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Purposeful scientific research as a pillar of sustainable development

Scientific Abstract of the Review: Use of molecular techniques in studying environmental patterns and studying interactions between genes and the environment.

Asmaa Adnan Marie, Ibrahim Omar Saeed

Depth. of Biology College of Science University of Tikrit, Tikrit, Iraq

asmaa.a.marie@tu.edu.iq , Email/dr.ibrahim1977@tu.edu.iq

ABSTRACT

The field of molecular ecology is moving forward quickly in the past few years largely driven by improvements in methods for molecular analyses. The aforementioned advancements have enhanced our comprehension of biodiversity and the cellular and genetic mechanisms that mediate the interactions of organisms with and within their environments. Snapshot: Molecular Ecology Making use of molecular approaches with or without prior organism observation to characterize ecological patterns; including environmental DNA (eDNA), genetic fingerprinting, high-throughput sequencing (HTS), etc.

The physical chemistry then takes into account the molecular environment where biological molecules actually work, in which pH, temperature, electrostatic forces and partial gas pressures all impact the stability of molecules and the rates of biochemical reactions.

Molecular methods used to study biodiversity and ecological trends include DNA sequencing, gene expression (e.g. RNA-seq), DNA fingerprinting and functional genomic analysis. Such methods are useful in many areas including medicine, agriculture and conservation biology.

One of the most promising tools, for example, is environmental DNA (also referred to as eDNA), which can allow monitoring of rare or conspicuous species, invasive species, and changes in ecosystem community composition without the need for environmental disturbance.

Another major consideration is that of gene-environment interactions, mediated by epigenetic mechanisms including DNA methylation and histone modification. These processes are examples of gene control in that organisms can functionally evolve based on environmental factors.

The review also discusses the applications of environmental genetics to fields such as personalized medicine and public health policy. And it tackles persistent problems, such as complex molecular data and the high level of genetic variation between individuals. Fundamentally, the integration of molecular techniques in ecophysiological research offers insights regarding organismal and population response to environmental stress and promotes the sustainable design of potential solutions in both areas of research ecologically and biomedically.

Keywords: Environmental dna (eDNA); High-throughput sequencing (HTS); Gene–environment interaction; Epigenetics.

1-Molecular ecology

- The past few decades have seen an explosive growth in molecular ecology, owing to the rapid development of molecular analysis techniques and their applications towards elucidating ecological relationships and evolutionary biology. This discipline is a sub-field of environmental and molecular genetics sciences that relies, in part, on tools such as deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and genetic fingerprinting, to study genetic diversity, gene flow, and the overall structure of biological communities. Such tools have resulted in a qualitative leap in ecological studies, especially for species that have not previously been studied or are difficult to monitor in the field (Avise, 2022, Bohmann et al., 2024). Radiometric techniques on biodiversity also include molecular ecology to facilitate accurate species identification beyond standard taxonomy. The genetic signatures of many species of microorganisms and complex organisms can also be detected in their natural environments using methods such as DNA barcoding and metagenomics (Lahoz-Monfort et al. affording us more detailed insights into ecological interactions and the ecological functions that these species may fulfill (Cristescu, 2019; Taberlet et al., 2018). Among the many common applications of molecular ecology is endangered species monitoring, tracking the origins of invasive species, or assessing anthropogenic effects on ecosystems. One of the modern innovations that the technique of environmental DNA (eDNA) is that bacteria or other living organisms can be detected if their DNA traces in water, soil, or air are analysed (Deiner et al., 2017; Ruppert et al., 2019). In addition, high-throughput sequencing (HTS) technologies have dramatically developed, allowing data from large samples to be generated and analysed, Although previously common, this has opened up new avenues for investigations of gene−environment interactions, local adaptation, and responses to climate change (Allendorf et al., 2022; Bálint et al., 2018). The simultaneous consideration of the environment and genetics has resulted in the idea of the "holobiont," representing an organism as an integrated unit made up of host and associated microbiome, By this, we hope to add to our comprehension of co-evolution at both the cooperative and microbiome levels (Bosch & McFall-Ngai, 2021). The need for interdisciplinary approaches to respond to contemporary challenges in molecular ecology at both an applied and fundamental level, involve aspects of biology, bioinformatics, statistics, and quantitative ecology [2]. This has placed this field at a fundamental role in contemporary ecological and evolutionary environmental research (Rieseberg & Willis, 2020; Alberdi et al. 2021). Ecology is a branch of biology that primarily focuses on how organisms interact with each other and with their environment in the wild. The molecular environment refers to the microscopic surroundings that envelop molecules within any system or living cell. This environment influences molecular interactions, their stability, and their chemical or biochemical reactions. Historically, these interactions were studied through field observations and experimental manipulations. Such phenotypic data, often based on one or more aspects of an organism's morphology, function, biochemistry, or behavior, have significantly enhanced our understanding of various species. What we consider traditional ecological studies have made invaluable contributions to our comprehension of the processes that sustain ecosystems The molecular environment encompasses several aspects, such as1-2. 1- Composition of the surrounding medium: This includes the presence of water, ions, and other small molecules (such as sugars and lipids) that influence solubility, molecular interactions, and the free energy of biomolecules. For example, reactions occurring in aqueous environments—such as within cells—differ significantly from those in oily or non-aqueous media 2. Common substances: Lemon juice has a pH of about 2.0, making it very acidic; pure water is neutral at pH 7.0, while tap water may vary slightly depending on its mineral content. 3. Environmental

