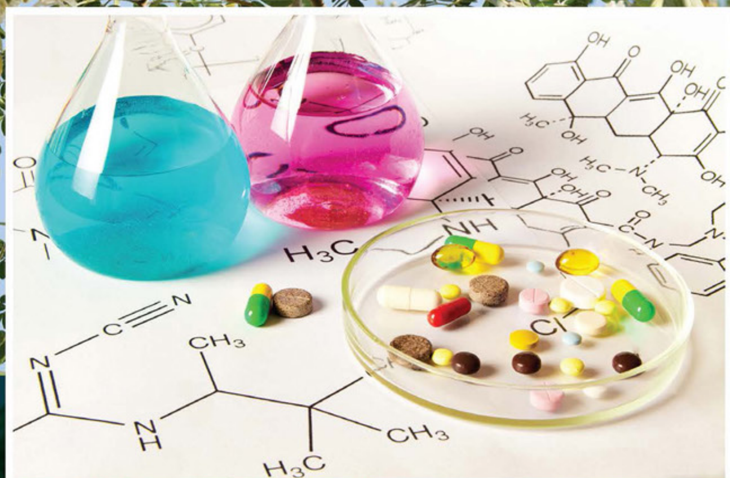

GREEN SYNTHESIS IN NANOMEDICINE AND HUMAN HEALTH

EDITED BY

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International Science Council
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Foreword

Nanotechnology is considered one of the most promising, cutting-edge and disruptive technological advancements. This technology can be applied in numerous industrial and biomedical sectors. Several factors, which include the versatility of nanomaterials and the relatively low production cost of nano-enabled products, make this technology particularly suitable in low-resource settings. The application of nanotechnology in water treatment, energy, agriculture and medicine is particularly relevant in countries with struggling economies. However, several factors, which include barriers to the commercialization of nanotechnology and the unknown impact of nanomaterials on the environment and humans, can impede the development of nanotechnology.

Nanomaterials can be synthesized using a top-down or bottom-up approach. The top-down approach aims to fabricate nanoscale materials by mechanical processes such as ball milling, lithography, laser and ablation. These methods of nanomaterial synthesis can be expensive and energy-intensive, and it can negatively impact the environment. The bottom-up approach, on the other hand, is based on the self-assembly of atoms into nanoscale structures and mostly involves chemical processes. These chemical approaches are not particularly eco-friendly, and there is a growing need to develop environmentally and economically friendly processes. The most common bottom-up approach for the synthesis of metallic nanomaterials is chemical reduction of the metallic cations by inorganic reducing agents to produce colloidal nanoparticles.

Green nanotechnology is a fairly new branch of nanotechnology, which aims to produce and utilize nanomaterials in a way that is safe for living organisms and their environment. It can also involve the production of nanomaterials that can solve environmental problems. It uses the principles of green chemistry, which aims to reduce or eliminate the use or generation of hazardous substances during the synthesis of chemical products. These processes also aim to develop synthetic methods, which are more energy-efficient. Aside from the fact that green nanotechnology can be beneficial to the environment, green nanomaterials produced in this fashion can also be more biocompatible and therefore more suitable for applications in nanomedicine. The impact of nanomaterials on the environment and human health is relatively unknown. The immense diversity of nanomaterials and contradictory reports on the safety of nanomaterials further exacerbate this problem. Moreover, the absence of standardized methods makes it difficult to study the impact of nanomaterials on ecosystems.

