Scientometrics (2020) 123:31–49
https://doi.org/10.1007/s11192-020-03367-y

Silver nanoparticles, research and development in Mexico: a bibliometric analysis

Sein León-Silva[1] · Fabián Fernández-Luqueño[2] · Edgar Záyago-Lau[3] · Fernando López-Valdez[4]

Received: 22 February 2019 / Published online: 30 January 2020
© Akadémiai Kiadó, Budapest, Hungary 2020

Abstract

Mexico has been the world's largest producer of silver for many years, and silver nanoparticles are the most important nanoparticles used in the industry worldwide due to a significant variety of properties. The main goal of this paper was to make a bibliometric analysis of the scientific and productive linkages about silver nanoparticles and their studies, developments, or applications in Mexico. This paper explores and shows the technological transfer of silver nanoparticles from the academic part until its industrial application. We analyzed the scientific publications, academic groups, and technological transfer. We analyzed the obtained data and we done a co-author network array, patent research, and commercial tracking. We found a marked set of researchers studying and developing several materials applied to diverse products range, where the academic production is limited to a number of granted patents. In addition, neither a complete knowledge of the environmental impacts and side effects caused by these particles were found, nor any public policy that regulates its manufacturing. The results suggest opportunities for research, development, application, and academic collaboration on nanoparticles and nanomaterials field, even for legislation and regulation areas. This article shows that Mexico has a good capability to do research and development, in order to generate a propitious environment to scale up the production and commercialization of these technologies on national and international markets, and strengthen collaboration with other countries.

Keywords AgNP · Silver nanoparticles · Environmental impact · Technological prospective · Bibliometric analysis

✉ Fernando López-Valdez
flopez2072@yahoo.com

[1] Science, Technology and Society Program, Cinvestav, Zacatenco, 07360 Mexico city, Mexico

[2] Sustainability of Natural Resources and Energy Program, Cinvestav - Saltillo, 25900 Saltillo, Coahuila, Mexico

[3] Development Studies Academic Unit, UAZ, 98610 Zacatecas, Mexico

[4] Research Centre for Applied Biotechnology, 'Centro de Investigación en Biotecnología Aplicada', Instituto Politécnico Nacional (CIBA - IPN), Carr. Estatal Sta. Inés Tecuexcomac – Tepetitla, km 1.5 s/n, 90700 Tepetitla de Lardizábal, Tlaxcala, Mexico

Introduction

Mexico has been the world's largest producer of silver for many years so far (Bell, s/f; "Mine Production", s/f; "The World's Leading Silver Producing Countries", s/f), with the Fresnillo PLC Company leading the world silver production ("The World's Leading Silver Producing Countries", s/f). Nowadays, it is estimated that about 1120 tons of silver nanoparticles (AgNP) are produced per year, and they are used in the industry worldwide (Stensberg et al. 2011). According to the Woodrow Wilson Inventory (Nanotech Project 2019), the number of products that contain AgNP reaches 443 around the world, as well as, 378 products register at the Denmark Nanodatabase (Nanodatabase 2019). Some studies have shown cases on health risks and potential side-effects of using AgNP on consumer products and workplaces (Benn et al. 2010; Kulinowski and Lippy 2011). In this way, there are two perspectives of development that continuously converging: on one side, the advantages and novel applications that AgNP leads, and on the other hand, the effects and impacts that these products will have during their life-cycle on humans and the environment.

Silver nanoparticles are one of the most commonly used nanomaterials (NM; Bastian et al. 2009; Piccinno et al. 2012). They have shown several important characteristics such as electrical, thermal, antimicrobial, optical, and diamagnetic properties, where the most important applications are optical imaging, photothermal therapy, antimicrobial coatings, drug delivery, biochemical sensing, and cancer treatment, among other applications (León-Silva et al. 2016, 2018). However, AgNP are considered by the Environmental Protection Agency (EPA) as a pesticide in some applications (Kulinowski and Lippy 2011). Nevertheless, due to the absence of proper knowledge about their toxicity mechanisms, the wide variety of processes and manufacture products could increase exposure to workers and consumers inevitably. Despite the continuing efforts of different health and environmental protection agencies, to understand the issues and consequences produced by this NM, the current regulatory policy does not establish maximum exposition levels and repercussions that these materials trigger.

In contradistinction to the American and European inventories, in Mexico, there are not institutions, statistics, protocols, or standards that regulate the production, import or use of AgNP. Therefore, this study aims to lay a foundation and provide an outlook of the development of AgNP in the country, which is ranked as second place on Research and Development (R&D) of nanotechnologies (NT) in Latin America (Kay and Shapira 2009). To analyze the research and production of this material, the areas in which it is implicated and the socio-environmental effects that it implies when it scales until commercial applications, an overhaul of three fields in a value chain was done. A bibliometric analysis was done on published articles, academic groups, and co-author network for the R&D; in the intellectual property field, a patent search with its application areas was done, and finally, the manufacturing companies and consumer products searching was done for the technological transfer section also. As a result, it was found that the '*Universidad Nacional Autónoma de Mexico*' (UNAM), '*Instituto Politécnico Nacional*' (IPN), and the '*Universidad Autónoma de San Luis Potosí*' (UASLP) have a large group of researchers developing and performing several investigations on the production of materials embedded or coated with AgNP. These materials are made for medical, electronics and homeware use, as shoe inserts, wounds, washing machines, vacuums, refrigerators, hair straighteners, and cleaning products.

The main goal of this study is to explore and show the technological transfer of silver nanoparticles from the academic part until its industrial application through of bibliometric analysis of the scientific and productive linkages about silver nanoparticles and their studies, developments, or applications in Mexico. There is not information about the academic activity and its relationship with technological transfer in the AgNP field. In addition, this article offers to open the opportunities for collaboration on their several interrelationships such as academic—academic, academic—industries, academic—government on national and international levels to give openings for several markets and strengthen collaborations with other countries.

Methodology and data

Study of several sources of information

Firstly, the R&D data were obtained using three strategies, which are articles and patents search, academic groups, and commercialization products, and a bibliometric analysis was implemented. For the bibliometric analysis, an advanced search was done to find who leads the scientific research on AgNP. This was implemented through published articles analysis, using the Web of Science (WoS) Core Collection database, Scival and Scopus databases as well, mainly; with the keywords: '***nano****' and '***silver***' in the topic (TS) field, which includes the title, abstract, keywords, author, and indexer. This information was used to create an array with all AgNP published articles from 2009 to 2019 period with at least one author affiliated with a Mexican institution, including public and private universities, research centres, government agencies, and enterprises. Once, the data matrix was obtained, several filters were carried out with keywords that allowed us to define the methods of synthesis, characterization, applications, and most exposed elements. The categories for each topic are illustrated in Table 1. The timespan was selected because the EPA (in August, 2008) took the first steps to directly regulate the potential environmental, health, and safety risks associated with the manufacture and use of NM, becoming that the turning point for impact and regulation studies.

