

Continuous proliferation and differentiation of epidermal cells of the skin are required for maintaining healthy skin.

They are also essential for a better and fast healing of wounds caused from injuries, ulcers or tumor removal (123, 124). A study has demonstrated that NTP can be employed in skin regenerating (125). It was shown that NTP allows keratinocytes to escape from G1 cell cycle arrest, increases the cell proportion in S and G2 phases, causes translocation of beta-catenin to nucleus and induces the transcription of target genes without damaging DNA (125). Moreover, another study has tested the effects of cold argon plasma on eggs of blow fly (126). Larvae of this fly produce myiasis which is a parasitic infection where larvae grow inside the host while feeding on its tissues. According to that study, NTP treatment on blow fly egg shells supported healing of these wounds (126).

Taken together, NTP is a promising effective technique to decontaminate, treat wounds and renew skins of farm animals and provide better health and hygiene of animals as part of soft infrastructure management.

NTP Inactivates Bio-aerosols Rapidly and Facilitates a Disease-free Ventilation in Farm Environment

Particles of biological origin such as microorganisms (fungi, bacteria and virus), pollen, allergens, endotoxins, plant debris and skin scales are considered as bio-aerosols (127). These bio-aerosols are reported to have adverse health effects in animals and humans (128). Therefore, the maintenance of air without bio-aerosols is necessary for healthy environmental conditions in an animal farm. Commonly, the particulate filters inside heating, ventilating and air-conditioning (HVAC) systems are used to control bio-aerosols (129). However, the efficiency of these filters is doubtful as the collected bio-aerosols are not inactivated and accumulate on the surfaces of filters. In addition, bio-aerosols proliferate during long periods (128). Therefore, as another method of air-sterilization, NTP has been investigated in previous studies (3, 128, 130, 131). It is more advantageous over other methods as it does not produce secondary environmental pollution and is cost effective (132).

One of those studies has reported that NTP generated from DBD deactivates indoor and outdoor bio-aerosols by reducing culturability, viability and diversity of microorganisms. Bacteria inactivation reached 95% and that of fungi 85-98% (128). Another study has demonstrated that NTP efficiently inactivates airborne pathogens which are resistant to antibiotics. According to that study the efficacy of NTP depends on the load of microorganisms, and the generation rate and flow rate of bio-aerosols. As the underlying mechanism of this inactivation, they suggested two key regulatory oxidative stress pathways which are mediated by superoxide dismutase and catalase (133). Another study has introduced a reliable bio-aerosol filter

which is not requiring any maintenance practices as it made by NTP (3).

NTP has also been demonstrated to inactivate various airborne viruses including MS2 virus and adenoviruses (8, 132, 134). This inactivation is primarily attributed to ROS released from NTP and the subsequent damage of virus proteins and genes (132).

According to this evidence, NTP is an applicable technology for indoor and outdoor air cleaning in animal farms as a cost-effective method to manage soft infrastructure.

Usage of NTP to Disinfect Packaging Materials and Inside of Sealed Packages

Food Packaging is an important aspect in animal husbandry as it uses packaged feed for feeding animals in farms and packages to pack their products for commercialization purposes. Therefore, usage of sterilized packing materials or disinfection of the inside of packages is essential to preserve food products from microorganisms and to extend the shelf-life of fresh products. NTP has been introduced as a sterilization method with numerous advantages over other conventional methods. Low operational cost, short treatment time, low temperatures, and non-toxicity make NTP an applicable disinfectant technique for variety of materials including heat and chemical sensitive materials (8, 135).

Few studies have examined the use of NTP in disinfecting the inside of sealed packages (135-137). One of these studies demonstrated the inactivation of high concentration of *E. coli* within few seconds in liquids contained inside sealed bags by NTP (135). Another study has introduced a DBD system to generate NTP inside packages containing cherry tomatoes. In this set-up of DBD systems the package itself serves as the dielectric material. According to that study, this set-up helps to preserve food products without disturbing their quality (137). A device to generate NTP inside sealed bags has been introduced by another study to sterilize single-use medical devices (136). It has been shown that NTP increases the shelf-life of packaged chicken fillets without any adverse effects (138). In addition to disinfection of the insides of sealed bags, some studies have shown that NTP disinfects packaging materials. According to these studies, the physicochemical and biodegradable properties of food packaging materials such as polylactic acid films can be improved through NTP treatment without negatively affecting these materials (8, 139).

Altogether, these studies indicate that NTP can be used to sterilize and disinfect the insides of sealed packages and improve the properties of packaging materials which are used to preserve food. Also, NTP protects the quality of foods inside packages without any adverse effects on packaging materials. Therefore, this can be considered as another application of NTP to manage soft infrastructure in animal husbandry.

Conclusion and Future Perspective

The studies highlighted in this review are focused on non-thermal plasma (NTP) technology as an emerging and effective technology in the field of infrastructure. NTP is produced from different devices such as DBD, plasma jet, coronas, and surface and microwave discharges. These studies were conducted in the field of animal husbandry as well as in other fields, such as medicine. Therefore, in this review we summarized the results of the application of NTP in the infrastructure of animal husbandry and we hypothesized the potential application of NTP in animal husbandry from the knowledge in other fields. Thus, further studies are needed on the application of NTP in the infrastructure of animal husbandry.

As a summary, NTP is a technology that can effectively be applied in infrastructure management over other technologies due to its environmentally friendly nature and low cost which is also a main part of infrastructure. Other than the economy, NTP provides better living conditions to animals by contributing to the maintenance of animal health, quality of nutrition and animal welfare. Better living conditions of animals also provides economic advantages through higher productivity. Therefore, NTP can be used for the proper management of infrastructure in animal husbandry.

Summary

Animal husbandry is one of the branches of agriculture which consists of animals that are raised for several commodities such as meat, milk, eggs, fiber or other products. Usually, it includes the day-to-day care of animals, rising of the livestock and selective breeding. A wide range of animal species such as cattle, sheep, goats, pigs, chickens, and rabbits are used in animal husbandry in different parts of the world. Moreover, insect farming and aquaculture are also considered part of animal husbandry. One of the main requirements in animal husbandry is the maintenance of better living conditions of animals for animal welfare and higher financial gains through higher productivity. Proper management of infrastructure is essential to provide those better living conditions of animals. Among various technologies, non-thermal plasma technology is gaining attention as an effective technology to improve the infrastructure at several stages of the production system in animal husbandry.

Conflicts of Interest

The Authors declare that there are no conflicts of interest.

Author's Contributions

T.K., N.C., D.K.J., and J.S.K., designed and wrote the whole manuscript; T.K., N.C., performed the figures; D.H.L., S.B.Y.,

J.R.L., Y.S., S.L., K.J.K., S.Y.L., S.Y.K., Y.J.J., M.K., B.J.P., J.K.L., contributed in the revision of the manuscript. All Authors read and approved the final manuscript.

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