Egyptian J. Anim. Prod. 57 Suppl. Issue, January (2020):67-71

FUTURE PROSPECTS OF NANOTECHNOLOGY INNOVATIONS IN ANIMAL PRODUCTION

A.A.M. Abdel-Megeed

Department of Plant Protection, Faculty of Agriculture, Saba Basha, Alexandria University, Alexandria 21531, Egypt, Corresponding author: ahmedabdelfattah@alexu.edu.eg

Received: 2/9/2019 Accepted: 24/10/2019

SUMMARY

Nanotechnology is a great innovation that is revolutionizing the agricultural practices. It is a science that works at the nanoscale and provides many benefits. In this review, the fundamental concepts of nanotechnology are clarified, focusing on its primary applications and a health and environment risk assessment especially in livestock production. There is currently a lack of reliable, cost-effective diagnostic tests for early detection of diseases in farmed livestock animals. Biosensing technologies have the potential to address these problems by developing innovative diagnostic tools for the rapid detection of key health threats within the agri-food livestock sector. It also allows for greater product innovation, with the creation of new food ingredients or supplements with nanoencapsulation or nanoemulsions, achieving a slow release of some composites, or perhaps obtaining healthier foods through the improvement of organoleptic properties in the product. Although nanotechnology provides many benefits, but as with all innovations, there are disadvantages and risks associated with its use. The risk assessment must take into account that the biokinetic profile and the toxicity in the target tissues can vary depending on which nanomaterial is being referred. A risk-benefit balance on the use of nanomaterials must be carried out, and in the majority of cases, though many people are open to the advancement, more information regarding the risks is required. Above all, it must be legally regulated to guarantee Agrofood safety in all products that have been manipulated using nanotechnology.

Keywords: Nanotechnology, Livestock Production, Innovation, Risk assessment

INTRODUCTION

Nanotechnology is a multidisciplinary science, which combines chemical and material engineering, biotechnology and industrial processing technology. As a general definition, Salvia-Trujillo *et al.* (2016) described nanotechnology as "the manufacture of materials, structures, devices and functional systems through control and assembly of matter at nanometre scale, and the application of new concepts and properties that arise as a result of a scale so small". However, there are other definitions which are more widely used which defined it as "the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale (Kingsley *et al.*, 2013; Ranjan *et al.*, 2014). It is important to define which range is being used in this small world. The length scale of interest for nanoscience and nanotechnologies is from 100 nm down to the atomic level (approximately 0.2 nm) and includes different structures such as atoms, molecules, nanoparticles, carbon nanotubes, etc. The main characteristic that gives nanomaterials its specific properties is their small size, which increases the surface area, achieving a higher reactivity(Fernández *et al.*, 2010). In nanostructures it was so-called "quantum effects", which provide them with interesting properties, such as for example that electrons that move within a nanoparticle can only possess certain energies (allowed levels of energy) (Dasgupta *et al.*, 2015). As the size is reduced these energy levels change resulting in changes in their catalytic, electrical, magnetic or optical properties when compared to conventional formulations of the same material(Ferrari, 2005; Salvia-Trujillo *et al.*, 2016). In addition, sophisticated tools (the scanning tunneling microscope and the atomic force microscope) have been developed to investigate and manipulate matter at the nanoscale. By controlling the shape, size and internal order of the nanostructures, properties (electrical conductivity, colour, chemical reactivity, elasticity, etc.) can be modified(Salvia-Trujillo *et al.*, 2016).

Nanomaterials production and classification:

The classification of nanomaterials is complex; however, several groups can be distinguished according to different criteria.