Study by academic groups

Secondly, all academic groups of the '*Programa para el Desarrollo Profesional Docente*' (PRODEP, Professional Development Program for Professors) of the '*Secretaría de Educación Pública*' (SEP, Ministry of Public Education) that promote research areas associated with nanotechnology and AgNP were examined. The PRODEP program catalogues the researchers and their studies interests affiliated with most public institutions of higher education in Mexico (Public State Universities, Polytechnic Universities, Technological Universities, Federal Technological Institutes, Decentralized Technological Institutes, and Normal Schools). The following table (Table 2) illustrates the filters used for processing all data.

For management the data matrix with the bibliometric material of the scientific knowledge derived from previous research in AgNP, a co-author network was designed using Gephi software, version 0.9.1 (https://gephi.org/), which is an open software for exploring, elaborating, and manipulating networks (Bastian et al. 2009), that illustrate the centrality of the researchers, the number of relationships among them, as well as, the institutions and communities as part of this technological category.

Table 1 Topics and keywords used for data searches on AgNP

Topic	Keywords
Synthesis technique	Spray techniques (flame spray pyrolysis, spray-drying, gas phase aerosol, electro spray), lithography (optical, electron-beam, nanoimprint, multiphoton, scanning probe, X-ray, charged particle), evaporation/condensation, ultrasonic fields, spark plasma sintering (SPS), Laser ablation, solvated metal atom dispersion (SMAD) catalysts, ultraviolet irradiation, arc discharge, solvothermal/hydrothermal, sonodecomposition, thermal decomposition, radiolysis, mircrowave IR/radiation, photodeposition, ionization radiation, similar radiolysis, sonochemical reduction/ultrasonic/ultrasonication/sonication, sol–gel process, microemulsions, electrochemical reduction, photochemical reduction, chemical reduction, reverse micelles, polysaccharide, polyoxometalate, tollens, polyphenols, biological reduction, green methods
Characterization techniques	Dynamic light scattering (DLS)/photon correlation spectroscopy (PCS)/quasi-elastic light scattering (QELS), sputtering method, atomic force microscopy (AFM), zeta potential (ZSP), static light scattering (SLS), electrophoretic light scattering (ELS), high resolution transmission electron microscopy (HRTEM), transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray diffraction (XRD), Tip enhanced raman scattering (TERS), surface enhanced raman spectroscopy (SERS), ultra violet–visible spectroscopy (UVV/UV–VIS/UV–vis), X-ray photoelectron spectroscopy (XPS), X-ray absorption spectroscopy (XAS), infrared spectroscopy (IR), inductively coupled plasma (ICP), flame atomic absorption spectroscopy (FAAS), nuclear magnetic resonance (NMR), atomic absorption spectrophotometry (AAS), auger electron spectroscopy (AES), ultrasonic spray pyrolysis (USP), Fourier transform infrared spectroscopy (FTIR), surface plasmon resonance (SPR), dielectric spectroscopy (DS)/impedance spectroscopy (IS)/electrochemical impedance spectroscopy (EIS), inductively coupled plasma mass spectrometry (ICP-MS), photothermal radiometry (PTR), energy dispersive x-ray spectroscopy (EDS/EDX/XEDS)
Exposed element	Vegetation, animal, environment, and human
Applications	Drug delivery, prevent infections, prosthesis, catheter, biomedical, acid uric determination, cancer detection, anti-HIV, wounds, photo catalysis, textiles, coatings, photovoltaic, electronics, sensors and diagnosis, optics, water treatment, food, houseware applications

For the intellectual property field, a search of patent applications and granted patents was done. It was carried out by using the advanced search from the '*Instituto Mexicano de la Propiedad Intelectual*' (IMPI, Mexican Institute of Intellectual Property) database. On this one, Mexican applications and granted patents were searched under the same period (2009–2019) as the bibliometric analysis. The Table 3 lists the searching parameters performed. Once the results were compiled, a manual analysis was conducted for each application to exclude those who did not have a direct relationship with the subject. The results were analysed and categorized into their status.

The technological transfer stage was done through the identification of companies in Mexico that declare containing AgNP in their products. It was manually compiled researching the terms ***silver*** and ***nano**** on the World Wide Web as filter parameters for Mexico, and consulting the Nano-economy inventory of companies (https://micrositios.cinvestav.mx/nano/Mapa) also. After that, it was explored every company and their products in detail, which the application area and the company localization for the searching of each type of product was implied. Sumarising, all searches were done consulting several

Table 2 Searching method for filtering data from PRODEP Academic groups

Searching filters			
1st. Subsystem	2nd. Knowledge area	3rd. Consolidation degree	4th. Keywords
a) Public Universities and related	a) Agriculture and fishing	a) Training Academic Groups (CAEF)	a) nano %silver
b) Polytechnic Universities	b) Health	b) In consolidation, Academic Groups (CAEC)	b) nano %Ag
c) Technological Universities	c) Natural Sciences and Engineering	c) Consolidated Academic Groups (CAC)	c) nano %plata
d) Federal Technological Institutes	d) Social and administrative		
e) Decentralized Technological Institutes	e) Engineering and Technology		
f) Normal schools	f) Education, humanities and arts		

The PRODEP program catalogues were used to elaborate this collection

Table 3 Keywords used for searching patents on AgNP

Keywords	Topic areas
'Nanopartículas plata', Nano* silver/*'nano* plata'*, *'Nanomaterial plata'*	Status, file number, product, applicant publication date, description, and inventors

sources, such as Web of Science (WoS) Core Collection database, Scival, and Scopus databases for scientific articles, PROMED catalogue for line of investigations of the researchers and their affialiations, IMPI databases for patents, and for technological transfer stage was done by an interview and inquiry with enterprises that accepted answer this one.

