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The National Significance of a DNA Revolution: A Call for Policy Action towards Sustainable Development Goals (SDGs)

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Abstract

Life has always remained a profound mystery, especially with the issue of inheritance, where no one knew how information was transmitted or stored. When it comes to the stability of life over a huge amount of time and its mutability in evolution, the DNA molecule forms a bigger part of the story than any individual might have thought. The discovery of DNA is considered a passport to all mysteries of life and the present challenges in health, agriculture, crime solving and environmental challenges in Ghana suggest that the national relevance of the DNA revolution will contribute to the achievement of sustainable development goals in Ghana.

Keywords: DNA; Ghana; Revolution; Food Safety; Sustainable Development Goals.

1. Introduction

The evolution of DNA, coupled with the technology revolution, has brought about magnificent progress in the world of scientific research. The DNA molecule, an instruction for all life, has been used for treasure-hunting since its discovery to find treatments, solutions, and possible cures for most of the ills of life. In advanced European and Asian countries [1], DNA technologies have led to genetic progress in cattle, pigs, and some plants. The progress has been reflected in health traits in animals as well as increased agricultural productivity in general. Genomic selection in breeding programs has already been advanced, and the big question is how these technologies will reach developing countries to combat food scarcity. There has been a belief by many scientists that the unlocking of the human genetic code will bring enormous benefits to human lives. Today, the whole genome has not only been crucial in the treatment of genetic diseases but has also made it easier for scientists to study, identify, and interpret genetic mutations.

With the help of DNA, massive advances have occurred in the criminal justice system over the past few decades. The accuracy with which DNA is used to identify criminals is incredible nowadays, and all indications are that DNA can serve as conclusive evidence material to clear suspects, exonerate innocent people, and convict real perpetrators of crimes. For instance, a well-publicized trial that utilized DNA evidence and also provided education on the proper utilization of DNA is the O.J. Simpson trial. He was linked to the murder of his wife and her friend, but after about 108 exhibits and several publications, DNA surprisingly was used to acquit him. Subsequently, the case was characterized as "the trial of the century" due to its international publicity [2].

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Even though DNA technology has put many cold cases to an end, many criminal cases have not yet been solved. Even though DNA technology has been massively applied, many dead remains and criminals have not been identified. This does not disparage the value of DNA but establishes that even though it provides a solution to contemporary social and environmental challenges, it is not a panacea. DNA technology in the health sector is becoming significantly cheaper and much easier to carry out [3]. In countries that have adopted DNA and recognized the technologies surrounding it as a priority, DNA technology is applied to solving health-related problems, especially rare genetic conditions. Today, next-generation sequencing (NGS) and improved sequence analysis methods have paved the way for the identification of genes that cause rare genetic conditions [4]. Traditional methods have been relatively efficient in solving many of the global challenges. However, while some may be convenient with the norm, scientists expect more than a 50% rise in productivity in all areas of relevance.

Soon we need to feed more people and produce more food to feed animals, understand human, plant and animal diseases, bring perpetrators of crimes to justice, identify individual's biogeographical ancestry, ensure food safety, counter bioterrorism, improve health through precision medicine and counter climate change in much more efficient ways without destroying the environment as having been achieved in practical instances in Table 1.

In this paper, we review the role of DNA in national development by focusing on specific sectors in Ghana. The paper discusses the challenges and potential benefits of DNA technology in Ghana by referring to real issues that have occurred over the years. It highlights recent trends in DNA application and hints at the significance of fully adopting DNA technologies to help the country towards achieving sustainable development. Finally, the paper presents real issues that require DNA technologies to be solved which can be found in Table 2 and recommends future directions towards achieving SDGs with these adopted technologies.

2. Methodology

This paper retrieves articles from journal databases, online news articles, and institutional reports related to the application of DNA technologies and their benefits. Keywords such as unidentified DNA and sustainable development goals SDGs were entered into the search engines and respective journal databases. Articles published between the years 2000 and 2022 were considered for this paper. Because the paper focused on the DNA revolution and SDGs, articles on biotechnology, molecular biology and SDGs were considered to provide in-depth knowledge about the subject. Real cases on the ground were considered as case boxes (see Appendix I) to give a clear picture of instances where DNA technologies have been applied towards solving problems in society. Because the paper is focused on calling for policy action, literature concerning international best practices on how DNA technologies have been used effectively was consulted.

3. The DNA Molecule

Many life processes are controlled by four major macromolecules (carbohydrates, proteins, lipids and nucleic acids (DNA and RNA)) that are very essential for life [5]. The discovery of genetic materials which determines specific traits of organisms and how these pieces of information are passed down from one generation to the next is highly attributed to the Austrian Monk Gregor Mendel. The study of genetics as a scientific discipline stemmed from the work of Gregor Mendel in the 19th century [6]. The evolution of genetics gave rise to the discovery of deoxyribonucleic acid (DNA). Of course, DNA is an essential molecule of life that controls protein-coding, growth, reproduction and survival of all living organisms. The discovery marked a milestone in the history of the scientific community and has led to the establishment of modern molecular biology techniques for understanding the chemical processes of life and how they are controlled by genes [7].

DNA is known as the set of codes that controls the genes that decide traits such as eye and hair colour, height, confer disease resistance, help understand the biogeographical origins, establish familial relationships, and link individuals to evidence found at the scene of incidents [8]. The body of a living thing is made up of billions of cells and DNA can be found in the nucleus of all living cells. DNA was first recognized and identified by the Swiss biologist, Johannes Friedrich Miescher in 1869 during his research on white blood cells. The structure of the DNA was investigated by Francis Crick and James Watson in 1953. Their investigation identified DNA as a double helix structure found in every living thing including viruses which were once considered as non-living [7]. There are four nitrogenous bases in the DNA namely adenine (A), guanine (G), thymine (T) and cytosine (C) whose sequence or orientation determines how DNA encodes genetic information used to carry out all cell functions. The varied compositions of the DNA differentiate living things from each other even though all tend to carry this biological material. Looking at what is so important in the DNA and what it does in the living thing simply explains the central dogma of life [8]. DNA confers the recipe for protein synthesis which controls the hierarchical flow of information from DNA to protein (the fundamental biological process that which individual cells build their specific proteins by combining single amino acids) [9].