Classification according to origin:

Nanomaterials are classified as: **a)** natural nanomaterials, e.g. ocean spray (O'Dowd *et al.*, 2004) and nanosized materials from combustion processes as forest fires and volcanic ash (Oberdörster *et al.*, 2005). **b)** Incidental or involuntarily nanomaterials generated by human activity such as internal combustion engines, thermal power plants and other sources of thermal degradation(Tiede *et al.*, 2008), and **c)** artificial or manufactured (engineered) nanomaterials (Tiede *et al.*, 2008) among which are inorganic, with surface features and organic (to improve the nutritional value) (Cuartas-Uribe *et al.*, 2010). Engineered nanomaterials are intentionally produced using nanotechnology. The “top-down” (mechanical-physical particle production processes) approach is the manufacturing method that reduces the size of larger materials; this is done by using processes such as trituration or milling; traditional source materials (such as metal oxides) are pulverized using high-energy ball mills until a nanostructure has been produced(Raab *et al.*, 2011). A major disadvantage is that this approach requires a great amount of energy and produces waste (Uribe and López, 2007). The “bottom-up” approach is the construction from individual components (atoms or molecules) by self-assembly, using physical and chemical techniques (gas- and liquid-phase). It includes aerosol processes, sol-gel processes, precipitation reactions and methods such as gas condensation, chemical vapour deposition, chemical vapour condensation, and solvothermal- and sonochemical methods (Charitidis *et al.*, 2014; Rajput, 2015). The disadvantage of the wet-chemical synthesis of nanomaterials is that the desired crystalline shapes often cannot be configured and that the thermal stability of the product powder is lower. The selection of “top-down” or “bottom-up” process depends on the chemical composition and the desired features specified for the nanoparticles(Raab *et al.*, 2011).Recently, the United States Environmental Protection Agency(EPA, 2019) classifies engineered nanomaterials according to their chemical composition and physical arrangement of the material: carbon-based, which are either, spherical, ellipsoidal (fullerene) cylindrical or tube (nanotube) shaped; metal/metal oxide-based (generally spherical nanoscale particles composed entirely or partly of one or more metals); dendrimers (repetitively branched molecules -typically symmetrical and spherical-which provide internal cavities for other molecules) and quantum dots (nanocrystalline semiconductors, usually metal complexes, selenides, or sulfides).

Nanotechnology and livestock production:

The environmental impacts of livestock production (e.g., on soil, water, atmosphere and forest reserves) are key challenges to bear in mind as we devise plans and policies to manage and further develop the production systems that are environmentally sustainable, economically viable, ethically acceptable, and provide wholesome and nutritious food for animals and humans on a global scale (Kettiger *et al.*, 2013; Joye *et al.*, 2014).This integration will be handled by decision support systems, which, to be most effective, must be robust under varying conditions; include technologies for rapid (automated) data collection via wireless data transmission systems (de Francisco and García-Estepa, 2018) (i.e., animal and environmental sensors); have substantial computing capacity for data analyses; have systems optimized to inform decision making and be reasonably easy to operate. The next breakthrough will be for these systems to use ‘real-time biometry,’ functioning in real time to monitor and control genotype, environment, wellbeing, productivity and animal product quality (Hasaneen *et al.*, 2014).

Biosensors technology for animal and livestock health management:

Advances in engineering research and biomaterials, coupled with the decreasing costs of electronic technologies, have resulted in the emergence of ‘sensing solutions’ and smart computing technologies that include internet and cloud–based connectivity to develop integrated and networked physical devices for data collection and analysis (Liu *et al.*, 2008). These systems are equipped to automatically collect data on physiological parameters, farm environment, production measures and behavioural traits (Su *et al.*, 2013).In the modern world, new diseases that threaten animals’ health emerge every year. There is currently a lack of reliable, cost-effective diagnostic tests for early detection of diseases in farmed livestock animals. Biosensing technologies have the potential to address these problems by developing innovative diagnostic tools for the rapid detection of key health threats within the agri-food livestock sector(Abdellah *et al.*, 2013). There are numerous factors that affect food production and have an influence on food security around the world. By 2050, food demand is expected to increase by 70%, and meat production will increase by 50%, making agri-food and livestock key industries for future growth. Health threats to animal populations can disrupt food supply chains and commerce with potentially long-lasting effects on human health, as well as economic impacts. With current technology, detecting diseases in the early stage requires time-consuming and expensive laboratory tests. There is a need for detection tools that can predict when an incident is likely to occur and in what population, inform diagnosis and treatment options, and forecast potential impacts on a given population (both human and animal). The biosensor market for the year 2013 was valued at US $11.39 Billion and is expected to increase to US$22.68 Billion by 2020 (Abdellah *et al.*, 2013).