Results and discussion

The AgNP could be the next tool for a new generation of diseases treatments (Rai et al. 2009), improving electronic devices (Li et al. 2005), coating medical instruments, and enhancing performance of several applications as sensorial detectors, electroluminescent displays and biological labels among others (Abou et al. 2010). Nevertheless, the absence of an appropriate regulation and the lack of control production can turn these promising advances into serious backwards. In this study, we follow the AgNP track, from the R&D until the commercialization sector. This outlook gives a first approach on how AgNP are inserted on the national production, in order to foresight their likely impacts as possible. The bibliometric research showed 902 scientific articles only using the keyword filters, ***silver*** and ***nano****. Nevertheless, excluding the scientific articles that did not cover the subject, we worked with a total of 714 research articles. Up to this time, Mexico is ranked in the 24th position of 100 countries of published articles, representing the 1.15% from 78,063 total papers over the World; with a marked increase since 2013 (Fig. 1). Furthermore, significant collaborations (13.3%) with American institutions were observed, as well as, an elevated attention of researchers at Institutions in the North of the country. San Luis Potosi, Nuevo León, Baja California, Sonora, and Jalisco all of these states are located in the North of Mexico, with a clear trending on material sciences, chemistry, physics, and engineering areas (Fig. 2), which show in the first instance, the orientation of the investigation generated at the country.

Furthermore, an analysis of the authors with more publications was executed, in order to locate the most published areas and the leadership Institutions. From the top 10 authors, half belong to the UNAM, nevertheless two authors from the "Universidad Autónoma de San Luis Potosi" (UASLP) leads the number of publications (Fig. 2).

In order to reach a broad spectrum over the type of research done, the full articles were downloaded and processed. It was found that 84% of the studies focus on the synthesis and characterization of AgNP, using mainly, different chemical reductions and Transmission Electron Microscopy (TEM) for characterization (Fig. 3). The synthesis is carried out by chemical methods using reducing compounds potentially hazard like sodium borohydride (León-Silva et al. 2016). Additionally, several articles suggested a high environmental exposure followed by human exposure, mainly through oral and dermal path (Fig. 4). Almost 57% of the total search done (714 articles) suggested a beneficial impact. However, only less than a half, *i.e.*, 27.6% (144 articles) advised a risk, meanwhile, 10.6% (76 articles) indicated a human damage with concerns related to the generation of reactive oxygen

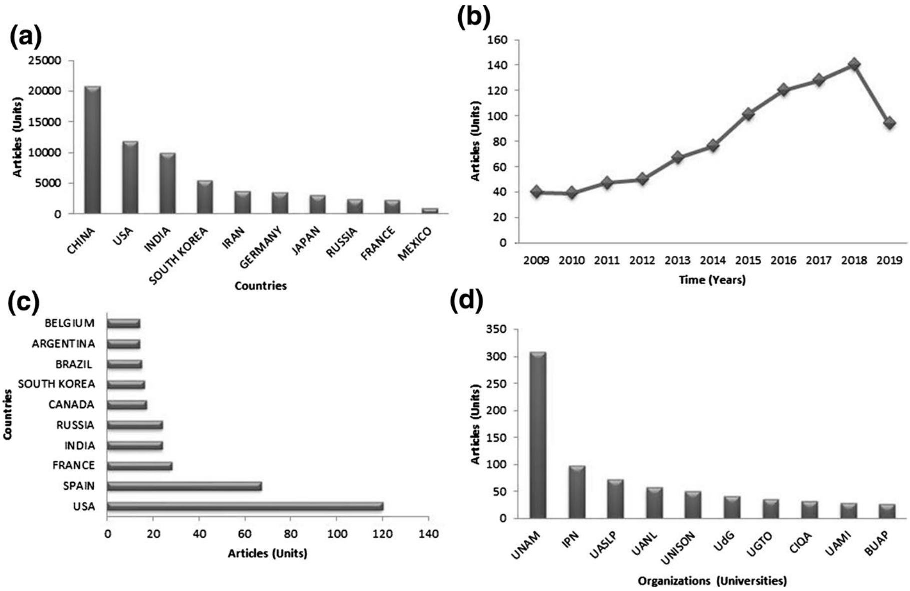

Fig. 1 The research articles on AgNP. **a** World comparison for the 2009–2019 period. **b** Behaviour of articles published in Mexico. **c** Mexican collaboration with others countries. **d** Articles published by Mexican institutions *Source*: Web of Science Core Collection Data, until September, 2019

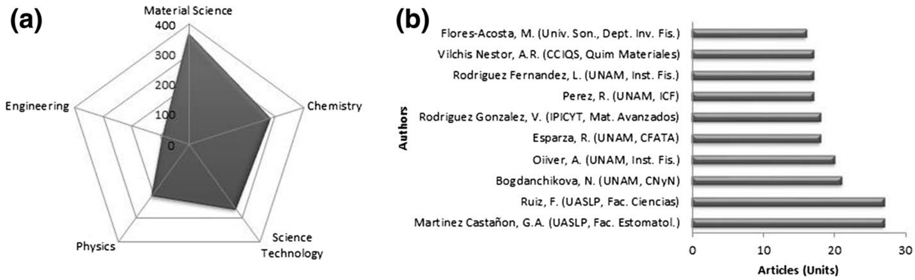

Fig. 2 **a** The most developed areas in AgNP. **b** The most published authors on AgNP topics in Mexico for the 2009–2019 period *Source*: Web of Science Core Collection Data, until September, 2019

species (ROS), inflammatory effects or mitochondrial damage. Furthermore, it is noteworthy that only 25 articles (3.5%) suggested an environmental damage recommending further studies and more in-depth investigations on their impacts. In the other hand, the primary applications of AgNP were focused on prevent infections and the development of sensors for diagnosis, followed by optical and biomedical applications (Fig. 5).

Thirdly, a register of the Academic groups that research AgNP was elaborated, finding 20 Academic groups, which represent the 11.5% from a total of 174 Academic groups that work with NT in the country. These groups incorporate 17 different institutions working on Materials Science and Physic-chemistry areas, restating the bibliometric analysis of top research areas (Table 4).