Table 1. Some Current DNA Technologies and Milestone Achievements Globally

Technology	Application	Results	Source
Genome sequencing	Sequencing of the whole genome of humans	A complete description of all the genes and their functions	Collins et al. (2003) [10]
Genome editing with CRISPR-Cas9	Using T7 RNA polymerase (T7RNAP) to efficiently edit the <i>Plasmodium. falciparum</i> genome.	Efficient manipulating the <i>Plasmodium. falciparum</i> genome to facilitate basic biological studies, and drug and vaccine development	Wagner et al. (2015) [11]
Forensic DNA phenotyping	Applied in the criminal justice community	Narrowing the focus of a suspect group to assist in the conviction of the guilty and exoneration of the innocent in criminal cases	Machado & Granja (2020) [12]
Forensic DNA profiling	Identification of missing persons and victims of mass disasters	Re-associated and identified through linking reference samples to recovered remains	Clayton et al. (1995) [13]
Single nucleotide polymorphism (SNP) genetic variation	Applied in molecular breeding to investigate the transcriptomic responses of Taiwan tilapia toward cold stress	Markers explored in this study can be used for the identification of genetic polymorphisms and cold tolerance traits in Taiwan tilapia.	Chu et al. (2021) [14]
Whole exome sequencing (WES)	WES facilitated rapid diagnosis	Used in analyzing a patient's DNA to determine the genetic cause of disease.	Al-Shamsi et al. (2016) [15]
Polymerase chain reaction	Usage of real-time PCR to detect and quantify tetracycline resistance in mixed microbial communities resident in wastewater	The method was sensitive across a wide range of gene concentrations and provided consistent and reproducible results from complex water samples	Smith et al. (2004) [16]
High throughput DNA analysis	To develop a quality, high throughput DNA extraction and short tandem repeat (STR) analysis procedure for the identification of disaster victims in New York City	Rapid DNA analysis of victim remains, their identification and return to family members	Holland et al. (2003) [17]
Recombinant DNA technology	Genetic engineering of bacteria plasmid to improve the health of patients with chronic metabolic conditions such as diabetes	Synthesis of insulin and erythropoietin	Landgraf & Sandow (2016) [18]
Genetic engineering of crops/plants	Improvement of pest resistance of maize plants through gene transfer	Production of Bt corn	Kumar & Kumar (2015) [19]
Gene alteration and knockout	Ten genes from the donor pig were altered for the transplant to be possible. The patient was ineligible for a conventional heart transplant	Successful transplant of a pig's heart into a patient with terminal heart disease	Jee (2022) [20]
DNA amplification	To enable DNA amplification on microspheres to rapidly detect and identify large numbers of different bacteria at once	Successful detection and typing of <i>Campylobacter jejuni</i> or <i>coli</i>	https://www.uq.edu.au/news/article/2013/01/bacteria-breakthrough-safer-food

Table 2. Real Cases of Underutilization of DNA Technology in Ghana

Case	Sector	Year	Status	Source
Twin disaster	Humanitarian	2015	Over 50 unidentified bodies	https://www.ghanaagenda.com/2016/06/june-3-disasters-over-50-bodies-yet-to.html
Unidentified bodies	Humanitarian	2019	Over 160 unidentified bodies	https://citinewsroom.com/2019/08/police-hospital-morgue-to-bury-160-unclaimed-bodies-en-masse/
Pest and disease incidence	Agriculture	2014-2015	An outbreak of soil arthropods and virus diseases	https://www.academia.edu/69859720/Incidence_of_arthropod_pests_and_diseases_of_groundnut_Arachis_hypogaea_L_in_northern_Ghana
Homicide rape	Judiciary	2021	Perpetrators unidentified	https://www.ghanaweb.com/GhanaHomePage/NewsArchive/16-year-old-girl-allegedly-raped-and-killed-in-Bodomase-1332919
Murder	Security	2014	Still under investigation	https://www.ghanaweb.com/GhanaHomePage/entertainment/Who-killed-Fennec-Okyere-Kwaw-Kese-asks-Ghana-Police-Service-633953
Crop pest and disease infestation	Agriculture	2016	About US\$64 million was lost in 2018 due to the infestation of about twenty thousand (20,000) hectares of farmlands	https://www.graphic.com.gh/features/features/generating-insights-for-crop-pest-and-disease-surveillance-through-farmers-reporting.html
Gang rape	Humanitarian / security	2021	Rapists Unidentified	https://www.pulse.com.gh/entertainment/celebrities/efya-reacts-to-reports-of-unknown-men-gang-raping-popular-ghanaian-lesbian-for-2-days/eljkr5
Pregnancy denial	Judiciary	2022	Denial of pregnancies increased in the Northern region within the periods 2020-2022	https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Denial-of-pregnancies-increases-in-Northern-Region-1451278
Malaria outbreak	Health	2020	54 deaths were recorded in the first quarter	https://citinewsroom.com/2020/04/ghana-records-54-malaria-deaths-in-first-quarter/
Yellow fever outbreak	Public Health	2021	At least 35 were killed due to the outbreak	https://www.youtube.com/watch?v=69lQk6nBS6o
Imported Dutch frozen chicken labelled to represent fish	Food Safety	2022	Unsuccessful food traceability investigations	https://www.modernghana.com/news/1137964/insight-the-wedgam-food-fraud-case-presented.html

4. DNA Application in Ghana

In recent years, the awareness about DNA application in Ghana has improved in that people know that it holds the potential to address a lot of contemporary social and environmental issues. The genomic revolution has fueled this emerging transformation globally as a result of cheaper DNA sequencing and more efficient DNA extraction techniques. The best-known applications of DNA in Ghana are very few. It is not surprising to hear varying perspectives from Ghanaians about DNA, and what challenges and benefits they think DNA comes with. DNA technology is underutilized but has been applied in a few areas which the paper categorizes as the determination of ancestry and family relationships, food and agriculture, justice delivery and veterinary and human health care delivery.