Bioinspired synthesis methods that use biological or organic reducers of metal cations have been developed to produce green nanoparticles. A number of living organisms, which include bacteria, algae, fungi and plants, have been used as sources of these biological or organic reducers to produce colloidal metal nanoparticles. The molecular interactions between microorganisms and metals, as well as between plants and metals have been well documented. Several bacterial strains are known to produce inorganic materials, including metals. The use of microorganisms and plants to develop safer nanoparticle production methods are thus not so far-fetched. Green nanotechnology aims to reduce the production of hazardous waste during the synthesis process and to develop more energy-effective methods. Bioinspired nanoparticles are considered more biocompatible than nanomaterials produced using traditional chemical synthesis methods and are therefore more suitable for biomedical applications. Bioinspired green nanoparticle synthesis using plants involves bio-reduction reactions that are catalysed by phytochemicals such as terpenoids, flavones, ketones, aldehydes, amides and carboxylic acids. These bio-reduction reactions can occur at low temperatures, which means that these reactions are more energy-efficient than traditional chemical synthesis methods. The use of plants to synthesize green nanomaterials has given rise to phytonanotechnology, which aims to synthesize nanoparticles using eco-friendly, simple, rapid and cost-effective methods.

Some of the unique physical, chemical and optical properties of nanoparticles make these materials useful for biomedical applications. Due to their small size and high surface area to volume ratio, nanoparticles are well suited as vectors to carry molecular mediators of disease therapeutics and diagnosis. Biomolecules, which include DNA, RNA and protein as well as small-molecule drugs, can be conjugated to nanoparticles for applications in therapeutics and diagnosis. The light scattering and absorption properties of plasmonic nanoparticles make these materials useful for application in the imaging and sensing.

The use of plants in African traditional healing is deeply interwoven with cultural practices and religious beliefs. Africa thus has a rich indigenous knowledge of plants which can be explored with phytonanotechnology to develop novel solutions for the treatment and diagnosis of diseases. Green nanoparticles synthesized from plants used for medicinal purposes can potentially incorporate the medicinal properties of the plant, since the same phytochemicals that are responsible for the medicinal properties of the plant can be involved in the synthesis of nanoparticles. There is thus a unique opportunity to integrate indigenous African flora into nanomedicine to develop cost-effective therapeutic and diagnostic solutions for the devastating deadly diseases such as HIV/AIDS, TB, malaria, Ebola, hypertension, heart disease and diabetes that plague Africa.

This book showcases bioinspired green synthesis of nanoparticles from plants as an emerging method for the development of nanomedicine to promote human health and well-being. The book describes the concepts of green synthesis and reviews the application of green nanoparticles for the treatment of non-communicable and communicable diseases such as cancer, TB and Ebola. Moreover, it highlights how green nanoparticles can be used to fight multidrug antimicrobial resistance. The book also focuses on the application of this technology to develop cost-effective diagnostic systems for early disease detection. A major stumbling block in science in general is the translation of research into commercial products, and the authors therefore also present considerations for commercialization of nanomedicines.

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Section I

Green Synthesis of Nanoparticles from Natural Plant Parts

General Overview

Maluta Steven Mufamadi, Rofhiwa Mulaudzi, Richard L.K. Glover and Daniel Nyanganyura

CONTENTS

Green synthesis of nanoparticles (NPs) has gained extensive attention as a reliable, sustainable and eco-friendly protocol for synthesizing a wide range of materials/nanomaterials, including metal/metal oxides nanomaterials, hybrid materials and bioinspired materials (Singh et al., 2018). It is regarded as an important tool to reduce the destructive effects associated with the traditional methods of synthesis for nanoparticles commonly utilized in the laboratory and industry. The green synthesis method is also known as biological synthesis or biogenic synthesis (Salem and Fouda, 2020). It is required to avoid the production of unwanted or harmful by-products through the build-up of reliable, sustainable and eco-friendly synthesis procedures.