In this review, the focus relies on the emergent bio-sensing technologies that have the ability to transform management in the livestock industry and the methods associated with it(Arora and Padua, 2010). Nanobiosensor applications will not only reduce the incumbent costs for reagents, sample handling, analysis times and transportation costs, but will also help in adapting and promoting sustainable agricultural techniques and ethical handling of livestock(Bouwmeester *et al.*, 2009). The future of biosensors relies upon utilizing the comprehensive knowledge of animal physiology, genetics, environmental sciences and animal nutrition, and integrating this knowledge in a meaningful way will aid in the translation into real commercial and societal benefits (Auffan *et al.*, 2009; Cuartas-Uribe *et al.*, 2010).

Biosensors tools in animal husbandry:

Future developments in biosensors are expected to result in the development of new methodological and technological approaches to measuring dynamic changes in real time, with respect to the changes in physiological state and metabolism (e.g., gastrointestinal flora, circulating levels of anabolic and catabolic hormones, immune function, gene expression). This is to better understand the factors influencing animals' responses, and to develop solutions (e.g., husbandry practices, technology and associated decision support system) that improve productivity and/or wellbeing of these animals (Cota-Arriola *et al.*, 2013).

Rapid characterization of animal feed :

Biosensors shall be used to develop approaches enabling the rapid, accurate characterization of dietary inputs and final products (meat, eggs, milk) in terms of nutrient content (total and bioavailable), antinutritional factors and bioactive components, as well as chemical and microbiological contaminants, with the aim of implementing this technology at the level of the commercial feed mill or animal food product processing plant (Cuartas-Uribe *et al.*, 2010). On the other hand, they would also help in the decision-making process to alter the composition of feed for the animals in case the animal products deviate from the expected nutritional status (Dasgupta *et al.*, 2015).

Sensors analysing metabolites in perspiration:

Most biosensors developed for analysing metabolites in sweat were developed with the purpose of human health monitoring. These have been used to analyse sodium concentration plant(Cuartas-Uribe *et al.*, 2010) and lactate levels, and converted to portable formats (belt form) to analyse sweat. The electrochemical sensor for lactate levels includes a flexible printed tattoo that can detect lactate levels with linearity up to 20 mM. The sensor has been shown to be resilient against mechanical deformation. This sensor can also be adapted for use in animal sweat monitoring, especially as a sign of physical stress in animals. Others have developed an adhesive radio-frequency identification (RFID) sensor patch, which allows for potentiometric sensing of solutes and surface temperature that can be read on a smartphone application.

Risk assessment and toxicity of nanomaterials:

The potential negative effects on health associated with the exposure of the agent are identified. Due to certain characteristics of the nanomaterials, the dangers can be identified with greater ease; however, they can react in a specific way that differs to their larger counterparts (Amenta *et al.*, 2015). This is both a quantitative and qualitative assessment of the nature of the negative effects associated with the agent. Such as in the case of nanomaterial where there is insufficient data, a risk assessment should be carried out on a case-by-case basis, which is to say determine the factors that need to be considered based on the dose-response relationship. For example, there are factors such as the small size or the insolubility of nanomaterials, which can be of a higher toxicity that proves difficult for an organism to eliminate(Gestal and Zurita, 2015; Kumar, 2015).In the exposure assessment, the channel for exposure and the amount of the agent are determined(Arora and Padua, 2010). In other words, the toxicokinetics of the material are assessed, this includes 4 phases not including deposition: absorption, distribution, metabolism and excretion(Dasgupta *et al.*, 2015). Absorption occurs when nanomaterials enter the circulatory system, passing through the barriers of the human organism. This can be via inhalation, oral or dermal exposure, etc. Normally nanomaterials are absorbed through the lungs, skin and the gastrointestinal tract. Absorption can vary, depending on the channel of exposure, the size, the shape, the charge(Ranjan *et al.*, 2014), the solubility and the composition of the particle (Dasgupta *et al.*, 2015). An example can be seen in silver nanoparticles, which due to their small size pass through the cellular barrier and form free radicals that can cause oxidative damage in cells and tissues. In addition these can become genotoxic, cytotoxic and carcinogenic (Pradhan *et al.*, 2015). On the other hand, small, gold nanoparticles have been found to penetrate the intestine very quickly (Dasgupta *et al.*, 2015). In addition, positively charged particles also facilitate skin penetration (Ranjan *et al.*, 2014). The distribution of nanomaterials in the organism depends on the affinity of the tissues. The primary influencing factors are the size and the state of aggregation. Aggregated particles are more likely to move to pleural mesothelial cells and accumulate in the lungs and heart; in comparison, the primary particles, have a more widespread distribution (Arora and Padua, 2010; Iversen *et al.*, 2011; Ranjan *et al.*, 2014).