5. Agriculture Sector

Conventional approaches have sustained humans and their agricultural activities for centuries. These approaches are becoming less significant due to the gradual climatic change and environmental deterioration and global population increment [21]. Global frontiers in science have developed and adopted DNA technologies to match up with trends. DNA technologies have been applied in agriculture for disease resistance, crop improvement, animal health, agroforestry and climate action which would otherwise be difficult to achieve with conventional methods [22]. As Ghana is not in isolation, the use of DNA technologies for various agricultural improvement schemes cannot be overlooked. Marker-assisted selection, DNA barcoding, mutagenesis, molecular breeding, modern plant tissue culture, and genetic changes are all common DNA technologies used to improve quality, yield, pest and disease resistance [23]. Even though there is a national reluctance to adopt DNA technology in Ghana [24], there are more benefits to be derived from these applied technologies in the agricultural sector [25], most importantly towards efficient crop breeding programs and conservation of crop genetic resources.

Otwe et al. (2017) [26] conducted a crop evaluation on cowpea accessions from Ghana using molecular markers. The study revealed that populations of cowpea crops can be characterized using genomic fingerprinting due to the polymorphism of the markers. This is an indication that the *germplasm* of highly favourable varieties can be readily characterized using molecular tools [27]. This also indicates that this technology could ensure that accurate variation is established between accessions to facilitate the removal of duplicate genotypes [28].

Generally, the lack of genetic surveillance systems can be blamed as one of the causes of the many unidentified sources of pest and disease outbreaks in the global agricultural sectors. In Ghana, plant pest diagnosis and identification have always been dependent on conventional methods rather than DNA mediated pathways. In countries like India, China and Thailand, DNA barcoding is used to identify and initiate surveillance of suspicious agents and pest infestations [29]. DNA barcoding was used in the case of *Spodoptera frugiperda*, invasion in some West African countries in 2016. The technology allowed early identification steps and the right control measures to be initiated to save many farmers from losing their crops [29].

To tackle protein deficiency, a leading cause of malnutrition and stunted growth in most children, the characterization of genomes of animals has been prioritized in Europe and the US to make breeding decisions easier. The technology has brought other benefits such as meat traceability and the potential of maintaining genetic resources which inform future breeding programs [30]. It is time for Ghana to adopt and prioritize these technologies to help towards conservation of animal resources as well as inform tailor-made solutions to some specific food needs. Furthermore, quality standardization is a crucial component in food production and consumption which has been adopted by many developed countries. To meet standards, whole-genome sequencing (WGS) of microbes associated with animals and animal products is used to identify and quantify microbes that are present in these products [31].

Livestock agriculture is a booming sector in Ghana. The rearing of livestock to produce meat, milk and byproducts generates extra income for farmers. The Northern regions of Ghana provide a suitable landscape and environment for livestock; however, the associated diseases and parasites cannot be ignored as a major threat that is hampering the sector. Understanding the genetic makeup of diseases and parasites that infect livestock within specific populations tends to provide a clear and strategic means of managing the situation. The genetic diversity of populations within a location varies according to history and contemporary literature and this makes the molecular characterization of species very important.

Recently, it has been understood that the same strain of African swine fever virus (ASFV) is being spread across Sub Saharan African regions like Mali, Senegal and Burkina Faso. Until this, the disease has been a burden on pig production in these regions. At this point, the pig farmer knows where to purchase their breeds to avoid battling with ASFV. Likewise, the Ghanaian livestock farmers are faced with the difficulty of treating animal diseases with traditional veterinary strategies. *Case Box 1* (Appendix I) describes how real issues of veterinary parasitology are being researched in Ghana with molecular tools and techniques.

Take the endangered African dwarf pig of Ghana for instance, when subjected to genetic analysis by the use of genome-wide SNP genotyping, Osei-Amponsah et al. (2017) [32] revealed the existential differences between it and

other members of the same genus. This data can be used to improve other close relatives, and with this possibility in pigs, many other endangered animals with traits of economic importance could have their genetic materials properly conserved for future utilization.

Genetic modification of forest trees is facing protest in advanced countries with valid points such as possible cross-contamination of pollens however the benefits of DNA technologies in the forestry sector cannot be overlooked [33]. Practically unlike other plants, forest plants take a long time to grow and scientific experiments may take several years. One key important point is that genetically modified (GM) trees are a better way to fix climate change [34]. In Nordic countries and South America especially Brazil, GM trees have been engineered to be disease resistant, grow at a faster rate and most especially drought-resistant towards conservation of forest genetic resources and afforestation agenda through NordGen forest and FuturaGene laboratory projects.

6. Health Care Delivery

In recent times, molecular biology has evolved greatly with the advancement of DNA methods. Undoubtedly, these methods paved way for the isolation and characterization of genes from any organism and the determination of the DNA and protein sequences. With this, DNA has found relevance in many fields of health development around the globe. DNA sequences and specific genes have been manipulated to produce therapeutic products and important bioproducts such as human insulin [35]. The use of specific DNA technologies such as recombinant DNA technology has led to the production of safe, quality and specific drugs [36]. Additionally, the advent of genomics holds the answers to seemingly unanswerable health scenarios in terms of diagnosis and treatment.

Diets and dietary patterns are having a toll on the renal health of many Ghanaians recently. Many of these cases are life-threatening. It is reported that live kidney donation is the current surest way of obtaining organs for transplant [37]. In the worst-case scenario, a greater proportion of patients have no alternatives to these situations and subsequently, they have kidney failures. Xenotransplanting is gaining ground through the consolidated activities of new gene-editing techniques such as CRISPR, gene knockout and gene knocking. Adoption of this procedure could be the cornerstone to sustaining many lives in Ghana.

Advancements in DNA technologies have helped in successful viral testing for Covid-19 using real-time PCR [38]. Many lives have been saved based on these diagnoses with several infected persons being efficiently managed at designated health facilities in Ghana. The relatively easier method and the less time it takes to obtain results have helped in the prevention of the indiscriminate spread of the virus. Aside from the timely prevention of loss of human resources, these apt DNA technologies (genome sequencing) saved many countries such as South Africa from the emergence of unknown variants through surveillance [39]. Nowadays infertility among couples is very common and advancements have been made leading to specific DNA testing that looks at genetic variants affecting pregnancy and fertility. Genetic testing among couples examines the genes that are capable of causing infertility in both men and women. In advanced countries, people have been able to make the right decisions with the help of genetic testing while others have been advised on certain genetic disorders such as sickle cell anaemia and cystic fibrosis thus helping them to live a better life of awareness [40].

