IMPLICATIONS OF THE APPLICATION OF NANOFERTLIZERS IN AGRICULTURE: A MULTI-DISCIPLINARY APPROACH

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ABSTRACT

Although the usage of agrochemicals has boosted agricultural production yet it has had a severe unfavorable impact on the soil along with the flora and fauna. The emergence of nanotechnology over the years, in the form of nano pesticides and nano fertilizers has enhanced solubility, bioavailability and the proper delivery of products, so on and so forth. Such nano materials or nanotechnologies have the potential to improve the pest management, reduce pollution arising out of the use of chemicals in agriculture and eventually the technology results in the hike of agricultural production. However, a plethora of questions or issues remain unanswered or irresolute in connection to the implications posed by nanotechnology in the context of the plant system. In this article, an attempt will be made to examine the benefits, risks, uncertainties as well as the ethical and legal issues involved with the usage of nanotechnology. Besides this, the regulatory and legislative measures in respect of the countries like the United States of America, Canada, European Union and Non-European Union Nations and the Asian Nations regarding the agri-nano products shall also be dealt with.

Keywords*: Agrochemicals, Nanotechnology, Nano Fertilizers, Risks, Uncertainties, Plant System.*

I. Introduction

THE REQUIREMENT for agricultural products and food resources has been considerably increased in the last few years due to the ever-increasing population. It has been provided in the 'World Population Prospect' of 2015 published by the Department of Economic and Social Affirms of the United Nations Secretariat that the population across the globe is on a rise by 1.24% per year and has been predicted to reach 8.5billion by the year 2030. On the basis of such forecasts by the UN, it can be stated that around 70% more crop production

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would be required by the world by the year 2050.[1]This is the reason it becomes crucially essential to embrace those farming practices that are sustainable in nature and which have the capability to improve the agricultural production without the use of chemical fertilizers in an excessive manner. Immoderate or imprudent and recurrent usage of such chemicals may lead to severe pollution and deterioration of the environment and human health.[2] The use of such agrochemicals in a quant it more than what is necessary may lead to rise in the agricultural expenses, cause substantial pollution, which in the long run unfavorably impacts the health of the public and the environment, as most of the traditional fertilizers disperse into the atmosphere or float up on the water bodies.

Hence, the evolution of novel and less innocuous fertilizers is urgently required along with the secured, modern and systematic techniques for averting the harmful implications of such products on the environment. In this direction, the use of nanotechnology in the agricultural system can be considered an ingenious apparatus and the application of nano fertilizers and composts becomes an emerging alternative to the conventional chemical fertilizers. It may lead to the intended delivery and also bring about several probable advantages t the environment and the agricultural productivity in the form of pest management and diminished pollution.[3] However, there are a plethora of questions or issues which remain irresolute in regard to the implications posed by nanotechnology in the context of the plant system which shall be discussed by the authors in this article.

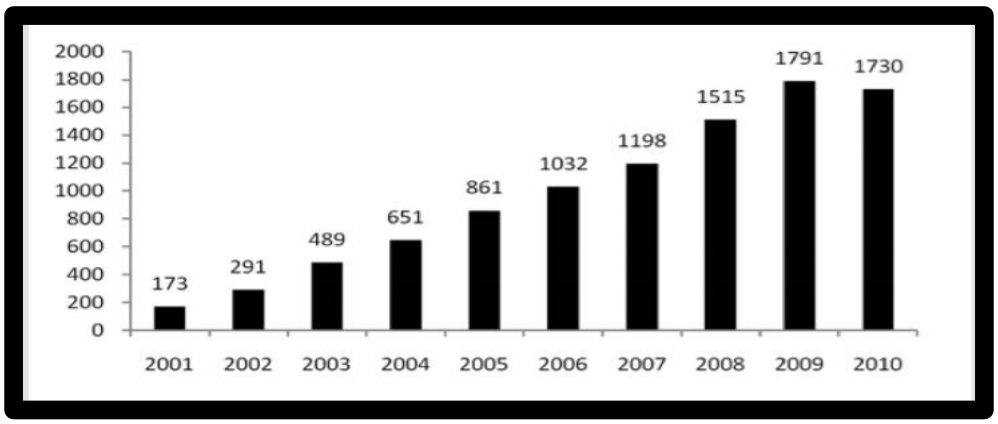
II. Origin and Meaning of Nanotechnology