examples: Seawater is slightly alkaline at pH ~8.0, which is important for marine life. Acid rain, resulting from industrial pollution, may have a pH near 5.0, which can harm ecosystems and infrastructure. 4. Electric and Magnetic Forces: These forces influence molecular stability and interactions. Electrostatic forces (e.g., Coulombic interactions) occur between charged molecules or ions. For instance, in a water molecule (H_2O), partial charges on hydrogen and oxygen atoms lead to strong hydrogen bonding. Magnetic interactions also occur in molecules with dipole moments, where external magnetic fields can affect their stability and reactivity. Such forces are fundamental to the behavior of macromolecules, including proteins and nucleic acids. Partial Pressure of Oxygen and Other Molecules:-5 Even in dipole moment bearing molecules, magnetic interactions take place where external magnetic fields can alter the stability and reactivity of the molecules. These kinds of forces drive the behavior of macromolecules, such as proteins and nucleic acids. The partial pressure of CO2 within a cellular environment has a huge impact on the biochemical reactions that occur in the mitochondria such as cellular respiration. It refers to the partial pressure of gas mixture represented by oxygen contributing the total gas pressure and it is calculated using Dalton's Law as the following: This means that: $P_total = P_O_2 + P_N_2 + P_OTHER\ GASES$ As an example, at sea level atmospheric pressure (760 mmHg), oxygen makes up ~21% of that, so: $P_O_2 = 0.21 \times 760 = 159.6$ mmHg It is a key idea underlying measurements of oxygen availability in tissues and environmental contexts. 6. Molecular Concentrations: Small but non-negligible changes in concentrations of molecules can have a dramatic influence on reaction rates. As an example, availability of ATP (adenosine triphosphate) and ADP (adenosine diphosphate) directly impacts the activity of energy-consuming cellular mechanisms. Energy is stored in high-energy phosphate bonds in ATPer Pearson, which is released when ATPer Pearson is converted to ADPers Pearson. The continual cycle of ATP production and degradation (the ATP–ADP cycle) is directly involved in many cellular processes such as muscle contraction, active transport, and biosynthesis. Quote: The molecular environment is highly complex and multi dimensional, with many factors that affect the behavior and interaction of molecules. This environment must be understood to describe many biological processes and chemical reactions occurring in living systems. 3- Molecular tools will be indispensable in probing environmental patterns because they can reveal interactions among organisms and between organisms and environments at fine scales [8]. The application of molecular techniques in pattern studies comprise numerous methods and approaches that benefit from advances in biotechnology for analyzing genetic material and other molecules inside living organisms, constituting with that fundamental insights into biodiversity, ecological interactions, and genetic adaptations that are not possible with traditional tools. . These methods have applications in a variety of fields, including medicine, agriculture, evolutionary biology, and ecology. Molecular techniques and pattern studies: Here are some specific details — 1 Using molecular techniques to study environmental patterns -(DNA Sequencing)1 Goal of DNA Sequencing: An examination of genes and the genetic code of organisms (A, T, C, G). Method: Extract DNA from cells and machines determine the order of nucleotides (A, T, C, G) Sanger Sequencing Next Generation Sequencing (NGS) Sanger Sequencing and Next Generation Sequencing (NGS) are the widely used techniques. Application: This technique is employed to study population genetics, study genetic diversity between species and to conduct the lineage tracing of genetic diseases. 2- (Gene Expression Analysis Gene Expression Analysis=. Purpose:To quantify messenger RNA (mRNA) from particular genes, which indicates activity of said genes. RT-PCR (Real-Time Polymerase Chain Reaction) Microarrays or RNA-seq. Techniques: Gene expression is studied using RT-PCR (Real-Time Polymerase Chain Reaction), Microarrays or RNA-seq techniques. Applications: These techniques are useful in pattern identification related to specific diseases or biological patterns emerging as a response to changes in their environment. 3. Polymerase Chain Reaction (PCR. To increase tiny amounts of DNA to a size at which it can be studied. Machine: Replicating specific segments