As cancer is known to be a consequence of DNA defects, many countries are battling with nipping it in the bud, particularly developing nations [41]. In the quest to get viable treatments with no future implications to replace the tedious radiation and chemotherapies, there is the need to consider DNA technologies. Explicitly, explorations of cancer patients' DNA have led to critical advancements in understanding the dynamics of the cancer genome in countries like the USA, India, China and some countries in Europe [42]. Unlike the advanced countries, in Africa, the WHO is supporting government efforts toward early cancer diagnosis in Senegal but not at the genetic level yet probably due to the cost of resources involved. With sequencing, various mechanisms of cancer cell progressions and their potential termination mechanisms can be known, particularly with the knowledge of their molecular resistance mechanisms to therapies [43].

The invention of DNA nanorobots is a milestone in the development of medical studies that is serving as a potential treatment for cancer. The technique which is much safer than other existing therapies uses bots made of single strands of DNA folded in the desired shape and targets the cancer cells and eliminates them from the body [41]. This technology is widely applicable in advanced countries in Europe and India as it has been identified as a key tool to fighting chronic diseases.

The challenge of water scarcity is very real in many communities in Ghana, however, there have been a couple of engineered solutions to solving this challenge. It is however unfortunate that there is a high likelihood to consume unclean water in Ghana. In some rural communities in Ghana, some people travel miles to fetch unclean water for consumption. There is widespread contamination of drinking water in Ghana. Research shows that water bodies in Ghana are contaminated with microbes and other chemical contaminants [76-78] that go a long way to exposing people living in these communities to health risks. Most of these water sources are full of rubbish, animal waste and parasites

that are detrimental to the health of individuals. Most diseases come from the source of water people drink and DNA in water has proven to be a very important material [79–81] which could provide evidence for the management of community health in Ghana. Many children die in Ghana as a result of water-related diarrhoea and other diseases. The people living in such situations deserve a better life where there will be early detection of disease and also the detection of previously undetected pathogens that might have caused serious health issues. Clean water is very essential and we need it for food production, sanitation and maintenance of ecosystem services.

7. Ancestry Determination

The West African subregion is one of the areas in Africa that is highly characterized by migrations from colonial history to date. Notably, the transatlantic slave trade which is known as the largest long-distance forced movement of people in history saw millions of men, women and children from various regions of the subregion transported to European and Euro-American regions for labour [44]. Presently due to inter-trade policies within the subregion, people move in and out of their countries in order to make business. These factors and others affect population movement within the region and have shaped the West African mitochondrial landscape [45].

In a study conducted in Ghana to establish an mtDNA dataset for forensic purposes in Ghana, the diversity of the Akan population was investigated concerning their surrounding populations. Full mitochondrial control regions of 193 Akan people from Ghana were sequenced and incorporated into the EMPOP database for phylogenetic considerations. The Ghanaian haplotypes were compared to 19 neighbouring populations and an extensive genetic admixture was found. This explains the long and recent migration history within the West African subregion with the use of DNA technology [45].

Another cross-sectional study conducted at the Korle-Bu Teaching hospital (KBTH) fertility clinic on Ghanaian men attending the facility showed that various abnormal sperm phenotypes are prevalent in the study population. This was confirmed to have no association with lifestyle or history of certain sexually transmitted infections. The study confirmed that mtDNA point mutations in selected genes that were analysed were mostly transition mutations which tend to be very critical for the development of abnormal sperm phenotypes causing male infertility in most Ghanaian males [46]. The use of DNA in the determination of ancestry has helped in the establishment of family relations in countries such as Australia, the US and the UK. In most cases where a reference sample is available, to predict the Biogeographical Ancestry (BGA) of a biological sample, genetic markers are selected based on their ability to differentiate between BGAs [47]. This technology has been applied in the identification of anonymous bodies, disaster victims, race and ethnicity, and other archaeological activities in developed countries.

Unlike the Takoradi kidnapping case which is described in *Case Box 2* (Appendix I) involving a lot of disputes and media pandemonium, another popular case where DNA application has made progress was a casework conducted at the Forensic Science Laboratory of the Ghana Police Service. A dispute between the family of a deceased person and mortuary workers led to the exhumation of two dead remains from a local cemetery in the Western region of Ghana. DNA samples were taken from the toenails and compared with DNA from the buccal swabs taken from an alleged son. In the end, the sample collected from the alleged son could not be excluded as the biological father because they shared common alleles at all 23 genetic loci. Based on these results one of the bodies was successfully identified and handed over to the family for re-burial [48].

Similarly, another well-publicised case of relationship and familial DNA application is the Nii Odartey Lamptey case. DNA was extracted from buccal swabs of his 3 alleged children and compared to his DNA at a medical facility which cost him close to five thousand Ghana Cedis as of 2014 indicating how expensive the service fee is in Ghana. Unlike criminal investigations, other accredited medical facilities are allowed to run DNA testing for relationship and familial identification in Ghana. The children's samples were excluded as the father did not share any common allele with them [49]. The few benefits of DNA application in this area cannot be overlooked however the existing gaps call for more efforts in the future.

8. Crime Solving and Justice Delivery

Crime and violence indicate unsustainability in an environment as it is accompanied by poverty, homelessness and increased crime rates in general [50]. Peace and stability is the bedrock of developing nations and in achieving SDG 16, Ghana needs to promote peaceful and inclusive societies, provide access to justice for all and build effective accountable and inclusive institutions at all levels.

Crimes such as sexual and physical assault, burglary and murders are quite common in Ghanaian societies; however, it is clear that finding the perpetrators of these crimes is always challenging [51]. This hinders development hence the need to find lasting solutions to these situations and other insecurities. Today DNA have proven to play a great role in solving most of the crimes in society. The use of DNA in solving crimes has revolutionised the world of crime-solving. The power of DNA reflects in how the minutest amount of biological evidence could be identified based on its origin and used to discriminate an individual from another in association with crimes.

Even with the credibility DNA has proven to carry, sampling from individuals tends to be a real challenge on the ground in many countries [52]. Unlike in the UK, where all individuals are required to present DNA samples provided, they are found around the scene of the crime, most countries leave that to the individual to volunteer or the investigation officer to request a court order to compel the individual.