Subsequently, with prior information and with the intention of understanding the development of the AgNP research communities in Mexico; a co-author network was

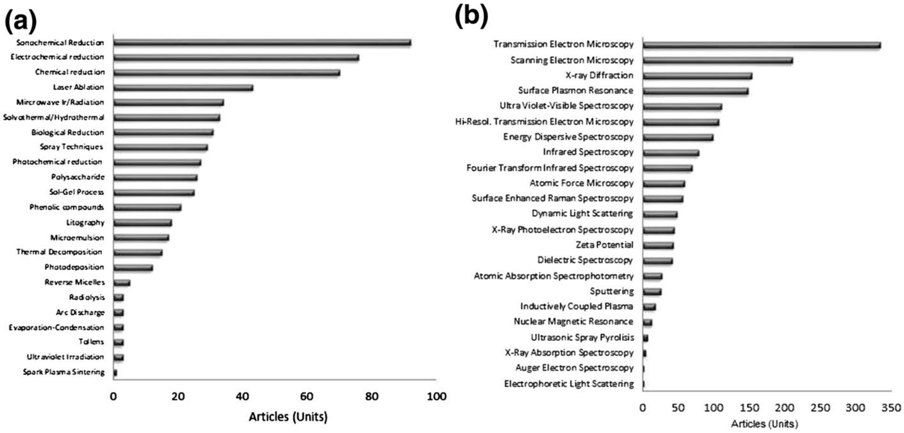

Fig. 3 **a** The most used synthesis techniques. **b** The most used characterization techniques *Source*: Web of Science Core Collection Data, until September, 2019

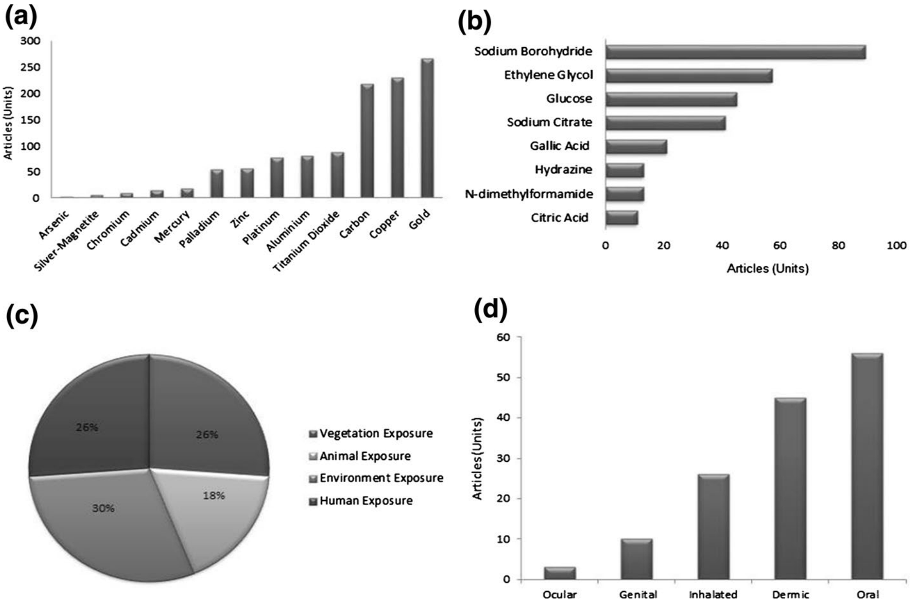

Fig. 4 **a** Elements used with AgNP. **b** Type of chemical reductors used in AgNP synthesis. **c** Elements exposed to AgNP. **d** AgNP principal route of exposure *Source*: Web of Science Core Collection Data, until September, 2019

done. With this procedure, we illustrate the institutional distribution, the collaboration between researchers and the existing communities in the area. On Figs. 6 and 7, the size of each node determines the frequency of their participation in articles, the edges represent co-author relationships, and the colours of each node represent the community to which they belong (Fig. 6), or the affiliation institution of each researcher (Fig. 7).

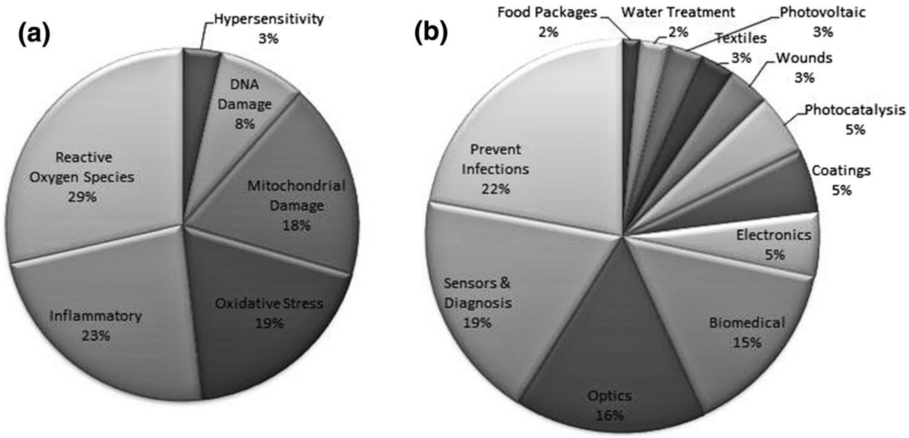

Fig. 5 **a** Principal research effects investigated over AgNP in Mexico. **b** Main applications of AgNP in Mexico. *Source*: Web of Science Core Collection Data, until September, 2019

The co-author network shows more than 1300 researchers working on AgNP. In which the UNAM, is the institution with the highest record of researchers, with more than 200. In the second place, the UASLP with 78 researchers was found, and the UANL, with 70 elements in third place. The most growing community (in yellow) had 107 researchers in which most of its members are developing, the Material Science area. Followed by Engineering and Polymers area with 87 researchers (in green), and 77 elements specialised on Physical-chemistry field. Additionally, Table 5 shows the top 10 researchers sorted according to the Eigenvector Centrality method, where the eigenvector measures the impact of a person involved in a social network. However, this should not be misunderstood as the unique and definitive way to measure the importance of a researcher; inasmuch as several parameters must be needed to be considered for a full sight.

Through this analysis of published data, we elucidate that the major development of AgNP in the country focuses on the exploitation of its antibacterial and antifungal properties for coatings and biomedical appliances, from basic science projects and with low interest on the environmental impact.

The next step on this AgNP outlook implies the intellectual property. In this section, it was done an advanced research in the IMPI's database, searching through several key filters as: '***nanopartículas de plata***', '***nanomaterial plata***', '***nano plata***', '***nanoplata***', and '***nano silver***'. It was found seventeen patents; eight of them belong to six private companies (Daewoo, Kimberly-Clark, Novartis, American Silver, Nanoholdings, and Saeco). Two patents belong to two international academic institutions (Indian Institute of Technology and Northwest University) (Fig. 8). The last seven belongs to national academic institutions (Universidad Autónoma de Nuevo León [UANL], Centro de Investigación en Química Aplicada [CIQA], Universidad de Sonora [UNISON], Universidad Nacional Autónoma de México [UNAM], and Centro de Innovación Aplicada en Tecnologías Competitivas [CIATEC]) it should be noted, that academic patents were related to synthesis or production methods. Meanwhile, the rest of the patents describe application products like household appliances with antimicrobial coatings. Additionally, it is notorious that the patenting process has had an increase from 2016 until now, since in this 3-year period, the patents granted have been increased to twice the total obtained from 2009 to 2019.