The word *nano* refers to the measurement of size. A nanometer refers to a millionth of a millimeter which is too large to be identified by bare eyes. The term *'technology'* refers to the methods and techniques advanced during the course of time. Hence, the words *nano* and *technology* when combined together refers to '*an arrangement of novel methods that are being developed to operate the matter on nanoscale*.[4]

The term nanotechnology is much in fashion in the present days having numerous usages and possible applications in the days to come. The world was familiarized with the concept of

[1] United Nations, Department of Economic and Social affairs, "World Population Prospects: The 2015 Revision, Key Findings and Advance Tables" (July, 2015).
[2] Luca Marchiol, "Nanotechnology in Agriculture: New Opportunities and Perspectives" (2018).
[3] *Ibid*.
[4] Anuj Anand, "Nanotechnology: A Social and Legal Insight" (2022).

the said technology in 1959 in a speech delivered by *Richard Feynman*.[5] However, it was only after 1974 when a physicist from Japan named *Norio Taniguchi* elaborated about this technology, the term 'nanotechnology' was devised.[6] This was followed by further development in the area of nanotechnology. It was encountered by the scientists that the performance of atoms and molecules is atypical at the nanoscale. Consequently, it is being considered by the specialists that such technology possesses a wide range of probable usages in different areas having major implications in respect of human health, biodiversity as well as security of the nation.[7] It becomes noteworthy that there has been substantial and vigorous research on the improved application of novel technologies in the plant system, which prove to be environmentally sustainable, for increased productivity and security of food crops. In this direction, some of the possible applications of nanotechnology in the area of agriculture shall be explored by the authors in the forthcoming segments.



GRAPH 1: SCIENCE CITATION INDEX [2001-2010][8]

The graph above shows the Science Citation Index of the year analyzed for a period of 10 years from 2001 till 2010. It implies that the first decade of the twenty-first century has seen a stable growth in the area. The graph signifies a rapid increase in research publications in the area of nanotechnology for the period mentioned above.

[5] 'There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics' was a lecture delivered by the Physicist Richard Feynman at the annual American Physical Society Meeting on the 29th Day of December, 1959 at Caltech.
[6] Dr. Norio Taniguchi, a Japanese Scientist framed the term "nanotechnology" in the year 1974 and defined it as the 'processing of separation, consolidation and deformation of materials by one atom or one molecule.'
[7] Supra note 2.
[8] Biglu M-H, *et al.*, "A Scientometric Analysis of Nanotechnology in MEDLINE" 1 *BI* 193-198 (2011).

III. Nano-Fertilizer and its Application in the Agricultural Sector

Some essential elemental nutrients are required by the plants necessary for their development. The dearth of such nutrients proves to be one of the major reasons for the hampered growth of plants as well as the animals and human being's dependent on such plants for food. The foundation of such mineral nutrients was essentially laid down by *Justus Von Liebig*. After further work in this direction, these elements were coined as *essential elements* by Arnon and Stout in the year 1939 and later on around seventeen elements were regarded as essential.[9]

Although initially the fertilizers have proved to be beneficial for the crop production because of their instant actions yet with the passage of time, the usefulness of the traditional fertilizers has diminished and resultantly, the quantity of the fertilizer-usage has increased to accomplish the targets of large agricultural production. Such increased application of the conventional fertilizers is rising on a continuous basis every year thereby leading to tremendous employment of such fertilizers which brings in several negative implications on human health and environment. Most of the synthetic fertilizers are made water-soluble for proper absorption of nutrients by plants, however, because of their nature, the nutrients get drained away with the rainwater or percolate into the ground polluting the lakes, rivers and other water-bodies. In this context, the application of fertilizers on the crops in the form of nano fertilizers is winning enormous attention.[10]

Nanotechnology occupies the most important position amongst the recent technological developments and Nano fertilizer is the novelist and scientifically advanced medium of discharging the required elements or nutrients into the soil in a regulated manner. It has the capability to split the seeds and advance the availability and accessibility of the important nutrients to the branches and leaves of plants thereby improving the development and quality of plants. Nanotechnology in the field of the agricultural sector leads to minimized application of pesticides and fertilizers, controlled discharge which ultimately results in meticulous farming.