In recent years, green synthesis of nanoparticles from natural plant parts and/or plant crude extracts has gained a lot of attention in both medical and pharmaceutical applications (Mukherjee et al., 2014; Mufamadi et al., 2019). There are different methods of nanoparticles synthesis such as chemical, physical and biological (i.e. green) synthesis methods. Traditionally, nanoparticles production is achieved by employing physical and chemical methods. However, both methods are very expensive, and chemical method and use of harsh toxic solvents limit their applications in clinical fields and are also harmful to both human health and the environment (Caroling et al., 2015). Green synthesis methods use various green sources such as bacteria, fungi, enzyme, algae and yeast as well as plant extracts for nanoparticles production (Kaviya et al., 2011; Mufamadi and Mulaudzi, 2019; Salem and Fouda, 2020). The advantages of using plant and/or plant crude extracts during green synthesis of nanoparticles are that they contain many compounds like proteins, polysaccharides, amino acids and secondary metabolites like flavonoids, phenolic acid, alkaloids, tannins and terpenoids that are responsible for the bioreduction, capping and stabilization of metallic ions during nanoparticle formation (Aromal and Philip, 2012; Ali et al., 2020). Plant-based synthesis is an ideal approach for nanoparticles formation because it doesn’t require high temperatures, energy, pressure and harmful chemical solvents. Furthermore, plant-based synthesis of nanoparticles is environment-friendly, cost-effective and easy to scale up for large-scale synthesis of nanoparticles (Benakashani et al., 2016).

The success in green synthesis of nanoparticles from natural plant parts has opened an opportunity for low- and middle-income countries such as African countries to start to elevate their research and development (R&D) in the nanomedicine area in order to address the burden of diseases that they are currently facing today. The advantages of using plant-based synthesis of nanoparticles are that it is easy to synthesize, uses single-step process, requires low or just room temperature for nanoparticles production, is easy to scale up for large-scale synthesis of nanoparticles, is easy to maintain and is inexpensive and/or economically viable. African countries, particularly those that are in sub-Sahara Africa (SSA), are facing many burdens of non-communicable diseases (NCDs), communicable diseases (CDs) and vector-borne diseases, as well as antimicrobial resistance. In order to overcome these challenges, African countries need to start to harness science-based health innovations (e.g. Green synthesis of nanoparticles from natural plant parts) as a way to achieve affordable and efficient health and medical solutions.

The main objective of this book is to showcase green synthesis as an emerging method for deriving nanoparticles from natural plant parts to be used in nanomedicine for promoting human health and well-being. It also looks at the advancement in nanoparticles production using plant parts/plant crude extracts (i.e. green synthesis) to combat non-communicable diseases (e.g. cancer, diabetes and oral candidiasis), communicable diseases (e.g. Ebola and tuberculosis) and vector-borne diseases (e.g. malaria), as well as antimicrobial resistance (extensively drug-resistant tuberculosis and antibiotic-resistant *Staphylococcus aureus*) in the African context. Furthermore, it unearths the prospects of utilizing nanoparticles to address cross-cutting disease and drug-related issues.

THE HISTORY OF NANOTECHNOLOGY

The idea of nanotechnology was first discussed in 1959 by American physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology (Caltech), in his talk entitled “There's Plenty of Room at the Bottom”. In this speech, Feynman discussed the importance “of manipulating and controlling things on a small scale” and how they could “tell us much of great interest about the strange phenomena that occur in complex situations” (Feynman, 1960). The term “nanotechnology” was first introduced by the Japanese scientist Norio Taniguchi in a 1974 paper on production technology that creates objects and features on the order of a nanometre (Taniguchi, 1974). In 1986, Eric Drexler began to promote and popularize nanotechnology through his book *Engines of Creation: The Coming Era of Nanotechnology*. The invention of scanning tunnelling microscope in 1981 by

Gerd Binnig and Heinrich Rohrer at IBM Zurich Research Laboratory allowed scientists to see materials at an atomic or molecular level (Binning and Rohrer, 1986). The National Nanotechnology Initiative (NNI) in the US Federal Nanotechnology Research and Development Program defines nanotechnology as *the understanding and control of matter at dimensions of roughly 1–100 nm, where unique phenomena enable novel application*. The term nanotechnology encompasses nanoscale science, engineering and technology and involves imaging, measuring, modelling and manipulating matter at this length scale. A nanometre is one-billionth of a metre (NNI, 2020; Bhattacharya et al., 2009). Currently, there are two unique approaches for synthesizing nanoparticles: top-down and bottom-up. Top-down approach is when bulk material is broken down or cut down until it reaches the size of nanoparticles by applying external force, e.g. mechanical milling, drilling, grinding and laser ablation, while bottom-up approach refers to self-assembly of atoms, molecule by molecule until nanosize particles are formed, using chemical or physical forces, e.g. chemical reduction and biological (green) synthesis (Iqbal et al., 2012).