of DNA using enzymes helps directly observe genetic patterns or mutations. Application: This technique is commonly employed in genetic disease diagnosis, pathogen detection, and large-scale genetic association studies. 4. Comparative Genomics. Purpose: Sequence comparison between organisms so as to find genetic relationship or evolutionary relationships between different organisms. Technique: It based on the sequencing of DNA and comparing homologous and non-homologous regions of the genome. Where to Use: It used mostly in evolutionary biology for evolutionary studies linguistic system process of organisms or genetic trait patterns in the other way in a response to environmental pressures. 5. Genetic Modification and CRISPR Techniques. Aim: The ability to make specific changes in genes to analyse its function or to identify genetic networks that regulate biological traits. Method: CRISPR-Cas9 which selectively cuts and pastes separate sections of DNA . How it is used: Used to provide insight into genetic patterns related to disease or trait and for gene therapy developments. 6. DNA Fingerprinting. Objective: To identify unique DNA patterns of individuals. STR (Short Tandem Repeats). Technique: Specific repetitive sites in the genome are analyzed using techniques such as STR (Short Tandem Repeats). Usage: It is used in forensic investigations, lineage studies, and paternity tests to determine genetic relationships between individuals. 7. Proteomics. Goal: To analyze cell-derived protein patterns. Gel Electrophoresis. Method: Methods used to decipher the compositions of proteins contained within cells, like Mass Spectrometry and 2D Gel Electrophoresis. Application: It can be used to identify patterns related to protein expression during the course of a disease (e.g. cancer) or the response of the body to environmental change. 8. Practical Applications in Human Genetics and Agriculture. Medicine: Or gene-pattern recognizability that are associated with particular diseases eventually lead to earlier medical diagnosisprescription and treatment prescribed specifically for that person: In Agriculture: Studying genetic patterns of crops and animals for enhanced traits such as disease resistance or higher yield. The availability of molecular techniques that allow the study of genetic and protein patterns has opened up many possibilities for elucidating the biology of the Oryza genus within its evolutionary context, as well as for the development of applications in agronomy, plant harvesting and human nutrition [8–11]. 3-2. Environmental DNA (eDNA). Environmental DNA is a method based on collecting samples from soil, water, or air to extract DNA of the organisms found in that ecosystem. It helps to identify various organisms without direct observation or isolation. . It enables detection of rare or endangered species that may not be visible by conventional methods. . It offers the possibility to study ecosystems without having to interfere with it. . Remote sensing biodiversity in both the marine and terrestrial realm. Detecting invasive species which could jeopardise ecological integrity.). Taberlet, P., et al. (2012) 3-3. High-Throughput Sequencing. High-throughput sequencing technology can rapidly analyze large numbers of genetic data [8].. This method is used for the analysis of microbial communities and the genetic sets of all species of organisms in an ecosystem. . Who can do thousands of genes in single samples . It offers a holistic view of the genetic and microbial diversity hosted by the ecosystem. . These include the microbiome studies in soil or marine ecosystems, as well as the decomposition of genetic patterns in ecosystems when climatic or environmental changes take place. Caporaso, J.G., et al.2012 3-4 Genetic Fingerprinting . It works by looking at variations in certain areas of DNA (like STRs or SNPs) to find genetic patterns. . It assists with gene flow tracking between species in various environments. . It gives a clue about the genetic variation of species in an ecosystem. . Like their migration and genetic behaviour in variable environments for example animals and plants. . The genetic structure of biological communities and how alterations occur within these communities in response to environmental change. Nybom, H. (2004) Nybom, H. (2004) 3-5 Functional Genomics . . Ecological functional genomicsFunctional genomics is a means of understanding how genetic changes alter the behavior of proteins and enzymes in ecosystems. It uses methods like metagenomics and metatranscriptomics. . It offers insight into how organisms react to environmental pressures at the molecular