Nano composites or fertilizers are prepared from ammonia, urea, plant wastes, ammonium humate, and so on. Nano fertilizers are presently categorized into three major

[9] Ajay Kumar Bhardwaj, *et. al*., "Switching To Nano Nutrients For Sustaining Agroecosystems And Environment: The Challenges And Benefits In Moving Up From Ionic To Particle Feeding" 20 *Journal of Nanobiotechnology* 19 (2022).
[10] *Ibid*.

types: I. Nanoscale input fertilizers II. Nanoscale additive fertilizers and III. Nanoscale host fertilizers.

The different types of nano fertilizers are discussed below:

Nanoscale input fertilizers:

The category of nanoscale input particles constitutes the restructuring at the nanoscale dimension of the fertilizers already present. The process involves diminishing the size of the active components or elements. The various examples falling under this category are nano-urea, nano-bacterial compositions, nano-ammonium, etc. That apart, a nano-mixture of neem cake and plant-development rhizobacteria has been formulated to slow down the discharge of nutrients. Such formulation was applied on *Vigna radiate,*[11] resulting in hiked weight of the grain, concentration of protein and production.[12]

Nanoscale additives fertilizers

The type of additive fertilizers constitutes the addendum of nano-particles or nano-composites to the already present conventional fertilizers at macro scale. The intention of the formulation of such additives is not to enhance the level of nutrition of the fertilizer but they are prepared to provide extra benefits, such as better water absorption, retention, transport, cell wall extension and ensuring the stability of soil. Carbon nanotubes and carbon nanofibers fall under this category. Carbon nanotubes have been studied to raise the uptake of water in plants by way of escalating molecular transport through xylem or diminishing the porosity in soils of uneven-texture which eventually lessens water loss.[13]

Nanoscale host fertilizers

The category of host fertilizers constitutes the fertilizers which are encased into the nano-pores or spaces of the host materials. The study reveals that covered or coated nanoparticles prove to be better in the context of slow discharge of nutrients, stability as well as bio-safety.[14]

Nano-fertilizers are prepared by the help of mechanical and biochemical procedures, that is to say, nano-particles are produced by grounding the materials mechanically and thereupon

[11] *Green gram*.
[12] *Supra* note 9.
[13] *Ibid.*
[14] *Ibid.*

biochemical mechanisms are applied on them to accomplish effectual nano-scale formulations. Fertilizers when encased within nano-materials present an enormous absorption potential and provide the plants with the required nutrition.[15]

It has been found by the researchers that the roots in the plants and stomatal opening leaves are considered as the entry ways which are highly permeable to the Nano fertilizers. It is also reported that nano-fertilizers transport nutrients via plasmodesmata. Important nanoparticles, such as silica and carbon nanotubes are effective in the transportation of essential nutrients to the plant's destination. Nano fertilizers are regarded as a system of lunchboxes where the plants may absorb the reserved nutrients as and when the conditions are apt.[16]

Nano-technology: A New Way to Sustainable Agriculture

One of the new aspects of the twenty-first century is nanotechnology that enhances the conventional modes of agriculture and helps in the sustainable growth by advancing the techniques to manage and conserve with less amount of waste generated. The application of agricultural chemicals is generally done by way of spraying in traditional methods, however in order to promote eco-friendly mechanisms in agriculture, the present-day nano-fertilizers in the plant system have grabbed the attention in respect of agriculture farming. The basic goal of a controlled delivery mechanism is to discharge a certain quantity of adequate agro-chemicals over a certain period of time and to gain complete biological competency with reduced hazardous consequences. Nanomaterials have an upper hand as they provide the benefits of effective delivery of the essential nutrients because of the vast surface area, effortless attachment and quick mass transfer.[17]

Nano-fertilizers: A Proficient Basis of Balanced Crop Nutrition

Ordinarily, the provision of important nutrients is unavoidable for the enhancement of the productivity of crops and fertility of soil. It is also well known that food is a fundamental human right. However, food insecurities have been widespread because of the limited availability of natural resources. In order to meet the demand of food, rigorous farming is being carried out which ultimately causes the wearing out of the fertility of soil. Hence, for

[15] *Ibid.*
[16] *Ibid.*
[17] Yifen Shang,*et al.,* "Applications of Nanotechnology in Plant Growth and Crop Protection: A Review" 24 *Mol* 1-23 (2019).

the purpose of lessening the deficiency of nutrients, the usage of nano-fertilizers is the best option.[18] For example, the usage of nanoparticles, such as zeolites, chitosan and so forth, considerably minimizes the harm of nitrogen by controlling the discharge and improving the uptake process by plants.