The Forensic DNA Laboratory (FDNAL) of the Ghana Police Service (GPS) uses the 6-dye, GlobalFiler™ PCR Amplification Kit manufactured by Applied Biosystems, USA, since 2016 and currently uses 24-locus STR consisting of STR loci accepted by Combined DNA Index (CODIS) Core Loci Working Group and the European Standard Set of Loci. DNA application in justice delivery in Ghana is in its infancy as the Forensic Science Laboratory (FSL) is the only institution that has the mandate to use DNA profiling to solve criminal cases in Ghana [48]. The FDNAL since its establishment has received some cases including murder, civil cases and DNA-related crimes. The lab is an ultramodern facility that uses a high throughput analyzer capable of processing two 96-well (168 samples) plates at a time and has received over 200 cases since 2011 [48].

Notably include the acquitting of Mr. Emmanuel Asante after he had served more than ten years out of his fifteen years sentence. This success was achieved after several years of appeal where the DNA application opened a new chapter for the case which led to his exoneration based on DNA paternity testing [53]. Genuinely, a turnaround time of two weeks can be estimated for nuclear DNA testing in a public crime laboratory in advanced countries [54]. Also, it could take from three weeks to 2 years turnaround time for a typical criminal case in court.

The duration of the Mr. Emmanuel Asante case indicates the delay in justice delivery even with the use of DNA. This suggests fundamental challenges in the application of DNA in the criminal justice system in Ghana which needs to be addressed. The relevance of DNA technology to the development of Ghana is evident based on real issues that have been attempted with the technology. It however appears that there are many other cases in various sectors of the economy which have been left unsolved even though DNA technology would be of great importance in those aspects.

9. Food Safety Management

One of the major issues bothering the world is unsafe food. Data from the WHO pegs the least number of people to fall ill and die annually due to unsafe food at 550 million and 230,000 respectively [55]. Efforts are therefore being made by organizations and individual governments to address these challenges and deaths. As far as the dangers posed by food safety and the issues bothering it persist, novel solutions and technologies are being called for and researchers are exploiting means to address the issues and help the world mitigate the dangers such as foodborne illnesses and deaths. DNA technology is one of the viable means to achieve this although a revolution in its application in the area of food safety management is yet to occur especially in Ghana.

There are several challenges bothering food safety, however, in Ghana, notable ones include, food contamination by biological and chemical agents, improper food handling and bad practices and the emergence of new pathogens due to climate change, challenges in detection of contaminants, antibiotic resistance and intentional food contamination, otherwise known as food fraud [56–59]

Conventional approaches and methods applied to tackling some of these issues have helped greatly, however, considering the rapid changes the food industry is witnessing alongside climate change issues, these methods no longer look promising as they were. In recognition of this, the USA Food and Drugs Administration (FDA) and other food safety regulatory authorities in developed countries have shifted towards modern approaches in their respective jurisdictions. For instance, the USA FDA has recently developed a new food safety management manual called the “New Era of Smarter Food Safety” [60]. This document specifically guides to achieving food safety by leveraging modern technologies of which DNA technology application and molecular-based approaches are core.

DNA technology has been applied as a contribution to understanding and addressing some of the food safety challenges in Ghana. The trend of its application in Ghana shifts greatly toward the identification of food contaminants such as bacteria, fungi and parasites as well as antibiotic resistance detections [61-62]. The application however exceeds these as DNA technology can be applied in several areas of food safety management such as food testing for authenticity and origin, DNA sensors for detecting biological and chemical contaminants, foodborne disease epidemiology, forecasting and predicting foodborne contamination and diseases as well as food safety risk assessment via source attribution of both frequent and sporadic foodborne illnesses [63-65].

DNA and nucleic acid-based methods for boosting food safety include Whole Genome Sequencing, Polymerase Chain Reaction (PCR) assays, DNA sequencing methods, Random Amplified Polymorphism Deoxyribonucleic Acid (RAPD), Gel Electrophoresis assays [66]. Methods including PCR assays and Gel Electrophoresis methods have been used to identify foodborne pathogens by Ghanaian researchers. A simple comparison of research in Ghana where conventional foodborne pathogen detection methods were applied and where molecular methods for the same foodborne pathogens in variated food samples were applied reveals that the DNA and molecular-based methods were more sensitive, rapid, highly specific, rapid and hence reliable [62, 67].

The relevance of DNA technology to the promotion of food safety in Ghana is therefore clearly evident since similar advantages for food safety management in Ghana may be realized if DNA technology is applied in addressing other food safety challenges. For instance in the area of testing for food authenticity (food defense), applied DNA sensors could detect several types of illegal or foreign ingredients or contaminants in food samples [68]. Chemical food contaminants are generally difficult to detect and often used in processed food fraud cases [69]. DNA which has most recently emerged as an advanced nanomaterial due to its ability to adopt several configurations has revealed new opportunities for the development of DNA sensors that can be used for accurate and quick on-site detection of chemical contaminants, allergens, pesticides and toxic additives in food [68].

Applying DNA technology to food safety management and coordination of the data and results of its application in Ghana will significantly contribute to boosting food safety, and preventing and mitigating foodborne-related illnesses and deaths. Much support from the government is however required by food safety authorities and regulators as well as private concerned bodies to ensure public safety through the application of DNA technology to food safety.

10. Future Directions towards Achieving Sustainable Development

The SDGs are a set of 17 goals put together in 2015 by leaders from 193 countries to face the future as billions of people in the world share the hope for a better future. As far as the SDGs are concerned, famines, wars and diseases and many other indicators impeding sustainable development need to be reduced. In recent years, sustainability has been a buzzword that relates to a variety of activities in areas such as agriculture, crime-solving, environmental protection and many others that boost the economies of nations.