Table 4 Main academic group researching AgNP topics in Mexico

Institution	Academic group	Research line	Researchers
Instituto Tecnológico de Querétaro	ITQUE-CA-2 *'Advanced Materials and Nanotechnology'*	Nanomaterials and nanotechnology Compound Materials Polymers and biopolymers	Gómez-Guzmán, Oscar Martínez-Hernández, Ana L Toscano-Giles, José A Velasco-Santos, Carlos
Instituto Tecnológico Superior de Irapuato	ITESI-CA-4 *'Micro and Nanosciences'*	Development of advanced materials from nanostructures Design and development of micro and nano systems Micro/nano optics	Cabal-Velarde, Javier Gustavo Guzmán-Altamirano, Miguel Ángel Pérez-Gerardo, Daniel Rebollo-Plata, Bernabé
Universidad Autónoma de Ciudad Juárez	UACJ-CA-47 *'Materials Science and Engineering'*	Science and technology of advanced materials Micro y nanotechnology Modelling and simulation of materials and processes	Camacho-Montes, Héctor García-Casillas, Perla Elvia Olivas-Armendáriz, Imelda Rodríguez-González, Claudia Alejandra
Universidad de Guadalajara (Centro Universitario de los Valles)	UDG-CA-583 *'Science of Nanomaterials and Condensed Matter'*	Synthesis, and application of colloidal systems Properties of carbon nanotubes with different nanoparticles Design, synthesis and characterisation of self-assembled materials	Ojeda-Martínez, María Luisa Renteria-Tapia, Víctor Manuel Velásquez-Ordoñez, Celso Yáñez-Sánchez, Irinea
Benemérita Universidad Autónoma de Puebla	BUAP-CA-246 *'Nanotronic'*	Bionano, NanoMed-nanotechnology on biology, medicine and life sciences Functional nanomaterials on nanotronics	Molina-Flores, Esteban Ramírez-Solís, Blanca Araceli Zehe-Kuhnt, Alfred Fritz Karl
Universidad Autónoma de Nuevo León (Facultad de Odontología)	UANL-CA-352 *'Oral microbiology'*	Synthesis and characterization of new antimicrobial agents broad-spectrum, by using microbiological, biochemical, molecular biology and biostatistics techniques	Cabral-Romero, Claudio Hernández-Delgadillo, René Martínez-González, Gustavo Israel

Table 4 (continued)

Institution	Academic group	Research line	Researchers
UASLP (Facultad de Ciencias)	UASLP-CA-9 *'Materials'*	Synthesis and characterization of materials Multivariate analysis and multi-agent systems Spectroscopies	Compeán-Jasso, Martha Martínez-Mendoza, José Niño-Martínez, Nereyda Ortega-Zarzosa, Gerardo Palomares-Sánchez, Salvador Ruiz, Facundo
Universidad Autónoma del Estado de México	UAEM-CA-154 *'Nanomaterials'*	Synthesis and characterization of functional nanomaterials	López-Téllez, Gustavo Morales-Luckie, Raúl A Olea-Mejía, Oscar Fernando Sánchez-Mendieta, Víctor Vilchis-Néstor, Alfredo
Universidad Juárez Autónoma de Tabasco	UJAT-CA-175 *'New Materials Research'*	Synthesis and Characterization of new materials Physical and Chemical properties of condensed matter	Acosta-Alejandro, Manuel Falconi-Calderon, Richart
Universidad Autónoma del Estado de Morelos	UAEMOR-CA-146 *'Design and characterization of nanomaterials applicable in Environmental Engineering'*	Study of metallic, nanostructured and natural origin materials applied in engineering for the sustainable care of the environment	Cuevas-Arteaga, Cecilia Torres-Salazar, Ma. Carmen Valladares-Cisneros, Ma. Guadalupe
Universidad Autónoma Metropolitana (Lerma)	UAM-L-CA-2 *'Nanostructured Materials'*	Water dispersed nanosystems Material analysis of nanostructured devices	Arroyo-Gomez, Maricela Hernandez-Zapata, Ernesto Lopez-Maldonado, Guillermo Perez-Martinez, Francisco Reyes-Mercado, Yuri Salazar-Laureles, Jose L
Universidad Autónoma Metropolitana	UAM-A-CA-137 *'Nanostructured Materials Engineering and its Applications'*	Chemical reactivity, synthesis, characterization and modeling of nano-structured systems for application in materials sciences	Arregui-Mena, Ana L Flores-Moreno, Jorge Hernandez-Perez, Isaias Loera-Serna, Sandra

Table 4 (continued)

Institution	Academic group	Research line	Researchers
Tecnológico de Estudios Superiores de Ixtapaluca	ITESIXTA-CA-2 *'Nanostructured Materials'*	Nanostructured Biomaterials Synthesis and characterization of advanced nanostructured materials	Garcia-Martinez, Jesus Montes-Hernandez, Edith Rivera-Olvera, Jesus
Universidad Michoacana de San Nicolás de Hidalgo	UMSNH-CA-102 *'Superficial physico-chemical phenomena'*	Synthesis and characterization Material Synthesis and application in environmental processes	Chavez-Parga, María Cortes Jose Apolinar Huirache-Acuña, Rafael Lara-Romero, Javier Maya-Yescas, Rafael
Universidad de Sonora	UNISON-CA-195 *'Bionanoengineering'*	Nanofabrication Nanosystems for biomedical applications	Guerrero-German, Patricia Gutierrez-Valenzuela, Cindy Lucero-Acuña, Jesus Armando Zavala-Rivera Paul
Universidad Veracruzana	UV-CA-305 *'Nanomaterials'*	Biomaterials Nanostructured materials	Garcia-Gonzalez, Leandro Hernandez-Quiroz, Teresa Hernandez-Torres, Julian Zamora-Peredo, Luis
Universidad de Sonora	UNISON-CA-199 *'Micro and Nano Biomedical Technologies'*	Molecular Biophysics Design and application of intelligent devices for drug delivery	Angulo-Molina, Aracely Burgara-Estrella, AlexelJ Sarabia-Sainz, Jose A Silva-Campa, Erika
Instituto Tecnológico de Oaxaca	ITOAX-CA-4 *'Biochemistry and Nanostructured Materials'*	Nanobiochemistry Development of nanostructured materials	Gil-Gallegos, Ma. Jesus Perez-Santiago, Alma Sanchez-Medina, Marco