The production of agriculture could hike by 35%-40% by way of balanced fertilizer management, proper irrigation and application of good quality seeds. Nanoparticles arouse a number of important aspects of the biology of plants because plant root and leaf surfaces are the major nutrient entrances of plants which are highly absorbent at nanoscale. It is worth mentioning that the improved productivity has the probability to motivate the farmers to work more efficiently and effectively.[19]In spite of the vivid applications of nanotechnology in agriculture, it also possesses certain uncertainties and risks. The next part shall deal with such negative aspects of the employment of nanotechnology in agriculture.

IV. Risks and Uncertainties Involved in the Usage of Agri-Nano Particles

Nano fertilizers are widely utilized in the agricultural sphere due to their high potential benefits. This is why it becomes quite evident that nanomaterials have the tendency to come into contact with the human bodies immediately. There are various issues that obstruct the development of nano fertilizers. One such major difficulty in the usage of nano fertilizers is toxic impact on the plants, animals, microbes, etc. The possible issues related to the toxic nature of nanoparticles have been discussed below:

Nano toxicity

Nanoparticles based on metal and metal-oxide are reported to display development in the plants, however, they are also reported to bring implications regarding nanotoxicity in the crops and plants. It has been disclosed in a study that the most regularly applied metal oxide nano-particles, for instance, CuO, Ag, NiO, ZnO, etc. have the potential to bring in nontoxicity through molecular-level damage and oxidative stress.[20] Not only the metallic

[18]*Ibid.*
[19]*Ibid.*
[20] Ma C, White JC, et. al.,"Metal-based Nano toxicity and DdetoxificationPpathways in Higher Plants" 49, 12 *ES &T* (2015).

nanoparticles but also the non-metal nanoparticles, such as Fullerenes and singled-walled carbon nanotubes have been proved to show nontoxicity.[21]

Harm to DNA

Some of the most evident abnormalities visible in plants exposed to some of the metal oxide nanoparticles and carbon nanotubes are micronuclei formation, diminished mitotic index, stickiness, chromosome disintegration and disorder.[22] A study of nickel-oxide nano-materials has shown to cause Geno toxicityin the case of tomato plants. The nanoparticles in this case were able to approach the DNA directly thereby causing irreparable harm to the cells.[23]

Damage to cell wall membrane

The pointed borders of nanoparticles also sometimes become responsible for harming the cell wall membranes. This is another nontoxicity process by which the cellular content gets leaked in the environment thereby causing cell death.[24]

The nanoparticles such as carbon nanotubes, nanofibers, fullerenes, etc. have shown undesirable impacts when research was conducted by Ostiguy et al. and Taoo et al., on certain creatures.[25] Besides this, an ample number of carbon nano-materials have also been proved to be cytotoxic to the human embryonic kidney cells (HCT 116), human alveolar epithelial cells (A549), Hepatocytes (Hep G2 Cells), intestinal cells (P407).[26] Fascinatingly, a few studies carried out for the purpose of inquiring about the implications of carbon nanotubes and fullerenes on the plant system, have shown results in affirmative in improving the development of plants thereby being marketed as plant growth enhancers. However, it also becomes worth-mentioning here that some studies conducted on nanoparticles have also shown the adverse impact of these materials on the growth of plants and on some advantageous micro fauna as well. That apart, nanoparticles constituting silver and copper, *inter alia*, have been proved to cause oxidative stress to earthworms.[27]

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[21] He A, Jiang J, Ding J, et. al., , "Blocking Eeffect of FfullereneNnanoparticles on the PlantCellStructure and its Phytotoxicity"*Chemosphere* (2021).
[22] Karami Mehrian S and De Lima R., "Nanoparticles Cyto and Gnontoxicity in Plants: Mmechanisms and Aabnormalities" 6, *ENMN*184-193 (2016).
[23] Faisal M, Saquib Q, et. al.,"Phytotoxic Hazards of NiO-nanoparticles in Tomato: AStudy On Mechanism of Cell Death" 250-251, 318-332 JHM (2013).
[24] Akhavan O and Ghaderi E., "Toxicity of Graphene and GrapheneOxide NanowallsAgainst Bacteria" 5731 *ACS Nano*(2010).
[25] Phenny Mwaanga, "Risks, Uncertainties and Ethics of Nanotechnology in Agriculture" Intech open(2018).
[26]*Ibid.*
[27]*Ibid.*

Thus, in order to make sure that the use of nanoparticles is made in a safe and secure manner and keeping in mind the health of human beings and environment, thorough and far-reaching risk evaluator mechanisms should be employed.