11. SDGs 1, 2 and 10 for Poverty Reduction, Food Security and Reduced Inequalities

The growing population of Ghana needs to be fed however this cannot be done by relying on conventional farming approaches. Everybody must be able to afford good and nutritious food to eat. The old story of the rich getting richer while the poor man staying poorer is not supposed to be the norm anymore. In the world we live today, we need policies that will create opportunities for everybody no matter who they are and where they come from. To double the food production per farm size, biotechnological tools which include recombinant DNA technology, marker-assisted breeding programs, molecular diagnostics, vaccine technology, protein engineering and genetic engineering techniques such as molecular pharming should be leveraged for sustainable crop and livestock production. The DNA revolution [70] is more forthcoming than imagined hence Ghana needs to move in the direction of precision agriculture to match up with drastic climatic occurrences. The application of DNA technologies in the agriculture sector will not only present the potential to feed the people of Ghana but also for foreign exchange.

The genetic improvement of farmed tilapia [71] is a very prudent way of increasing profitability in the fisheries and aquaculture sector by causing less harm to the ecosystem. A typical example of Recombinant DNA technology has to do with the introduction of a gene sequence into an organism to achieve the desired outcome [3]. The fall armyworm management during its emergence in 2017 saw local farmers in Ghana resort to the abuse of a variety of techniques including the application of local and household or synthetic chemicals to get rid of these crop pests. In the future, these unprofessional farming practices could be avoided because farmers will be able to combat fall armyworm and other related crop pests without using harmful chemicals that could contribute to pesticide resistance as a consequence of prolonged usage. Rather we anticipate farmers patronizing the use of crop varieties engineered to express a bacterial gene that controls certain insect pests. The molecular characterization of pathogenic organisms that are prevalent in specific regions of the country should be prioritized to boost consumer confidence in the meat and milk products they purchase. Consequently, molecular breeding should be incorporated into academic and research sectors to train scientists with modern and effective breeding methods to augment the conventional ways for efficiency and productivity. DNA application in the agriculture sector will eventually lead to good health and wellbeing, reduced hunger, increased food production, and creates jobs and employment to reduce poverty and protection of life on land and water which reflect key goals among the 17 SDGs.

In the roots and tubers development sector, technologies such as TILLING (Targeting Induced Local Lesions in Genomes), zinc finger nuclease mediated mutagenesis and *meganucleases* have been experimentally used to obtain improved cultivars through targeted mutations [72]. Full-scale adoption and incorporation of these techniques would result in very desirable roots and tubers, especially in the wake of debilitating yields of cereals which are the most consumed food types. When food is in abundance there is more to supply at a given time at regulated prices and everyone will not be left out.

12. SDGs 3 and 6 for Ensuring Good Health and Wellbeing

Ensuring good public health and food safety through safe foods is still a challenge for Ghana hence the less than 50% score under quality food provision for Ghana on the Global Food Security Index at the end of 2020 [69]. Adoption of DNA technology in food safety management could help address several challenges of food safety in Ghana. With DNA

technology in food safety, it would be easy to understand if a pathogen implicated in a foodborne contamination or disease outbreak is a result of recurrent contamination or sporadic contamination [65]. Because of a database of pathogens which will eventually be formed due to DNA technology, new and emerging pathogens would be easily identified. For example, [73] through DNA technology identified additional novel virulence factors in *Listeria monocytogenes* by comparing them with genomes from other isolated food samples.

Serious health risks and economic losses occur due to food fraud which is significantly on a rise in Ghana. Robust DNA approaches currently exist to either confirm or detect the origin, identity and composition of several foods such as oils, meats, rice and honey [66]. An initiative by the government to facilitate the application of DNA technology to the sector of food fraud will significantly contribute to generating income through the exportation of certain local foods as there will be confidence in the quality and authenticity of the foods produced in Ghana. Currently, 30% of palm oils on the Ghanaian market have failed the FDA's nationwide zero Sudan dye test. Ghanaian palm oil is currently banned in certain foreign countries [74].

There are a host of diseases that occurs as a result of a lack of specific biological machinery. To help correct these defects there is the need to understand the genetic basis. It is very common to find people go to the doctor when they feel sick. Adopting DNA technologies will be a new way to replace annual health checks with predictive detection tests. DNA technology will not necessarily push away medicines, it adds up to the efforts toward disease prevention at the early stages. A very classic paradigm is to vaccinate people before they are infected; however, with DNA technology, we might be able to vaccinate people with infections. The DNA revolution from a pragmatic viewpoint will lead to a greater extended life expectancy. There will be cures for some diseases like cancers, learning disabilities and brain damage if the future of DNA research is decoded.

In the contemporary health sector, there is the need to implement whole-genome sequencing of pathogens as well as the patients, this would form the basis of modern diagnosis while the genome sequencing of the pathogens would serve as a benchmark to track subsequent infections, which would initiate an outbreak surveillance system using these genomes. Additionally, challenges emanating from genetic disorders, rare diseases and cancer could be adequately dealt with using the gene-editing technique of CRISPR.

Sociocultural practices are typical of Ghana and it is characterized by customs and traditions which have sustained communities throughout time. Just like in the case of the spirit children in Sirigu, Bikum in Northern Ghana and some southern parts of Burkina Faso` as reported by Anas Aremeyaw Anas in an Aljazeera documentary in 2013. In this case, children with birth defects and disabilities were considered spirit children and therefore possessed bad spirits. They were given poisoned concoctions to drink and die thereof. In the future, precision medicine based on advancements in whole-genome sequencing should be adopted to rapidly diagnose and administer targeted therapies to patients. With this modern way of health care delivery, misconceptions and myths surrounding individuals with birth defects and other conditions arising from DNA issues will be well understood.

Ghana needs to adopt DNA technologies in its healthcare delivery system as a key way of diagnosing genetic and rare diseases, carrying out monitoring and surveillance to forestall any outbreak and adequately informing the treatment of patients rather than generic treatments. Furthermore, with DNA technologies, rapid diagnostic diagnosis tests could be developed for certain rather difficult to access but common diseases such as tuberculosis (TB), hepatitis and cancer. This would increase the health awareness of the greater citizenry; hence national policies on health development would be crafted representatively based on the awareness data. Traditional and herbal medicine in Ghana should be subjected to molecular techniques to understand how they function with the human DNA as it has been reported on several occasions that they have implications on the liver and kidneys. Recombinant DNA technology could be used to produce massive quantities of new drugs from these indigenous herbs to avoid the importation of medicines that are incompatible with the system of the local population. When proper health policies are implemented, Ghanaians are at a higher advantage of reaping the benefits of the sensitivity and specificity DNA technology brings to the table.