Nanomedicine is the medical application of nanotechnology. It uses nanoscale materials (1–100 nm) for health innovation to improve various kinds of diseases treatment, diagnosis, prevention and monitoring (Tinkle et al., 2014). The use of nanotechnology in the development of new medicines offers an enabling tool for providing new and innovative medical solutions to address unmet medical needs (Sadikot and Rubinstein 2009; Soares et al., 2018). The advantage of using nanotechnology in medicine includes target drug delivery, i.e. the capability of delivering biological or small molecules – active pharmaceutical ingredients (APIs) –to where they will be most effective. To achieve target drug delivery, APIs encapsulated nanoparticles are surface functionalized with different receptor ligands such as protein, peptide, antibody, folic acid, receptors, polysaccharide and polynucleotide so that they can be localized at the disease-specific site, without affecting the normal cells and/or healthy tissues. Site-specific drug delivery system reduced side effects and improved therapeutic efficacy and safety of therapeutic molecules (Bazak et al., 2015). The use of nanotechnology with natural products in nanomedicine is a rapidly developing innovative field that brings multiple advantages: it improves the effectiveness of natural compounds in disease treatment and prevention and/or offers better treatment outcome (Watkins et al., 2015). Incorporation of nanoparticles increases the bioavailability, targeting and controlled-release profiles of the natural products.

GREEN SYNTHESIS OF NANOPARTICLES: CONCEPTS AND SCIENTIFIC CONTEXT

The goal of using green methods for the synthesis of nanoparticles – "green nanotechnology" – was to produce nanomaterials and nano-products that are safe for human health and are environment-friendly, an alternative method for chemical and physical synthesis methods. Both chemical and green synthesis methods utilize the concepts of bottom-up approach for nanomedicine manufacturing. Green synthesis strategy uses existing principles of green chemistry and green engineering for the production of green nanomaterials and/ or nanomedicine products (Anastas and Warner, 1998). In medicine, nanotechnologies are designed to focus on the human health, environmental impact and social and economic benefits. Moreover, nanomaterials and nano-products production are achieved without the use of toxic ingredients, at low temperatures and less energy. Green synthesis strategy is cost-effective and requires low maintenance with relative reproducibility (Kalaiarasi et al., 2010). Plant extracts or microorganisms become "chemical factories" for greener nanomaterials or nano-products. During nanoparticle synthesis, both plant extracts and microorganisms can act as reducing/capping and stabilizing agents. However, plant-based synthesis approaches for nanoparticles formation are more ideal than those employing microorganism-based synthesis. Plant-based synthesis is easy and faster to formulate, and it produces nanoparticles that are more stable compared to those that are fabricated employing microorganisms-based synthesis approaches (Roy and Das, 2015; Ali et al., 2020; Salem and Fouda, 2020). In addition, plants are easily available and have a broad variety of novel metabolites or "green sources" from plant crude extracts, such as protein, vitamins, antioxidants, amino acids, enzymes, polysaccharides and secondary metabolites (e.g. flavonoids, phenolic acid, alkaloids, tannins and terpenoids). Different green sources extracted from various plant parts such as stem, root, leaves, fruit, flower, seed, callus and peel have been used as green "bio" reductants and capping agents during green synthesis of nanoparticles (Awwad and Salem, 2012; Ahmed et al., 2015; Mufamadi and Mulaudzi, 2019; Alphandery, 2020). African scientists are also using different plants parts or extracts for green synthesis of metallic nanoparticles such as *Moringa oleifera* (Leaf), *Thevetia peruviana* (leaf), *Aloe vera* (whole plant), *Agathosma betulina* (leaves), *Combretum molle* (leaves), African *Galenia africana* (whole plant), *Hypoxis hemerocallidea* (whole plant), *Microsorum punctatum* (leaf), *Cassia fistula* (leaf), *Melia azadarach* (leaf) and many more (Chiguvare et al., 2016; Oluwaniyi et al., 2016; Elbagory et al., 2017; Moodley et al., 2018; Nate et al., 2019; Kedi et al., 2020; Naseer et al., 2020). Metallic nanoparticles include silver (Ag), gold (Au), iron (Fe), copper (Cu), zinc (Zn), palladium (Pd), platinum (Pt), lead (Pb), selenium (Se), titanium dioxide (TiO_2), zinc oxide (ZnO), iron oxide (FeO) and copper oxide (CuO) (Ramesh et al., 2014; Shah et al., 2015; Avoseh et al., 2017; Chung et al., 2017; Singh et al., 2018; Mufamadi and Mulaudzi, 2019; Verma et al., 2019; Naseer et al., 2020). The mechanism of metallic nanoparticle synthesis using plant extracts involves the reduction of the silver metal ion (Ag^+) into metallic silver nanoparticles (Ag^0 or AgNPs) with a size of 1–100 nm and different shapes (e.g. spherical, hexagonal and cuboidal). The green synthesis of nanoparticles protocol is a one-step synthesis involving the assembly of zero-valent metals or metal oxides or metal salts together with plant extract broth containing metabolites (i.e. phytochemicals) as reducing, capping and stabilizing agent (Roy and Das, 2015). The formation of metallic nanoparticles is confirmed by the colour change, e.g. AgNPs from initial reagent yellow solutions to dark brown mixture solution (Moodley et al., 2018). Dynamic light scattering (DLS), scanning electron microscopy (SEM), atomic force microscopy (AFM), transmission electron microscopy (TEM), X-ray diffraction (XRD), ultraviolet and visible spectrophotometry (UV-vis), Fourier-transform infrared spectroscopy (FTIR), low-energy ion scattering (LEIS) and energy-dispersive spectroscopy (EDS) are used for further validation and physicochemical characterization of the metallic nanoparticle (e.g. size, shape, morphology and surface properties).