Apart from the benefits and risks involved in the usage of nanotechnology in the plant system, answers to a few questions are still ambiguous. For instance, are the present toxicity evaluating protocols adequate enough to provide for the required information regarding delayed toxic effect of nanoparticles? Is there available a satisfactory framework that ensures and regulates the security of the usage of nanotechnology in respect of agriculture? Is there available such risk evaluating protocols used for both terrestrial and aquatic organisms that provide reliable information in respect of contact of humans through ingestion or some other process? What would be the implication of nano fertilizers on valuable soil microorganisms?[28]

As regards the toxicity evaluating protocols, it can be stated that the evaluation systems are traditional in nature and quite expensive and time-consuming also. Regrettably, such tests often fail to take into consideration the delayed toxicity. Although a few mechanisms are now available for the purpose of detection and characterization of nanoparticles, such mechanisms require validation in tandem with the need to further develop standard materials required in such mechanisms.

V. Various Perspectives in Respect of Agri-Nanotechnology

Ethical Concerns

Despite being highly fruitful for agricultural production in the twenty-first century, nanotechnology needs to be adopted with much care and caution as there is absence of adequate knowledge regarding the inadvertent implications of the technology due to its novelty. The United States and the European public also seem to know less about the technology as per the reports. When little is known about a particular object or subject-matter, its acceptability depends largely on ethics followed by the industries in handling it. Another facet that impacts the perception of the public in respect of nanotechnology is the media. The level of coverage of such technology is comparatively low in less developed nations as compared to the developed nations along with low levels of research in technology.

[28] *Ibid.*

Hence, a few questions come up in the context of ethics in nanotechnology, such as, despite the uncertainties regarding the safety of nanoparticles in plant systems, should the industries continue to apply them? Is it just for the government to fund the expansion of nanotechnologically produced fertilizers, despite the present degree of uncertainty? Should there be regulations set in regulating nanotechnology in agriculture to increase public perception and acceptability? If solutions to these questions are not provided timely, the public might develop a negative viewpoint regarding the usage of nanotechnology in agriculture.

Health Concerns

One of the major issues that involve the plausible impacts of the nanoparticles is that of health. The high surface areas of the particles are easily soaked up by the body through inhalation, dermal exposure and ingestion, in comparison to the low surface areas of the particles. The nanomaterials can delve into the cells with ease through membranes, endocytosis and transmembrane sources leading to the cell death and other malfunctions.[29]

Environmental Concerns

A term ordinarily used for the waste produced by nanoparticles is known as *Nano pollution.* Due to their molecular structures, size, shape, area of surface, the nano-materials could be more hazardous than the other traditional waste materials. It becomes important to mention here that such materials have the potential to remain in air for weeks and also have the capacity to pass through a long distance and thereafter seep in the animal, plant and human cells, consequently inviting several side-effects. In order to ascertain the environmental, ecological and health implications of nanotechnology, it is important for the researchers and scientists to delve deeper into the study of kinds, processing mechanisms and degrees of degradation of the nanomaterials.[30]

Legal Perspective

With the rise in nanotechnology in the agricultural and industrial sectors, regulatory frameworks are also being embraced at an expeditious rate. However, the regulating authorities in the developed nations are struggling with the difficulty of how to reduce the

[29] R. Asmatulu, *et al.*, Safety and Ethics of Nanotechnology (2022), *available at:* https://www.researchgate.net/publications/283135430 (last visited on December 28, 2022).
[30] *Ibid.*

potential risks involved with such technology and also reduce the uncalled-for pressure on the researchers and industries from conflicting approaches around the world. The advent of novel technology gives rise to new legal challenges and concerns. Several issues might arise here, for instance, in the circumstances when a nanoparticle cannot be detected with a naked eye and leaves no hint of being in a particular property ever, does it interfere with the owner's right to property? What is the way to protect an individual in case any such nanoparticles enter his body without his knowledge causing damage? In case, an individual fortuitously inhales a nanoparticle which eventually causes his death, on whom and how the liability would be imposed?[31] Which instrument or equipment should be required to establish the violation of such rights?