Table 4 (continued)

Institution	Academic group	Research line	Researchers
Instituto Tecnológico de Tijuana	ITTIJ-CA-4 *'Applied Chemistry'*	Nanotechnologies and materials for new technologies	Cortez-Lemus, Norma Felix-Navarro, Rosa Licea-Claverie, Angel Lin-Ho, Shui Perez-Sicairos, Sergio Reynoso-Soto, Edgar Salazar-Gastelum, Moises Trujillo-Navarrete, Balter

Elaborated with data from database PRODEP, 2019

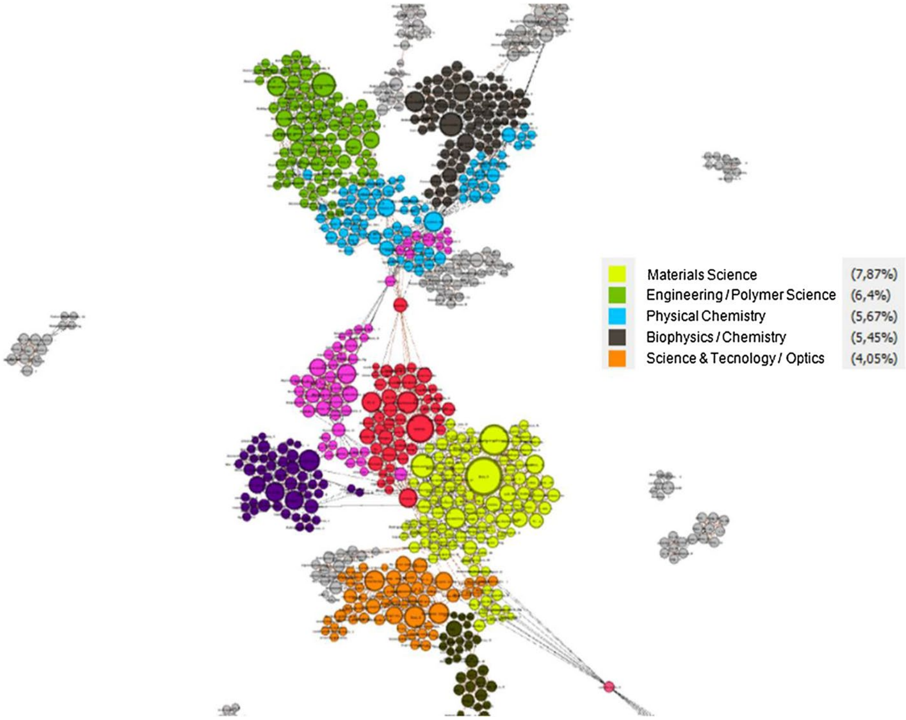

Fig. 6 AgNP co-author network communities. *Displaying communities above 4% from total. Designed with WoS data and Gephi software

Furthermore, it was also detected twelve trademarks from five companies (Golden Silver, Agrovit, Vitasoil, Conair, and Samsung) declaring AgNP in household products such as fridges, hair straighteners, dryers, brushes, soil remediation, and dietary supplements. Finally, eighty-four patent applications were traced; six of them were abandoned or denied, thirty-three were distributed in several applications belonging to twenty-five different companies, from this group eight request of patents are from Mexican enterprises (Bionag, A.G. Mexicana de Nanotecnología, Versatilidad de Plásticos, Kaisha Consultoría, La Joya, Versaplas, and Nanomateriales), thirty-eight requests become from Mexican Academic Institutions, while the remaining seven are from private applicants. In addition, fifteen applications from the academic group requests, seek patent an application or product. However, the other twenty-three requests try to patent a synthesis method or process. Finally, it should be noted, that we found two patent applications belonging to an American Institutions (Northwest University and Texas University) (Fig. 8). Purposely, the United States is the country that most collaborate with Mexico (Lancho-Barrantes and Cantú-Ortiz 2019).

It is noteworthy that in three of the Mexican companies (Bionag, Versaplas, and Nanomateriales) the registered inventors are also leading researchers. These are a good example where they have successfully managed the technological transfer from R&D into commercial products. The final step is the commercialization of AgNP products. Twenty-four companies that announced to use AgNP on their products or production processes were identified (Table 6). Thirteen transnational enterprises as Conair, Croc,

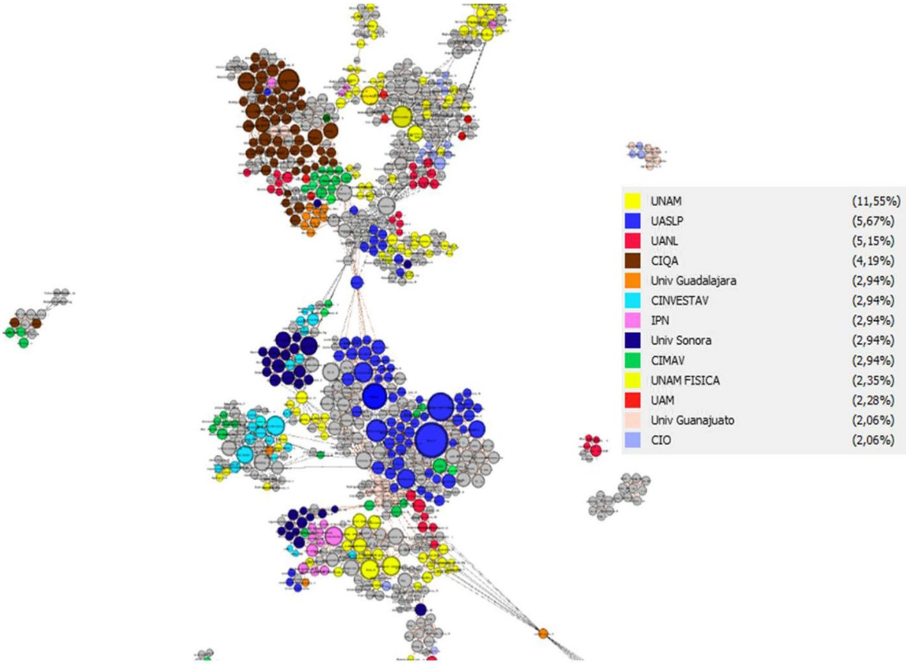

Fig. 7 AgNP co-author network by Institution. *Displaying Institutions above 2% from total. Designed with WoS data and Gephi software

Table 5 Author's centrality, affiliation institution, developing area, and number of co-authors