Conclusion and Future perspectives:

Precision livestock farming aims at creating a management system that relies upon autonomous, continuous, real-time monitoring and control of all aspects of livestock management, including reproduction, animal health and welfare, and the environmental impact on livestock production (Kettiger *et al.*, 2013; Reidy *et al.*, 2013). It is assumed that the direct monitoring of animals will achieve greater control over their health status, which will eventually translate into better animal product quality over longer periods of time. Biosensor technology shall enable accurate and affordable acquisition of data points, while the smart algorithms, coupled with networked farms, shall further decision making and management processes in the animal farms (Pradhan *et al.*, 2015). The primary goal of precision livestock farming is to generate reliable data using biosensors and run it through intelligent software systems to create value for the farmer, the environment, and the animals in the form of improved animal health and welfare, increased productivity and yields and reduced costs while minimising the impact on the environment. While the biosensor technology is available for individual parameters, key advancements in the field are expected to generate robust monitoring systems for a multitude of parameters. Another key challenge currently faced is the slow uptake of these technologies on commercial farms. This has been attributed to the fact that although the precision systems and biosensors generate abundant data, the data is currently not being converted into useful information that could be utilized for the decision-making process in livestock management (Pradhan *et al.*, 2015). Furthermore, the economic benefits of using these advanced systems is set to be demonstrated to individual farmers, who are reluctant to make investments in these systems in the absence of a clear economic benefit.

REFERENCES

Abdellah A., Abdelhalim A., Loghin F., Köhler P., Ahmad Z., Scarpa G. and Lugli P., 2013. Flexible carbon nanotube based gas sensors fabricated by large-scale spray deposition. IEEE Sensors Journal 13:4014-4021.

Amenta V., Aschberger K., Arena M., Bouwmeester H., Moniz F.B., Brandhoff P., Gottardo S., Marvin H.J., Mech A. and Pesudo L.Q., 2015. Regulatory aspects of nanotechnology in the agri/feed/food sector in EU and non-EU countries. Regulatory Toxicology and Pharmacology 73:463-476.

Arora A. and Padua G.W., 2010. Nanocomposites in food packaging. Journal of Food science 75:R43-R49.

Auffan M., Rose J., Bottero J.-Y., Lowry G.V., Jolivet J.-P. and Wiesner M.R., 2009. Towards a definition of inorganic nanoparticles from an environmental, health and safety perspective. Nature nanotechnology 4:634.

Bouwmeester H., Dekkers S., Noordam M.Y., Hagens W.I., Bulder A.S., De Heer C., Ten Voorde S.E., Wijnhoven S.W., Marvin H.J. and Sips A.J., 2009. Review of health safety aspects of nanotechnologies in food production. Regulatory toxicology and pharmacology 53:52-62.

Charitidis C.A., Georgiou P., Koklioti M.A., Trompeta A.-F. and Markakis V., 2014. Manufacturing nanomaterials: from research to industry. Manufacturing Review 1:11.