Nowadays people are very focused on the insurance of the compatibility of the cosmetic products they use [75]. Many consumers are now interested in greener alternatives because of the health and wellness of their skin. As we sustain the business, we also need to sustain the environment. Traceability of natural products in the cosmetic industry which is one of the booming sectors of the Ghanaian economy requires more improvement. For instance, if genetic traceability is applied at the ingredient and finished product stage, a lot of chemical and nonorganic resources will be avoided in the production process. The industry will produce cosmetics that do not predispose individuals to health risks. Also, there will be environmental sustainability as natural resources in the environment that are been used in the industries but do not play any key role in the effectiveness of these products will be identified and allowed to survive. With current advancements in the cosmetic sector, cutting-edge DNA-based cosmetic technology is one of the great ways for personalized skincare to produce cosmetics based on customer DNA for the use of risk-free cosmetics.

Everything seems to be interconnected at this stage and it is a fact that sustainable development will be achieved if there is good health. Because the child living in a community in Ghana with access to clean and potable water means getting better health, more time to go to school and improved safety due to the short distance travelled to access water.

13. SDGs 13, 14, 15 for Climate Action to Protect Life Below Water and on Land

As Ghana grows towards responsible consumption and production, protecting life on land and water and finally achieving climate action, the length of time for growing trees such as shea (*Vitellaria paradoxa*) and mahogany (*Swietenia macrophylla*) and other indigenous forest trees could be reduced through successive molecular breeding processes. These and other forest trees will be of economic importance by playing supportive roles in the ecosystem and the environment towards climate action [82]. The application of molecular breeding techniques would ensure the quick recovery and maintenance of the various agro-ecological zones which have been affected by timber logging and charcoal production.

The FALCON (Hierarchical Genome Assembly Process (HGAP) pipeline) has been used to sequence the whole genome of the shea tree [83], which is an indigenous West African tree with many benefits. This success presents a roadmap for the full utilization of available DNA techniques to improve this economically wild crop to help in climate action as well as compete effectively like perennials [84]. Also, in ensuring efficient management of forest and timber resources, DNA barcoding can be used to augment the morphological identification process of tracking illegally sawn trees [85], this would help conserve the fast depleting forest zone of the country.

Impact-based actions such as strengthening the national law enforcement, improving the prosecutorial and judiciary capacity and already available traditional forest degradation identification methods could be supported with DNA technology to help in the preservation and sustainable use of the forest. At this stage, more resilient communities are built to withstand the insurgency of climate change in Ghana. The forests through these stabilization initiatives will forever be the home of our indigenous breeds of wildlife and a stabilized ecosystem as a whole.

Ecological and forest crimes that occur in wildlife zones in Ghana seems to be of low risk to the nation however the impact it has on biodiversity and ecological systems development is very overwhelming. Environmental DNA technologies could be leveraged as urgent actions to protect the trafficking and poaching of species of flora and fauna in our waters and forests. This will serve as a cutting-edge forensic solution which will use concrete and measurable evidence-based interventions to protect life on land and below water.

14. SDGs 5 and 16 for Gender Equality while Building Peace, Justice and Strong Institutions

Many women in Ghana still face discrimination in private and public spheres. The root causes of discrimination in other words discrimination laws have resulted in the perpetuation of all forms of violence against women and girls. Sexual exploitation and trafficking of girls in Ghanaian communities are normally underreported because of the unavailability of substantive evidence from victims. Advocacy groups could leverage the power of DNA technology to solve gender-based violence and crimes such as sexual assault, prepubescent and adolescent kidnapping and trafficking of girls in Ghana just like The DNA for Africa crusaders in South Africa.

Regardless of the concerns about DNA as private data, it has helped to minimize the crime rate and solved many cold cases over the past few decades. It is time for the legislature, the scientific community, and relevant stakeholders to synergistically fight toward the passing of a DNA bill that will go a long way to solve five pressing issues in the domain of human identification. These areas include authentication of accused, victim and crime scene DNA and establishing a link between missing persons and unidentified bodies' DNA samples. Ghana needs a national DNA database that will facilitate the apprehension of criminals and help to reduce crime rates in society. Counting the cost of implementation, well-established specific DNA databases can be a very prudent measure to fighting crimes in Ghanaian societies as it has proven effective in other countries.

DNA databases will also go a long way to assist investigations concerning anonymous dead bodies and disaster victims and link them to their respective families for proper burial services. Genetic understanding of the biogeographical origin of certain people who enter the country through both authorized and unauthorized routes is very necessary. In order words, DNA application can help in strengthening the rule of law by serving as conclusive evidence in criminal and civil cases at the court of law to achieve SDG 16 which is an accelerator of all SDGs. This will foster justice and respect for human rights based on the rule of law in our societies.

Lastly, the government of Ghana should endeavours as a matter of urgency to draft policies for the implementation of a roadmap to establish a national DNA database. The government should encourage the use of DNA technologies in all sectors of production and service delivery by providing targeted funding and support to institutions that are interested in DNA research and application. There should be national funding allocated towards research into molecular biology and DNA applications in Ghanaian universities and research institutions with strategic timelines for the development of respective beneficiary sectors. Laboratories and universities that run molecular biology and DNA-related programs should be sponsored with well-equipped laboratories for students to appreciate research into DNA, which is a very important aspect of building the nation through agriculture, social justice, proper health care, and many others. Many of the sustainable development goals (SDGs) would be achieved wholesomely.

15. Conclusion

The impact of the DNA revolution presently gives an idea of what the future will be like with it, but there are still a few who are not yet familiar with this claim. It is no doubt that as others see the bright future of genetic engineering, recombinant DNA technologies, CRISPR/Cas9 and other relevant DNA technologies, others fear the unforeseen future. Researchers across the world are using CRISPR to modify mosquito DNA to eliminate mosquito-borne diseases such as malaria. In some advanced countries, DNA techniques have been used to limit the growth of the mosquito population. While some believe that it's not enough and practicable, GMOs are estimated to increase global agriculture yield by 22%. Today, mutations responsible for certain rare genetic diseases such as cystic fibrosis have been discovered, and the cystic fibrosis DNA test is not only helping to cure the disease but also helps in the identification of carriers.