Author	Degree	Eigenvector centrality	Affiliation institution	Community
Ruiz, F.	61	1.0	UASLP	Material Science
Martinez-Gutierrez, F.	46	0.9129	UASLP	Material Science
Nino-Martinez, N.	39	0.6965	UASLP	Material Science
Martinez-Castanon, Ga.	39	0.6915	UASLP	Material Science
Gonzalez, C.	43	0.6821	UASLP/NCTR	Science and Technology/Neuroscience
Orrantia, E.	35	0.5907	CIMAV	Material Science
Sanchez, Em.	20	0.5188	UASLP	Material Science
Rosas-Hernandez, H.	31	0.5142	UASLP	Science and Technology/Neuroscience
Noriega-Trevino, Me.	19	0.3980	UASLP	Material Science
Espinosa-Cristobal, Lf.	17	0.3844	UACJ	Material Science

Elaborated with WoS data and Gephi software

Andis, Bayer, Kemet, Sony, Daewoo, Samsung, Whirpool, Mabe, Phiten, Vitasoil, and Vacman, manufacture products as razors, hair straighteners, dryers, brushes, chemical coatings, fridges, washing machines, camera lens, vacuums, and nanocapacitors. The

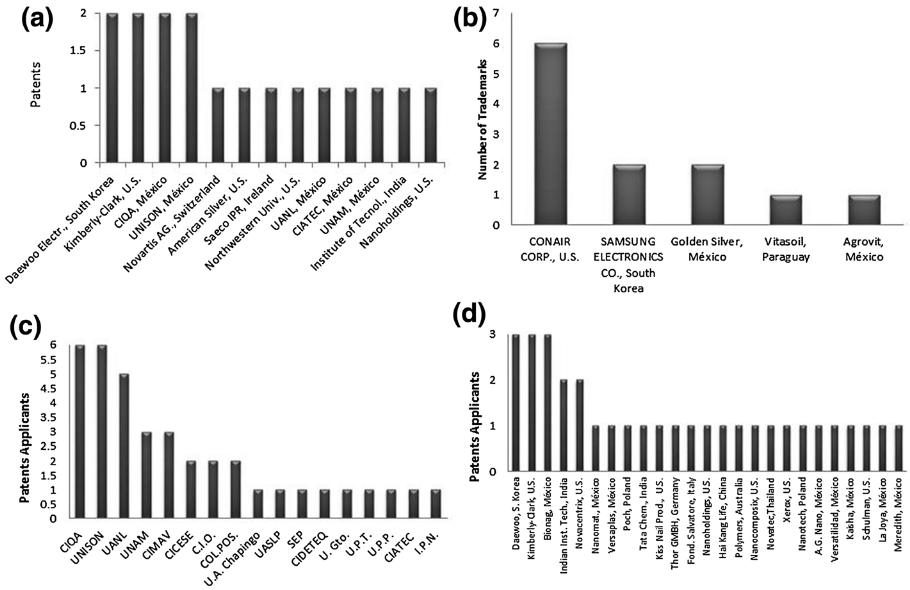

Fig. 8 Analysis of AgNP patents in Mexico according to IMPI's database. **a** AgNP patent holders. **b** Trademark holders. **c** Mexican institutions patent applications. **d** Companies patent applications *Source*: IMPI database until September, 2019

remaining eleven were national companies, selling antibacterial solutions, cleaning and purifying products, and shoe inserts. These companies are located in the North of the country such as States of Baja California, Nuevo León, and Guanajuato, mainly. Also, two of them have their headquarters in Mexico City.

Furthermore, during research on World Wide Web, it was found that ten companies are developing projects in Mexico that include AgNP. Products for coatings, cosmetics, textiles, polymers, paintings, prosthesis, and nutritional suppliers will be produced using AgNP; all of these companies have manufacturing plants located in the North and Centre of the country, mainly (Table 7). It should be considered that this results were obtain with the information achieved by companies declaring using AgNP, however, it is extremely difficult to list all companies that use AgNP due in part the difficulty of tracking the total companies in Mexico at any given time and due the lack of a legal structure, labelling or registered nano-products on the market in order to identify them.

The previous results present a first approach to the AgNP status in Mexico; ranging from R&D to commercialization products. This outlook denotes a vast capacity of basic research regarding silver nanoparticles, suggesting the opportunity for developed more applications. In addition, there was noted an increase of Mexican patents, applications, and registered trademarks since 2016 as well as Mexican companies trading products. Finally, this study offers a first approach to the scientific and commercial transfer of AgNP technology, in order to infer and taking decisions, and make projections at different terms, according to this information. This country has a high capability to do research and development, nevertheless, still requires consolidating their relationship with the industry to generate a propitious environment to scale up the production and commercialization of these technologies in national and international markets and strengthen collaboration with other countries.

Table 6 Selling products in Mexico that announced to contain AgNP

Product	Company	Localization
Antibacterial purifier (Splash Tek)	Aqua Silver Tek	San José del Cabo, Baja California Sur, Mexico
Vacuum (Robot Platinum)	Robot Turmix, Vacman Int.	Miguel Hidalgo, Mexico City, Mexico
Shoe Inserts (Aqua Silver)	Phiten Mexico	San Pedro Garza, Nuevo León, Mexico
Coatings	Protect Industries Vitasoil	Coyoacán, Mexico City, Mexico Cuahutemoc, Mexico City, Mexico
Hair straighteners and brush (Infiniti Nano Silver and Nero)	Conair Croc Tool Science	Connecticut, USA California, USA Texas, USA
Razors (Nano-silver Magnetic)	Andis	Wisconsin, USA
Nanocapacitors	Kemet Mexico	South Carolina, USA
Antiseptic and sanitizers products	Gresmex, S.A.	Naucalpan, Estado de México, Mexico
Nano-Ink	Bayer	Barmen, Germany
Washing machine, fridge, air conditioner (Nanosilver)	Daewoo LG Samsung Whirlpool	Seoul, South Korea Seoul, South Korea Suwon, South Korea Michigan, USA
Synthesis nano-silver	Lotto Bio Nano Laboratories Versoplas, S.A.	León, Guanajuato, Mexico El Marques, Querétaro, Mexico
Antibacterial	Nanomateriales, S.A. Bionag	Apodaca, Nuevo León, Mexico Tijuana, Baja California, Mexico
Shoe inserts	Vector Vita	Ensenada, Baja California, Mexico
Plant tissue culture	Agrovit	Texcoco, Estado de México, Mexico
Camera lens (Silver Nano MRC)	Sony Mexico	Santa Fe, Mexico City, Mexico