Cota-Arriola O., Onofre Cortez Rocha M., Burgos Hernández A., Marina Ezquerra Brauer J. and Plascencia Jatomea M., 2013. Controlled release matrices and micro/nanoparticles of chitosan with antimicrobial potential: development of new strategies for microbial control in agriculture. Journal of the Science of Food and Agriculture 93:1525-1536.

Cuartas-Uribe B., Vincent-Vela M., Álvarez-Blanco S., Alcaina-Miranda M. and Soriano-Costa E., 2010. Application of nanofiltration models for the prediction of lactose retention using three modes of operation. Journal of food engineering 99:373-376.

Dasgupta N., Ranjan S., Mundekkad D., Ramalingam C., Shanker R. and Kumar A., 2015. Nanotechnology in agro-food: from field to plate. Food Research International 69:381-400.

de Francisco E.V. and García-Estepa R.M., 2018. Nanotechnology in the agrofood industry. Journal of Food Engineering 238:1-11.

EPA U.S.E.P.A., 2019. Exposure Assessment Tools by Chemical Classes - Nanomaterials, USA.gov, United States.

Fernández A.M.C., Palomar J.C., Sáez A.C., Rovira R.F., Carou M.C.V., Gallego Á.M.J. and Rodríguez R.L., 2010. Informe del Comité Científico de la Agencia Española de Seguridad Alimentaria y Nutrición (AESAN) en relación al uso de la nanotecnología en la industria alimentaria. Revista del Comité Científico de la AESAN:29-46.

Ferrari M., 2005. Cancer nanotechnology: opportunities and challenges. Nature reviews cancer 5:161.

Gestal M.C. and Zurita J., 2015. La nanotecnología en la producción y conservación de alimentos. Revista Cubana de Alimentación y Nutrición 25:24.

Hasaneen M., Abdel-Aziz H., El-Bialy D. and Omer A.M., 2014. Preparation of chitosan nanoparticles for loading with NPK fertilizer. African Journal of Biotechnology 13.

Iversen T.-G., Skotland T. and Sandvig K., 2011. Endocytosis and intracellular transport of nanoparticles: present knowledge and need for future studies. Nano today 6:176-185.

Joye I.J., Davidov-Pardo G. and McClements D.J., 2014. Nanotechnology for increased micronutrient bioavailability. Trends in food science & technology 40:168-182.

Kettiger H., Schipanski A., Wick P. and Huwyler J. (2013) Engineered nanomaterial uptake and tissue distribution: from cell to organism. International journal of nanomedicine 8:3255.

Kingsley J.D., Ranjan S., Dasgupta N. and Saha P., 2013. Nanotechnology for tissue engineering: need, techniques and applications. journal of pharmacy research 7:200-204.

Kumar L.Y., 2015. Role and adverse effects of nanomaterials in food technology. Journal of toxicology and health 2:2.

Liu S., Yuan L., Yue X., Zheng Z. and Tang Z., 2008. Recent advances in nanosensors for organophosphate pesticide detection. Advanced Powder Technology 19:419-441.

O'Dowd C.D., Aalto P.P., Yoon Y.J. and Hämeri K., 2004. The use of the pulse height analyser ultrafine condensation particle counter (PHA-UCPC) technique applied to sizing of nucleation mode particles of differing chemical composition. Journal of aerosol science 35:205-216.

Oberdörster G., Oberdörster E. and Oberdörster J., 2005. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. Environmental health perspectives 113:823-839.

Pradhan N., Singh S., Ojha N., Shrivastava A., Barla A., Rai V. and Bose S., 2015. Facets of nanotechnology as seen in food processing, packaging, and preservation industry. BioMed research international 2015.

Raab C., Simko M., Fiedeler U., Nentwich M. and Gazsó A., 2011. Production of nanoparticles and nanomaterials. Institute of Technology Assessment of the Austrian Academy of Sciences 006en:1-4.

Rajput N., 2015. Methods of preparation of nanoparticles-A review. International Journal of Advances in Engineering & Technology 7:1806.