APPLICATION OF GREEN SYNTHESIZED NANOPARTICLES IN HUMAN HEALTH

Eco-friendly and the unique properties of green synthesized nanoparticles from plant extracts (i.e. phytochemical) make them excellent candidates for medicine and pharmaceutics applications. The novel properties of the green synthesized nanoparticles of plant extracts include optical or fluorescent properties, thermal, biosensing, photocatalyst, photodynamics, immunotherapeutic, antiangiogenesis, antibacterial, antifungal, antiparasitic, antioxidant, antiviral and anticancer activities. The applications of green synthesized nanoparticles on human health include therapy, drug delivery, diagnostics, biosensing, theranostics (a combination of therapy and diagnosis) and bio-imaging. According to Mukherjee et al. (2014), metallic nanoparticles synthesized from plant parts are promising to offer a multifunctional biomedical system, a 4-in-1 system that comprises biocompatibility, bio-imaging and antimicrobial and anticancer activities. The presence of *Olax scandens* leaf extract acted as a bio-reducing as well as stabilizing/capping agent during the formation of green AgNPs. The red fluorescence activity of AgNPs synthesized employing methanolic extract of *Olax scandens* leaf extract inside cancer cell makes it a potential diagnostic tool for cancer disease in the future. The optical and fluorescence properties of the green synthesized AgNPs and AuNPs could make them suitable candidates for replacing radiolabelled isotopes for tumour detection in the future, and ultimately they will reduce the side effects associated with radiotherapy (Ovais et al., 2016). A recent study by Varghese et al. (2020) demonstrated that green synthesized AgNPs from neem leaf extracts have biosensing and photocatalytic properties, and this was evaluated using mancozeb (MCZ) agrofungicide and optimum surface plasmon resonance (SPR). Riley and Day (2017) demonstrated the photothermal therapy employing green synthesized AuNPs. The study showed the green synthesized AuNPs to be capable of absorbing incident photons and converting them to heat to destroy cancer cells and/or tumours.