level. . And assists in finding out genetic functions that drive what organisms would do to adapt themselves to particular conditions. . For example, the reactions of plants to climate change. . Further, knowing how those environmental pollutants change gene expression of the organisms in the ecosystem. Zhou, J., et al. 2015 3-6 RNA Sequencing (RNA-seq) Technology. RNA-seq technology is one of the important tools of gene expression processing, which identifies which of the genes are expressed and how they ae regulated under different varying environmental conditions. Changing gene expression to adapt to changes in the environment in living organisms. Informing molecular mechanisms of adaptation to environment. For example, ecology studies the interaction between living things in an ecosystem. Studying how plant or animal communities respond to pollution/resource shortage Mortazavi, A., et al. 2008. Recent advancements in molecular technologies including environmental DNA and high-throughput gene sequencing coupled with functional genomic analytical methods provide a reliable and systems-level representation of environmental patterns. Using these techniques, scientists are able to study biodiversity, genetic interactions, and how organisms respond to environmental changes. These techniques depend on sampling and analyzing the genetic material from these samples providing the potential for insights into ecological scaffolds and how living things interact with them. 4-Gene-Environment Interaction It is a branch of science that examines the interactions between genes and the environment, and how those interactions affect the development, behavior, and traits of organisms. This discipline tries to understand the interaction between genetic predisposition (genes) and environmental stressors in the course of an individual's lifetime in terms of health outcomes and phenotypic traits both physical and psychological. Some genetic mechanisms include a few interacting factors that dictate how genes will be expressed, and how the environment is going influence them, and they are:(Methylation): DNA methylation is a biochemical process that is the addition of a methyl group (-CH_3) to DNA, specifically to cytosine next to guanine. The addition makes it difficult for transcription factors to bind to DNA leading to downregulation of gene activity and subsequently, gene silencing/repression. Methylation is one of the basic mechanism of regulating the expression of genes in embryogenesis and differentiation.(Histone Modifications): Histones are DNA-binding proteins that serve to organize DNA into a more compact structure inside the nucleus. Chemicals groups like acetyl, methyl or phosphate can be attached to histone tails, a phenomenon known as histone modification. These alterations play a role in making the chromatin (genetic material) more open or closed, and therefore impact the ability of transcription machinery to bind to and access genes. Acetylation, for instance, typically promotes activation of the gene, whereas methylation can either activate or repress depending on the context. (Epigenetic Changes): Epigenetic changes are those that simply regulate genes without causing a change in sequences in the DNA. Such changes could be triggered by environmental factors such as nutrition, stress, exposure to toxins and made either heritable or acquired.. These include methylation, histone modifications and other changes that do affect how genes are expressed, but do not change the genetic code itself. 4. (Gene-Environment Interaction):. This is called how the environment influences gene expression. : Genes are not entirely in control of their fate, either; they can be influenced by numerous environmental factors that affect their expression — including nutrition, stress, physical activity, and chemical exposure. As an example, one might inherit the genes that predispose them to certain ailments, but whether or not they express those genes often depends on the environment. Environmental exposure may activate certain genes or suppress them, which, in turn, can either promote good health or disease at the biological level.: Bird, A. (2007) 4-1 (Gene-Environment Interaction) Gene-environment interaction means the interaction between one or more environmental factors and the expression of an individual genotype (Genetics 2017). So, you have two primary ways in which these interactions can take place: Genes that influence how a person responds to the environment: Within areas of human variation where operable proximate causative mechanisms exist,