Ranjan S., Dasgupta N., Chakraborty A.R., Samuel S.M., Ramalingam C., Shanker R. and Kumar A., 2014. Nanoscience and nanotechnologies in food industries: opportunities and research trends. Journal of Nanoparticle Research 16:2464.

Reidy B., Haase A., Luch A., Dawson K.A. and Lynch I., 2013. Mechanisms of silver nanoparticle release, transformation and toxicity: a critical review of current knowledge and recommendations for future studies and applications. Materials 6:2295-2350.

Salvia-Trujillo L., Martín-Belloso O. and McClements D.J., 2016. Excipient nanoemulsions for improving oral bioavailability of bioactives. Nanomaterials 6:17.

Su H.C., Zhang M., Bosze W., Lim J.-H. and Myung N.V., 2013. Metal nanoparticles and DNA co-functionalized single-walled carbon nanotube gas sensors. Nanotechnology 24:505502.

Tiede K., Boxall A.B., Tear S.P., Lewis J., David H. and Hassellöv M., 2008. Detection and characterization of engineered nanoparticles in food and the environment. Food additives and contaminants 25:795-821.

Uribe G.M. and López J.L.R., 2007. La nanociencia y la nanotecnología: una revolución en curso. Revista Perfiles Latinoamericanos 14:161-186.

الآفاق المستقبلية لابتكارات التقنيات متناهية الصغر في الإنتاج الحيواني

أحمد عبد الفتاح محمود عبد المجيد

قسم وقاية النبات، كلية الزراعة سابا باشا، جامعة الإسكندرية، الإسكندرية، جمهورية مصر العربية، ص.ب ٢١٥٣١ بولكلي الإسكندرية

تعتبر تقنية الصغائر (تقنية النانو) ابتكارًا كبيرًا أحدث ثورة في شتى الممارسات الزراعية. فالعمل على مقياس النانو يوفر العديد من الفوائد في هذا المجال. ففي هذا الاستعراض، يتم توضيح المفاهيم الأساسية للتقنية النانوية، مع التركيز على تطبيقاتها الأساسية وتقييم المخاطر الصحية والبيئية خاصة في مجال الإنتاج الحيواني.بالرغم من أنه يوجد نقص شديد في اختبارات التشخيص الموثوقة والفعالة في الكشف المبكر عن الأمراض في مجال الإنتاج الحيواني بصفة عامة، إلا أنه تمتلك تلك التقنيات مثل الاستشعار الحيوي القدرة على معالجة هذه المشكلات من خلال تطوير أدوات تشخيصية مبتكرة للكشف السريع عن التهديدات الصحية الرئيسية في قطاع الثروة الحيوانية. كما تسمح تلك التقنيات الحديثة بالمزيد من الابتكارات التقنية من خلال إنشاء مكونات غذائية جديدة أو مكملات غذائية تحتوي على كبسولات نانوية أو مستحلبات متناهية الصغر، مما يحقق إطلاقًا بطيئًا لبعض تلك المواد المركبة من شأنها تحسين الخصائص الحسية والإنتاجية للمنتج. وعلى الرغم من أن تقنية النانو توفر العديد من الفوائد، ولكن كما هو الحال مع جميع الابتكارات والتقنيات الحديثة، هناك مخاوف ومخاطر مرتبطة باستخدامها. لذلك يجب أن يأخذ تقييم المخاطر في الاعتبار من خلال السمية في الأنسجة المستهدفة والذي يمكن أن يختلف اعتمادًا على المادة النانوية ومقدارها. لذلك يجب إجراء توازن بين الفائدة والمخاطر من خلال استخدام تلك المواد متناهية الصغر، وفي معظم الحالات، على الرغم من أن الكثير من الناس مقبلون على هذه التقنية الجديدة، إلا أنه يلزم مزيد من المعلومات المتعلقة بالمخاطر. ومن ثم يجب أن ينظم استخدامها بشكل قانوني لضمان سلامة الأغذية الزراعية في جميع المنتجات منعاً من التلاعب باستخدام تقنية النانو.