Many studies reported antimicrobial and anticancer activities employing green synthesized metallic nanoparticles from plant extract or phytochemical extracted from different parts of plants, e.g. leaves, fruit, flower, stem and root (Awwad and Salem, 2012; Chiguvare et al., 2016; Oluwaniyi et al., 2016; Elbagory et al., 2017; Kedi et al., 2020; Naseer et al., 2020). However, the antimicrobial and anticancer mechanism of action of green synthesized nanoparticles is still not fully understood. Various mechanisms have been proposed to illustrate the activity of green synthesized nanoparticles as antimicrobial and anticancer agents:

Antimicrobial Mechanism of Action

- Disabling the respiratory of chains
- Cell membrane disruption and leakage of its cellular contents

- Binding to functional group of proteins causing protein denaturation and cell death
- Blocking the DNA of replication
- Denaturation of proteins and cell death through binding to functional groups of proteins

Anticancer Mechanism of Action

- Cytotoxicity that disturbs the cell membrane permeability and cellular internalization resulting in cell death through a cascade of events
- Inducing apoptosis through caspase-dependent and mitochondrial dependent pathways
- Generation of reactive oxygen species (ROS) that leads to induction of ROS resulting in cellular damage
- Trigger upregulation of p53 protein and caspase-3 expression through apoptosis pathway activation leading to cell death
- pH-dependent release of metal ions from green synthesized nanoparticles leading to cancerous cells death
- Inhibiting the function of vascular endothelial growth factor (VEGF)-induced angiogenesis

Green synthesized nanoparticles from plant extract shown to have the potential to enhance the diagnosis and treatment of non-communicable diseases (e.g. cancer, diabetes and oral candidiasis), communicable diseases (e.g. Ebola and tuberculosis) and vector-borne diseases (e.g. malaria) as well as antimicrobial resistance (extensively drug-resistant tuberculosis and antibiotic-resistant *Staphylococcus aureus*) are discussed in this book.

Non-Communicable Diseases

NCDs are a diverse group of chronic diseases that are not communicable and cannot be passed from person to person. NCDs are responsible for the premature mortality around the world. According to the World Health Organization (WHO), the four main risk factors for major NCDs are high consumption of alcohol, tobacco consumption, lack of physical activity and unhealthy diet (WHO, 2015). According to Marquez and Farrington (2013), by 2030, NCDs such as cancers, diabetes, cardiovascular diseases (like heart attacks and stroke) and chronic respiratory diseases (pulmonary disease and asthma) will become the leading cause of death in sub-Saharan Africa. The challenge of treating NCDs is that most of them can only be diagnosed at a late stage of affliction, making it very difficult to treat or manage, e.g. cancer diseases present at a late stage (5-years later) and/or once the tumour has already formed (Mulisya et al., 2020). Combating these NCD burdens demands immediate measures and tools that could enable early and rapid diagnosis and treatment, such as nanomedicine (Chandarana et al., 2018). Nanomedicine promises to offer better approaches towards identifying NCDs at an early stage and to overcome treatment challenges associated with them.

Therapeutic benefits of using nanomedicine in NCDs include improved drug circulation times, target delivery that enhances treatment efficacy and the ability to act as a therapeutic (Sanna et al., 2014; DiSanto et al., 2015; El-Readi and Mohammad, 2019; Lafisco et al., 2019). Moreover, nanomedicine promises to provide better diagnostic tools, medical imaging and theranostics, by the combination of therapy and diagnosis in a single application (Mukherjee et al., 2014; Chandarana et al., 2018).