genetically determined susceptibility or transient resistance to particular types of environmental influence is possible. Environment that influences gene expression: Environmental factors such as diet, stress, or exposure to toxins may alter gene expression patterns (the process of transcription from DNA to RNA and then translation into proteins) and influence the functions of living organisms: Rutter, M. (2006) 2-4. (Mechanisms of Gene-Environment Interaction) 4-2-1. (Epigenetics) Epigenetics refers to changes in gene expression that occur without altering the underlying DNA sequence. Environmental factors such as diet, pollution, and psychological stress can influence gene expression through processes such as:- a. (DNA Methylation): DNA methylation involves the addition of methyl groups to the DNA molecule, typically at cytosine bases. This modification can suppress gene expression by preventing transcription factors from binding to DNA. b. (Histone Modification): Histone modifications refer to chemical changes in histone proteins that DNA wraps around. These changes can influence how easily the transcription machinery accesses genes. 4-2-2(Interactive Genetic Regulation) Interactive genetic regulation refers to the activation or suppression of specific genes in response to environmental stimuli. For example, certain genes may only become active in the presence of environmental stressors such as stress or nutrient deficiency. 4-2-3 (Genetic Susceptibility) Genetic susceptibility refers to inherited variations that make some individuals more vulnerable to environmental influences. For instance, genes regulating the body's response to fats may make certain individuals more likely to develop obesity when exposed to a high-fat diet. : Caspi, A., et al. (2003- 4-3 (Interaction of Genes and Environment) 4-3-1(Genetic Predisposition to Diseases) Many chronic diseases, such as diabetes, hypertension, and heart diseases, depend on the interaction between genes and environmental factors. For example: Type 2 Diabetes Genes that affect the body's response to insulin may predispose some individuals to diabetes if they live in environments with poor diets or limited physical activity. 4-3-2 (Stress and Its Genetic Effects) Chronic stress can influence genes related to hormonal and stress responses, such as those in the cortisol system. Individuals with a genetic predisposition to overreact to stress may be more likely to develop disorders such as depression or anxiety when living in highly stressful environments. 4-3-3(Food Interaction). Diet plays a significant role in modifying gene activity. For example, some individuals may carry genetic mutations that allow them to benefit more from omega-3-rich foods,. while others may not gain the same benefits. 4-4. (Environmental Genetics Studies) 4-4-1 (Study of Twins) Monozygotic (identical) twins offer an excellent model for studying environmental genetics, as traits can be compared between twins raised in different environments, to determine the influence of environment on gene expression despite genetic similarity. Studies of identical and fraternal twins: Comparing identical twins who share all their genes with fraternal twins who share only half, can help disentangle the effects of genetics from those of the environment. 4-4-2(Genome-Wide Association Studies - GWAS) Genome-wide association studies (GWAS) are a tool for examining gene-by-environment interactions sign of common genetic variations in large populations and taking comparisons with other environmental characteristics. GWAS has been or is currently being used to study things such as the compulsive behaviour of obesity and the environmental factors associated with it, such as diet. Visscher, P.M., et al. (2017) Visscher, P.M., et al. (2017) 4-4-3(Mutational Studies) These studies allow scientist to examine the organism reaction when exposed to environmental effectors with some specific genetic mutation. This is particularly useful, for instance, where a particular type of gene mutation can be examined to put their effect on the heat- or pollutant-tolerant capacity of the body to the test. : Caspi, A., et al. (2003) 5- (Applications of Environmental Genetics) 5-1(Personalized Medicine) Environmental genetics, among the grundlagen for the establishment for personalized medicine. because treatment plans can be personalized for a given person depending on genes and environment. For instance, those that harbor certain mutations might react differently to a specific kind of treatment if environmental factors are taken into account. : Trevaskis, J.L., et al. (2010) 5-2(Public Health