Another concern is in regard to patentability of nanoparticles. An invention, in order to be patentable, must be new and something which is not apparent or obvious. Problems arise in respect of patentability of a nanoparticle while evaluating its obviousness and novelty because such nano-particles may be analogous to previous macroscopic inventions. A later invention may be naturally apprehended even if not so mentioned in the previous invention. Such cases of natural apprehensions have the tendency to refuse patent protection to any such nano-particle that is merely a nano-version of a macroscopic previous art. Another issue is with regard to non-obviousness of an invention. This means that an invention must be of unpredicted and unanticipated consequences to gain patent protection. Here, taking the example of a single-walled carbon nanotube which can carry a billion amps per square centimeters which the macroscopic carbon nanotube cannot, when compared, one can hold that capacity to carry high current of the nano carbon tube is unforeseen. Hence this proves the non-obviousness of such nano-structures. Therefore, it can be stated that a proper all-encompassing regulatory or legislative framework must be prepared and implemented in respect of the new technology and nano-structures.

Educational Perspective

Commendable benefits have been offered by nanotechnology to the environment as well as to human life, since its very inception. Although much research work has been already conducted regarding the usage of nanotechnology in agriculture yet unfortunately the development of education in this field has not been as swift as has been in technology.

[31] *Supra* note 4.

Interdisciplinary and multidisciplinary education and instructions must be provided on nanotechnology and ethics to the students, social scientists, technologists, agriculturalists, so on and so forth as this would be of immense benefit. Other than this, guidance in this respect could also be provided through seminars, conferences, etc. with a view to impart knowledge on the subject. That apart, with every novel progress, the websites should be regularly updated in this regard. Private Companies and Government Authorities like Environmental Protection Authority, Food and Drug Administration, National Institute of Health, National Science Foundation should also be provided with financial aid so that they can effectively participate in the imparting of education and knowledge in respect of nanotechnology and nano-fertilizers.[32]

VI. Regulatory Framework of Nanotechnology Across the Globe

Nanotechnology has the capability to revolutionize the agri-food sector. Nations across the globe have efficiently scrutinized the aptness of their legislative and regulatory frameworks for handling nanotechnologies. Consequently, various perspectives have been adopted in the regulation of agri-nano products. In this direction, the regulatory frameworks of nanotechnology in the EU, Non-EU and Asian Nations shall be discussed here.

Regulatory Framework in the USA, Canada, EU and Non-EU Nations

The United States of America

The authority responsible for regulation of an agricultural product under the Federal Food, Drug and Cosmetic Act (FFDCA) is the Food and Drug Administration (FDA). But as of now the FFDCA constitutes no specification for products based on nanotechnology. The Authority has, nevertheless, categorically stated that 'an approach depending upon each case' is necessary for evaluating the safety of a finished nano-product. That apart, the United States Environmental Protection Agency (US-EPA) regulates the pesticides under the sanction of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Unfortunately, there exist no provisions in respect of nanoparticles under this particular regulation. However, a public notification has been issued as to how such nano-enabled pesticides should be controlled and incorporated under the abovementioned Act.[33]

Canada

[32] *Supra* note 29.
[33] Alok Adholeya*.*, "*Zero Draft Policy on Regulation of Nanoproducts in Agriculture*" TERI, 2017).

The two authorities that are together responsible for regulating agri-products are the Canadian Food Inspection Agency (CFIA) and Public Health Agency of Canada (PHAC). However, no particular rules and regulations exist for nano-based fertilizers.[34]

European Union

There is presence of ample number of regulatory frameworks for dealing with nano-enabled agri-products, such as, Regulation on the provision of Food Information to Consumers (1169/20119), Regulation on Plastic Food Contact Materials and Articles (10/2011), Regulation on Active and Intelligent Materials and Articles (450/2009), The Biocidal Products Regulation (528/2012), The Cosmetic Products Regulation (1223/2009), and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulations (1907/2006). Despite the fact that there exists the Plant Protection Products Regulation (1107/2009) which addresses the nano-enabled pesticides, yet it is regarded by the European Union that the nano-enabled pesticides are a different category of pesticidal product which would consequently demand a distinct risk evaluation and sanction from the concerned authority.[35]

Non-European Nations (Switzerland, Turkey, Russia)

The power for the sanction of nano-enabled products, in Switzerland, inclusive of agriculture rests with the Federal Office of Public Health (FOPH). For the purpose of registration, the application must constitute some requisites, such as, composition, shape, aggregation state, particle size, coatings, surface area and utility of a nano-particle. However, surprisingly, no such applications for registration of such products have been served to the concerned authority. The Ministry of Environment and Urban Planning is the authority playing an effective role in regulating and dealing with nano-enabled products in Turkey. As regards Russia, the Russian Corporation of Nanotechnologies is accountable for the control of nano-tech sectors. There has been initiation of various programs at the federal level which fundamentally incorporate the safety provisions of WHO.[36]