Communicable Diseases

CDs or infectious diseases are communicable, which means that they can be passed from person to person either directly or indirectly by disease-causing agents, humans or animals (Nash et al., 2015). The disease-causing agents include viruses, bacteria, fungi and parasites, and account for approximately 15 million deaths worldwide (Singh et al., 2017). Africa has the highest prevalence of CDs in the world. HIV/AIDS, tuberculosis, acute respiratory infections, malaria and diarrheal diseases are on top in the list of the deadliest CDs in Africa. Four of them combined are predicated to be responsible for nearly 80% of the total infectious disease burden and claiming more than 6 million people per year (Boutayeb, 2010). Since the establishment of the sustainable development goals (SDGs), Africa has set new ambitious targets which include ending the prevalence of HIV/AIDS, TB and malaria by 2030 (Narayan and Donnenfeld, 2016). However, the rising cost of the antibiotics, antimicrobial and antiparasitic resistance and also the adverse side effects due to prolonged drug use indicate that the battle against CDs is far from over (Blecher et al., 2011). Therefore, in order to envision a future without these CDs, it will require an improved antimicrobial agent or newer and more effective therapies. The unique physical and chemical properties of nanoparticles make them an ideal candidate to improve the therapeutic effects associated with current conventional therapies and/or to end the prevalence of HIV/AIDS, TB and malaria by 2030. The roles that nanomedicine is promising to play in CDs include improved therapeutic, diagnostic and prevention/vaccination approaches (Blecher et al., 2011; Dube, 2019). In the case of CD diagnostics, nanomedicine promises to offer cheap and quick diagnostic test. When it comes to CD treatments and vaccine, nanomedicine promises to offer immunotherapy that is capable of neutralizing viruses and to improve drug circulation times, target delivery, combination therapy, pharmacokinetics and pharmacodynamics.

Nanomedicine Innovations: New Trend

The convergence of material science, biotechnology, engineering and nanomedicine is promising to transform medical technology and the pharmaceutical industry. Moreover, the improved nanomedicine is promising to offer accurate diagnoses, targeting therapies with fewer side effects, and providing better medical imaging and personalized medicine (de Smet et al., 2011; Zhang et al., 2017). A new trend in nanomedicine technology is influenced by the advancement in nanoformulation that led to a new type of nanomedicine:

- Stimuli-responsive nanomedicines that trigger drug release in an on-demand manner or influence by stimulus, e.g. pH, light, thermal, redox and magnetic and electronic fields
- Nanotheranostics (i.e. smart pill) that combines therapeutics with imaging agents into one pill
- Polytherapy (i.e. polypill), which combines multiple active pharmaceutical ingredients into one pill
- Nanosensors that can diagnose certain diseases through analysing human exhaled breath, and thus recognizing the biomarker gases related to diseases in human exhalation
- Fully autonomous DNA nanorobot that is capable of transporting vaccines and drugs to the targeted site

The development of these new types of nanomedicines was to address the issue of multidrug resistance (MDR) in current antimicrobial and anticancer agents (Fattal and Tsapis, 2014; Tangden, 2014; Kim et al., 2017; Zhang et al., 2017; Li et al., 2018; Zhou et al., 2018). In addition, it was to overcome challenges associated with conventional nanomedicine such as poor stability, poor bioavailability, drug toxicity and hurtful side effects (Fattal and Tsapis, 2014).

Commercialization Aspects

Many different nanomedicines have been developed over the years to improve the therapeutic efficacy, target drug delivery system and safety for various types of diseases (Ventola, 2012; Curley et al., 2017). According to Metselaar and Lammers (2020), more than 50 nanomedicine formulations are currently approved for clinical use by the Food and Drug Administration (FDA) and many others are currently undergoing clinical trials. However, none of those approved nanomedicine formulations are from Africa. Although nanomedicines have the potential to provide affordable and efficient medical solutions, only few African countries are prioritizing on it: South Africa, Egypt, Morocco and Nigeria (Mufamadi, 2019). African countries need to start embracing their own health innovation, research and/or local technologies and stop depending on the international market for every technology they need (Singer et al., 2008). If African scientists need to commercialize their nanomedicines, they need to find a commercialization strategy that matches their potential and sustainability, such as licensing, equity investment, strategic alliances and private consortium or cluster alliance (Mufamadi, 2019). Moreover, they need to make a substantial investment towards the infrastructure along with the increase in human capacity building and nanomedicine-based products. Furthermore, they need to find a way of attracting investment from local or international investors and big pharmaceutical companies.

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