Policies) Genetic Epidemiology Gene-environment interactions: implications for public health policy like the disease prevention programs based on susceptibility of common diseases and the surrounding environmental risks. 6- (Challenges in Studying Environmental Genetics) Data complexity:- But studying gene-environment interaction requires huge quantities of data. which complicates proper analysis. Individual variability:- We are each an extraordinarily complicated set of genes that interacts in unpredictable and unfathomable ways with our environment. So, predicting interactions between genes and environmental stressors is challenging.

2- Molecular Ecology

The past few decades have seen an explosive growth in molecular ecology, owing to the rapid development of molecular analysis techniques and their applications towards elucidating ecological relationships and evolutionary biology.

This discipline is a sub-field of environmental and molecular genetics sciences that relies, in part, on tools such as deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and genetic fingerprinting, to study genetic diversity, gene flow, and the overall structure of biological communities.

Such tools have resulted in a qualitative leap in ecological studies, especially for species that have not previously been studied or are difficult to monitor in the field [1,2]. Radiometric techniques on biodiversity also include molecular ecology to facilitate accurate species identification beyond standard taxonomy.

The genetic signatures of many species of microorganisms and complex organisms can also be detected in their natural environments using methods such as DNA barcoding and metagenomics [3,4]. This affords more detailed insights into ecological interactions and the ecological functions that these species may fulfill [5,6].

Among the many common applications of molecular ecology is endangered species monitoring, tracking the origins of invasive species, or assessing anthropogenic effects on ecosystems. One of the modern innovations is environmental DNA (eDNA), in which bacteria or other living organisms can be detected if their DNA traces in water, soil, or air are analysed [7,8].

In addition, high-throughput sequencing (HTS) technologies have dramatically developed, allowing data from large samples to be generated and analysed. Although previously uncommon, this has opened up new avenues for investigations of gene–environment interactions, local adaptation, and responses to climate change [9,10].

The simultaneous consideration of the environment and genetics has resulted in the idea of the "holobiont," representing an organism as an integrated unit made up of host and associated microbiome, thereby enhancing comprehension of co-evolution at both the cooperative and microbiome levels [11].

The need for interdisciplinary approaches to respond to contemporary challenges in molecular ecology at both an applied and fundamental level involves aspects of biology, bioinformatics, statistics, and quantitative ecology [12]. This has placed this field in a fundamental role in contemporary ecological and evolutionary environmental research [13,14].

Ecology is a branch of biology that primarily focuses on how organisms interact with each other and with their environment in the wild. The molecular environment refers to the microscopic surroundings that envelop molecules within any system or living cell. This environment influences molecular interactions, their stability, and their chemical or biochemical reactions. Historically, these interactions were studied through field observations and experimental manipulations. Such phenotypic data, often based on morphology, function, biochemistry, or behavior, have significantly enhanced our understanding of various species. Traditional ecological studies have made invaluable contributions to our comprehension of the processes that sustain ecosystems.