Regulatory Framework of Nanotechnology in Asian Nations (India, China, Japan)

[34] *Ibid.*
[35] *Ibid.*
[36] *Ibid.*

Of late, the concept of nanotechnology has cropped up as a potential way for the development and expansion of the agricultural sector. As the rapid rise in the population of the world has proliferated the demand for food, so has the demand for nanotechnology in the food sector has also increased to a great extent. However, the usage of such technology in the agricultural sector requires proper approval from the authorities concerned in order. Such approvals are necessary for the safety of the environment as well as the consumers. There are several countries across the globe which have been trying to evaluate their regulatory frameworks so as to ascertain whether these are appropriate for dealing with nanotechnology. This part would be dealing with the regulatory frameworks of different nations in respect of the usage of nanotechnology in the agricultural sector.

India

There are several departments of Government which attempt to support and advance nanotechnology and nanoscience in different sectors. To be specific, the Department of Science and Technology and the Department of Biotechnology have played a major role in conducting various programs, investments, setting up and promoting laboratory facilities, expanding human resources and collaborating internationally. In order to raise the commercialization of nanotechnology, the Indian Government has presented a few regulations to control and sustain the eminence and security of the nano-products and mechanisms. The major purpose of such guidelines is to supervise the application of numerous nano-agri input products (NAIP) and nano-agriproducts (NAP) which are spreading over the Indian markets in recent times, with a view to get away with the toxicity present in nanoparticles thereby preventing the human health and the environment from any harmful effects of the said technology.

The guidelines for valuation of nano-agri input and nano-agriproducts were made public on the 1st day of August, 2019. The push for the advancement of nanotechnology is not new. The Government of India had launched a National Nano Mission in the year 2007 for the promotion of Nano-biotechnology. The mission was basically about the application of nanoscience and technology for clean and safe drinking water, sensor development, and so on and so forth. That apart, in the year 2017, the Energy and Resources Institute (TERI) had initiated a ‘Zero Draft’ on the management of nano-products in the field of agriculture. The fundamental objective of such a draft was to revolutionize the food production system globally. The TERI Report had also stressed on the fact that the application of

nanotechnology in the agricultural sector minimizes nutrient deficiency.[37] That apart, we also have some legal measures in the form of legislations which indirectly deal with such technology in the agri-sector in India. Some of the important laws are being discussed here:

I. **The Environment Protection Act of 1986:** The MoEFCC[38] has been authorized by the said Act to govern the production as well as the import and export and usage of the harmful substances which also constitutes nanoparticles.[39]
II. **The Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2016:** The said regulations demand the registration and approval of the services that create, collect and clear out the harmful wastes which also includes nanoparticles.
III. **The Food Safety and Standards Act, 2006:** The Statute empowers the authority on food safety which is responsible to evaluate the safety and proper condition of the Indian food products. Certain instructions have been issued for the usage of nanotechnology in respect of food, also constituting agricultural products.[40]
IV. **The Seeds Act, 1966:** The Statute monitors the quality of the seeds utilized for agricultural purposes. The said legislation has also undergone amendments so as to constitute provisions for the governing of the seeds which are genetically modified. This may also include the usage of nanotechnology within its purview.[41]

It could be stated that the rules and regulations regarding the usage of nanotechnology in the context of agriculture are still sprouting. However, it is to be noted that India has no express legislative framework till date which could legally govern and supervise the use of nano fertilizers in agriculture.

China

The authorities dealing with national policies and standards in respect of the nanotechnological sector are the National Centre for Nanoscience and technology (NCNST) and the Commission on Nanotechnology Standardization. However, it is noteworthy to

[37]The Wire, Mayank Aggarwal, "Govt Proposes New Guidelines for Safe Use of Nanotechnology in Agriculture," 2019, *available at:* https://www.thewire.com/ (last visited December 28, 2022).
[38] The Ministry of Environment, GOI, Forest and Climate Change.
[39] The Environment Protection Act, 1986 (Act 29 of 1986).
[40] The Food Safety and Standards Act, 2006 (Act No. 34 of 2006).
[41] The Seeds Act, 1966 (Act No. 54 of 1966).