Nano economy in Mexico and world wide web, until September, 2019

Table 7 Companies developing projects with nanoparticles of silver in Mexico

Product	Company	Localization
Prosthesis	RD Research and Technology	Hermosillo, Sonora, Mexico
Antibacterial toilettes	Lamosa	Monterrey, Nuevo León, Mexico
Medicines	Neopharma Mexico	Vallejo, Mexico City, Mexico
Nutritional supplies	Rubio Pharma and Associated	Hermosillo, Sonora, Mexico
Polymers	Provista	El Marques, Querétaro, Mexico
Cosmetics	Beiersdorf (Nivea)	Cuauhtémoc, Mexico City, Mexico
Moisture proof	Comex	Naucalpan, Estado de México, Mexico
Ink	Du Pont	Tlalnepantla, Estado de México, Mexico
Electrical	Prolec	Cuauhtémoc, Mexico City, Mexico
Textiles	Kaltex	Naucalpan, Estado de México, Mexico

Nano economy in Mexico and worldwide web research, until September, 2019

Conclusions

Firstly, there is a lacking of regulatory policy and an absence of a suitable technological transfer infrastructure, that cause a slow growth in this area. Additionally, all, articles (714) published shown results where the environmental impact was put aside, without concerning any of their impacts; so, the long-term environmental effect studies are needed to demonstrate the real accumulation, permanency, and disposal of the AgNP after their use, on their different environments.

Second, academic institutions are focus on basic science, meanwhile transnational companies are introducing consumer products from their countries and others, which certainly delay the growth of the national industry. Nevertheless, we found nine national industries versus twenty-three international companies, all of them showed products, projects or patents registered in Mexico. This is done without any regulation or legal obligation to label their products containing any kind of nanotechnology, and also, we found there is not either a record of nanotech products or even, a catalogue of products or companies.

Third, results suggest opportunities for development, application, and collaboration on NP and NM fields, even for legislation and regulation fields.

Finally, Mexico has a good capability to do research and development, nevertheless, is required consolidating their relationship with the industry in order to generate a propitious environment to scale up the production and commercialization of these technologies in national and international markets, and strengthen collaboration with other countries.

Acknowledgements We would like to thank the Instituto Politécnico Nacional, Cinvestav-IPN, and CONACyT (for their financial support, Proj.: CB-2016-01 287225). F. L.-V. and F. F-L per grant-aided support received. We to thanks to Dr. Silvia Luna-Suárez and Itzel Villegas for improving an enriching this study.

Compliance with ethical standards

Conflict of interest The authors declare that they have not conflict of interest, and actual or potential financial interests also.

References

Abou, E. N. K. M. M., Eftaiha, A., Al-Warthan, A., & Ammar, R. A. A. (2010). Synthesis and applications of silver nanoparticles. *Arabian Journal of Chemistry, 3*(3), 135–140. https://doi.org/10.1016/j.arabjc.2010.04.008.

Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. *Third International AAAI Conference on Weblogs and Social Media*. https://doi.org/10.1136/qshc.2004.010033.

Bell, T. (s/f). *Learn about the world's 10 biggest silver producers*. Retrieved February 12, 2019 from https://www.thebalansce.com/the-10-biggest-silver-producers-2340234.

Benn, T., Cavanagh, B., Hristovski, K., Posner, J. D., & Westerhoff, P. (2010). The release of nanosilver from consumer products used in the home. *Journal of Environmental Quality, 39*(6), 1875–1882. https://doi.org/10.2134/jeq2009.0363.

Kay, L., & Shapira, P. (2009). Developing nanotechnology in Latin America. *Journal of Nanoparticle Research, 11*(2), 259–278. https://doi.org/10.1007/s11051-008-9503-z.

Kulinowski, K., & Lippy, B. (2011). *Training workers on risks of nanotechnology*. National Institute of Environmental Health Science. http://cohesion.rice.edu/

Lancho-Barrantes, B. S., & Cantú-Ortiz, F. J. (2019). Science in Mexico: A bibliometric analysis. *Scientometrics, 118*(2), 499–517. https://doi.org/10.1007/s11192-018-2985-2.

León-Silva, S., Fernández-Luqueño, F., & López-Valdez, F. (2016). Silver nanoparticles (AgNP) in the environment: A review of potential risks on human and environmental health. *Water, Air, and Soil Pollution, 227*(9), 306. https://doi.org/10.1007/s11270-016-3022-9.

León-Silva, S., Fernández-Luqueño, F., & López-Valdez, F. (2018). Engineered nanoparticles: Are they an inestimable achievement or a health and environmental concern? In F. López-Valdez & F. Fernández-Luqueño (Eds.), *Agricultural nanobiotechnology: Modern agriculture for a sustainable future* (pp. 183–212). Cham: Springer. https://doi.org/10.1007/978-3-319-96719-6_10.

Li, Y. N., Wu, Y. L., & Ong, B. S. (2005). Facile synthesis of silver nanoparticles useful for fabrication of high-conductivity elements for printed electronics. *Journal of the American Chemical Society, 127*(10), 3266–3267. https://doi.org/10.1021/ja043425k.

Mine Production. (s/f). Retrieved February 12, 2019 from https://www.silverinstitute.org/mine-production/.

Nanodatabase. (2019). *Developed by the danish consumer council, the danish ecological council and DTU Environment*. http://nanodb.dk/en/.

Nanotech Project. (2019). *The project on emerging nanotechnologies*. http://www.nanotechproject.org

Nanoeconomía en Mexico. https://micrositios.cinvestav.mx/nano/Mapa.

Piccinno, F., Gottschalk, F., Seeger, S., & Nowack, B. (2012). Industrial production quantities and uses of ten engineered nanomaterials in Europe and the world. *Journal of Nanoparticle Research, 14*(9), article number 1109. https://doi.org/10.1007/s11051-012-1109-9.

Rai, M., Yadav, A., & Gade, A. (2009). Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances, 27*(1), 76–83. https://doi.org/10.1016/j.biotechadv.2008.09.002.

Stensberg, M. N., Wei, Q., McLamore, E. S., Porterfield, D. M., Wei, A., & Sepúlveda, M. S. (2011). Toxicological studies on silver nanoparticles: Challenges and opportunities in assessment, monitoring and imaging. *Nanomedicine (Lond), 6,* 879–898. https://doi.org/10.2217/nnm.11.78.

The World's Leading Silver Producing Countries. (s/f). Retrieved February 12, 2019 from https://www.worldatlas.com/articles/the-world-s-leading-silver-producing-countries.html.