The molecular environment encompasses several aspects:

1. Composition of the surrounding medium: Includes water, ions, sugars, and lipids that influence solubility and stability. Reactions in aqueous environments differ significantly from those in oily or non-aqueous media.

2. Common substances: Lemon juice (pH ~2.0) is acidic, pure water is neutral (pH 7.0), seawater is slightly alkaline (~8.0), while acid rain has a pH near 5.0.

3. Electric and magnetic forces: Electrostatic and dipole interactions influence molecular stability and macromolecule behavior such as proteins and nucleic acids.

4. Partial pressure of gases: For example, oxygen at sea level is ~159.6 mmHg, influencing mitochondrial respiration.

5. Molecular concentrations: Small changes in ATP/ADP can significantly affect energy-dependent processes such as muscle contraction and biosynthesis.

Quote: "The molecular environment is highly complex and multidimensional, with many factors that affect the behavior and interaction of molecules. This environment must be understood to describe many biological processes and chemical reactions occurring in living systems."

3- Molecular Tools and Environmental Patterns

Molecular tools are indispensable in probing environmental patterns because they can reveal interactions among organisms and between organisms and environments at fine scales [15]. Applications span medicine, agriculture, evolutionary biology, and ecology.

3-1. Molecular Techniques

1. **DNA Sequencing:** Includes Sanger and Next-Generation Sequencing for studying population genetics and genetic diversity.
2. **Gene Expression Analysis:** Using RT-PCR, microarrays, or RNA-seq to quantify mRNA and gene activity.
3. **Polymerase Chain Reaction (PCR):** Amplifies DNA for pathogen detection, mutation studies, and diagnostics.
4. **Comparative Genomics:** Compares genomes to reveal evolutionary relationships.
5. **CRISPR and Genetic Modification:** Enables targeted gene editing for functional studies and therapy.
6. **DNA Fingerprinting:** STR-based analysis for forensics and lineage studies.
7. **Proteomics:** Mass spectrometry and 2D electrophoresis reveal protein-level patterns.
8. **Applications:** In medicine for precision diagnostics, and in agriculture for crop improvement [16–18].

3-2. Environmental DNA (eDNA)

Detects organisms from soil, water, or air without direct observation. Useful for biodiversity surveys, invasive species monitoring, and conservation [19].

3-3. High-Throughput Sequencing

Enables holistic genetic analysis of microbial communities and ecosystems [15,20].

3-4. Genetic Fingerprinting

Identifies genetic structure, migration, and community alterations [21].

3-5. Functional Genomics

Uses metagenomics and transcriptomics to study how genetic functions respond to environmental pressures [22].

3-6. RNA Sequencing

Examines dynamic gene expression under environmental changes such as pollution or resource scarcity [23].

4- Gene–Environment Interaction

This branch examines how genes and environment interact to influence health, traits, and behavior. Mechanisms include DNA methylation, histone modifications, and other epigenetic changes [24–26].
Examples include:

- **Genetic predisposition to disease:** e.g., diabetes risk influenced by poor diet.
- **Stress:** Chronic stress alters cortisol-related genes, affecting mental health.
- **Diet:** Nutritional inputs modulate gene expression.

Research methods include twin studies, genome-wide association studies (GWAS), and mutational studies [27,28].

5- Applications of Environmental Genetics

1. **Personalized Medicine:** Tailoring treatments based on gene–environment profiles [29].
2. **Public Health Policies:** Using gene–environment data to design preventive programs.

6- Challenges in Environmental Genetics

- **Data complexity:** Requires massive datasets and advanced analytics.
- **Individual variability:** Human gene–environment responses are diverse and unpredictable [29].

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