mention here that the Chinese Authorities have not sanctioned the usage and application of such technology in the field of food and other agricultural areas.[42]

Japan

Japan has no specific regulatory framework in respect of nanoparticles and nanotechnology till date.[43]

VII. Conclusion & Suggestions

Various challenges are being faced by the agricultural sector in the twenty-first century to increase production and supply to a growing population along with smaller working forces, climate change and the developing urbanization. Such difficulties would get more intensified in the days to come paving the way for an extra requirement for food crops and other agricultural products. Hence, particularly in the agricultural sector, nanotechnology has an exceptional capability to aid the precision techniques of farming. The acceptance of nanotechnology by nations would play an incomparable role in feeding the growing population with diminishing natural resources. However, it is also worth mentioning that the stance of the novel technology in this area is not crystal clear in the minds of the public. That apart, thorough study and research in this field is also the need of the hour in order to understand in-depth the potential benefits and risks involved with the use of nanotechnology on the living organisms and environment.

Recommendations:

I. Membership of International fertilizers Development Center: Nations must become members of *International Fertilizer Development Center (IFDC)*. The benefit of such membership would be that the countries will be provided with recent updates regarding the international development of nano-particles and products aimed at agricultural application.
II. Public Awareness: Nations must begin a country-wide agenda for raising the awareness of the public about the use of such products in agriculture and the environmental issues relevant to them.

[42] *Supra* note 33.
[43] *Ibid.*

III. Risk-assessment of nano-particles: Development of smart techniques and mechanisms for confirmation of the evaluation of risks in respect of the nano-products to be employed in agriculture.

IV. Studies and Guidelines to be framed regarding nanotoxicity: Guidelines on the basis of studies conducted in respect of toxicity of such materials must be framed before the rules and policies are approved.

V. Standards to be laid down for the application of nano fertilizers in agriculture: Comprehensive standards must be laid down and laboratories must be set up for the purpose of evaluation, approval and certification of nanoparticles and products for the purpose of their employment in agriculture.

The recommendations in respect of the safe application of nanotechnology in agriculture have been explained with the help of a diagram.[44] It is essential that nanotechnology and safety and ethics regarding this must pursue the similar trends of development with a view to boost public safety and reduce all issues associated with such novel technology.

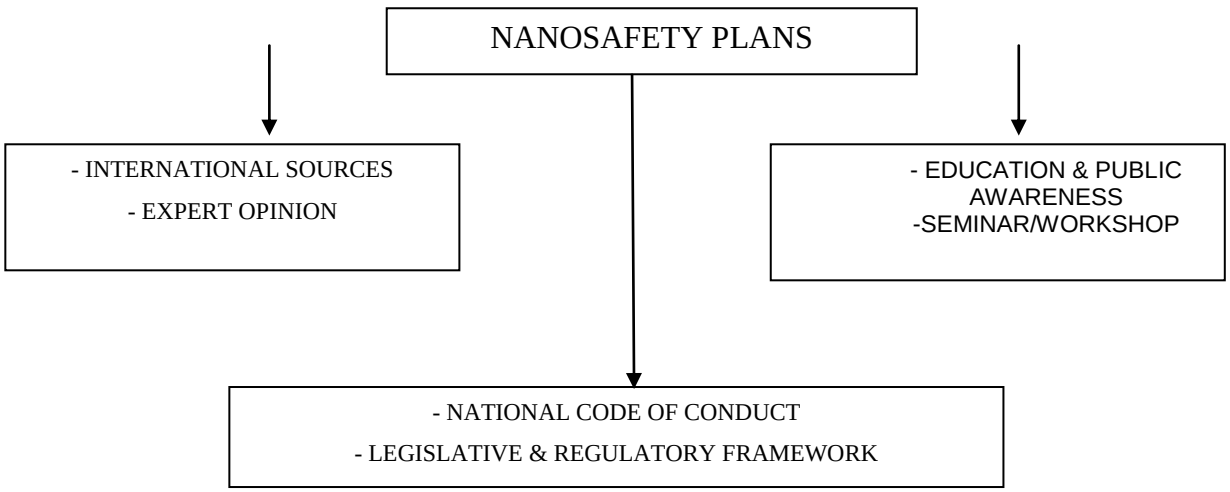

Diagram 1: Nano safety Strategy Framework

[44] F. Allhoff, P. Lin, *et. al., "Nanoethics: The Ethical and Social Implications of Nanotechnology "*Wiley, (2007).