Presently, the University of Ghana has introduced genetic counselling as a postgraduate programme to train undergraduate biological science degree holders to acquire postgraduate degrees, which will add value to the level of communication health practitioners have with patients. This will, in the short term, help to advocate the benefits of genetic studies and awareness, while in the long term, help to manage the extent of rare and neglected tropical diseases in the country. Also, the first of its kind in the West African Subregion is the Ghana Genome Project, which has been instituted to build genetic health capacity in Ghana to ultimately provide access to all aspects of genetic medicine in the country. It is time for Ghanaians to push the boundaries of nature as a country if we want to achieve sustainable development through the DNA revolution.

There are many schools of thought which say that the DNA revolution might come up with high levels of discrimination and inequality. It is understandable for people to come up with negative perceptions about DNA and its applications. The impact of the DNA revolution, however, speaks for itself, and as it stands, there is a high chance that it will improve the state's economy, as it has in advanced countries that believe in the fourth industrial revolution. Lastly, a general call for sensitization and education on DNA and its application is imminent as it occurs that cultural and religious beliefs tend to influence the decisions of individuals concerning this biological material.

16. Declarations

16.1. Author Contributions

Conceptualization, Y.S.S, O.A.S; methodology, Y.S.S, O.A.S; writing original draft preparation, Y.S.S, O.A.S; writing review and editing, Y.S.S, O.A.S, M.L, I.O, L.Q, S.M, M.D; supervision, L.Q and I.O. All authors have read and agreed to the published version of the manuscript.

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16.5. Institutional Review Board Statement

Not applicable.

16.6. Informed Consent Statement

Not applicable.

16.7. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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Appendix I

Case Box 1

Dr. Francis Addy is a Lecturer and Researcher in the Department of Biotechnology at the Faculty of Biosciences at the University for Development Studies. His research cuts across many areas of molecular biology and he primarily works on animal parasites, basically molecular parasitology. He believes that “it is clear now that everyone should know that we need a national effort to make DNA technologies readily available in almost every institution that has something to do with biology.” Upon his return to Ghana after his Doctoral studies, his response to this imminent call toward a DNA revolution has always been to work on parasites affecting livestock for close to a decade in Ghana. He has used molecular techniques to understand the genetic variability of common parasitic species affecting livestock production in a couple of regional studies in Northern Ghana. Notable among his researches are;

- Aghayan, S., Gevorgian, H., Ebi, D., Atoyian, H. A., Addy, F., Mackenstedt, U., ... & Wassermann, M. (2019). *Fasciola* spp. in Armenia: genetic diversity in a global context. *Veterinary parasitology*, 268, 21-31.
- Addy, F., Romig, T., & Wassermann, M. (2018). Genetic characterisation of *Fasciola gigantica* from Ghana. *Veterinary Parasitology: Regional Studies and Reports*, 14, 106-110.
- Addy, F., Narh, J. K., Adjei, K. K., & Adu-Bonsu, G. (2021). *Dicrocoelium* spp. in cattle from Wa, Ghana: prevalence and phylogeny based on 28S rRNA. *Parasitology Research*, 120(4), 1499-1504.
- Addy, F., Gyan, K., Arhin, E., & Wassermann, M. (2020). Prevalence of bovine fasciolosis from the Bolgatanga abattoir, Ghana. *Scientific African*, 8, e00469.
- Anane, A., Dufailu, O. A., & Addy, F. (2022). *Ascaridia galli* and *Heterakis gallinarum* prevalence and genetic variance of *A. galli* in rural chicken from the Northern Region, Ghana. *Veterinary Parasitology: Regional Studies and Reports*, 29, 100692.
- Addy, F., Adu-Bonsu, G., Dickson, A. E., Dankwa, D., Aryee, R., Dufailu, O. A., ... & Wassermann, M. (2022). Prevalence and genetic variance of *Taenia hydatigena* in goats and sheep from northern Ghana: Preliminary data on a globally neglected livestock parasite. *Veterinary Parasitology: Regional Studies and Reports*, 30, 100711.
- Addy, F., Bofo, K. F., Yakubu, A. B., Aryee, T. K., Narh, J. K., Adjei, K. K., & Adu-Bonsu, G. (2021). *Taenia hydatigena* in goat and sheep in Ghana: a cross-sectional abattoir survey in Northern and Upper West Regions. *Journal of Parasitic Diseases*, 45(2), 454-458.

Source: Sulley Y, S, Seidu A, O. (2022). *Towards a DNA Revolution in Ghana-Interview. E-Mag-Scientect*. Available online: <https://scientect.org/category/e-mag> (accessed on May 2022).

Case Box 2

Takoradi Kidnapping

During the last quarter of 2018, serial kidnapping and murdering syndicates of adolescent and prepubescent girls were at their peak. In the Western regional capital, Takoradi, an official statement was made by the regional police concerning the state of missing people in the region. Four girls were reported missing and suspected to be kidnapped between July and December (2018). After several months of bargaining and communication with the kidnappers, human remains were discovered in a septic tank in the residence of the suspected culprits. After several months of disputes and disagreement on the police report of the missing girls being dead, the genetic relationship between the remains and the families involved was established. The police reported that DNA analysis of the remains had turned positive.

After the analysis, it was found that all four samples shared a common allele with all loci tested with a Combined Paternity Index (CPI) of 25767.9834, 202552413.7053, and 53160961.519 for 3 remains while a CPI of 1293669.4766 and CMI of 11703487616.3591 appeared for both parents respectively who were linked to one set of remains. The Probability of paternity and maternity testing for all samples was also recorded as 99.99%. Even though some of the families still do not believe their children are dead, it was concluded by DNA analysis that all the remains had a link to the familial samples collected and that, “Skull 1, 2, 3 and 4 cannot be excluded as the biological children of all the relatives whose DNA samples were used as reference. The two Nigerians were tried and sentenced to death by the Takoradi high court afterwards.

Source: Adjei, E, A. (2020). *DNA confirmed skeletal remains of Takoradi kidnapped girls – Medic*. Available online: <https://3news.com/dna-confirmed-skeletal-remains> (accessed on May 2022).