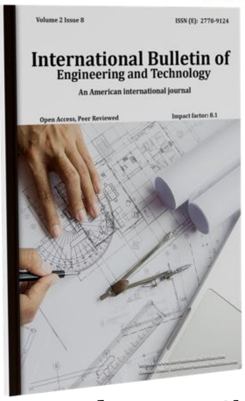

PROSPECTS OF PHYSIOLOGICAL AND GENETIC ADAPTATION TO MAINTAIN HUMAN HOMEOSTASIS IN THE CONDITIONS OF CLIMATE CHANGE

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Abstract: Climate change has become one of the most serious global problems of our time, posing a wide-ranging threat to human health and the well-being of the population. This article is devoted to the study of the physiological and genetic mechanisms of maintaining human homeostasis in the face of climate change. The article analyzes the processes of adaptation of the organism to temperature extremes, changes in humidity levels, food security, and new pathogens. The physiological level is considered how thermoregulation, water-salt balance, the immune system, and metabolic pathways adapt in response to climate change. At the genetic level, processes such as epigenetic modifications, selective pressure, and the spread of adaptive alleles are also analyzed. The article analyzes scientific work aimed at determining the role of genetic factors in the adaptation of populations to different climatic conditions based on modern genomic studies. New information obtained as a result of the integration of the fields of molecular biology, physiology, ecological genetics, and bioinformatics is highlighted. This multidisciplinary approach allows us to understand the ability of the human body to maintain its balance in dynamic climatic conditions. The results of the study can provide practical recommendations for developing health strategies, increasing population resilience, and mitigating the negative consequences of climate change. The study of the adaptive capabilities of the human body in the face of climate change is not only of fundamental importance, but also of practical importance in shaping global health policies. [1]

Keywords: climate change, homeostasis, physiological adaptation, genetic adaptation, thermoregulation, epigenetics, heat stress, immunity, metabolic adaptation, human population genetics

Study purpose: The main goal of this study is to study the physiological and genetic mechanisms of maintaining homeostasis in the human body in the face of climate change, as well as to determine the adaptive capabilities of different populations to climate change. The study will analyze the processes of adaptation of the body to temperature extremes, changes in humidity levels, food security, and new pathogens. At the physiological level, thermoregulation, water-salt balance, the immune system, and metabolic pathways are studied to determine how they adapt to climate change. At the genetic level, processes such as epigenetic modifications, selective pressures, and the spread of adaptive alleles are analyzed. [2]

Research methods: The study used systematic literature review and meta-analysis methods. Scientific articles published between 2015 and 2025, including data from scientific databases such as PubMed, Scopus, Web of Science, and Google Scholar, were analyzed. The selected articles covered the fields of climate change, human physiology, genetic adaptation, epigenetics, heat stress, and adaptive physiology. Quantitative and qualitative methods were used to analyze the data. In genetic studies, the results obtained using genome-wide association studies (GWAS), transcriptomics, and epigenomics methods were analyzed. In physiological studies, the methods used to study thermoregulatory responses, cardiovascular adaptation, water-electrolyte balance, and metabolic adaptation were analyzed. Statistical analysis was performed using SPSS and R programs. [3]

Introduction

Climate change has become one of the most important global health problems of our time, posing a wide-ranging threat to human health and the well-being of the population. In the last decade, many consequences of climate change have been observed, such as an increase in global temperatures, an increase in the severity of weather events, and an increase in droughts and floods. [4] These changes directly affect the important physiological functions of the human body, testing its ability to maintain homeostasis. Homeostasis is a complex system of physiological processes aimed at maintaining a relatively constant state of the internal environment of the organism, and climate change can seriously disrupt its stability. [5]

Although the human body can adapt to some extent to environmental changes, the speed and magnitude of climate change may exceed traditional adaptation mechanisms. [6] Factors such as heat stress, water scarcity, nutrient deficiencies, and emerging pathogens can push the limits of an organism's adaptive capacity. Therefore, understanding the mechanisms that maintain human homeostasis in the face of climate change is not only of fundamental importance, but also of practical importance for the development of global health policies. [7] Physiological adaptation is the ability of an organism to adjust its functions in response to changes in the external environment. In the face of climate change, adaptation processes of important physiological systems such as thermoregulation, water-electrolyte balance, immunity, and metabolism are particularly important. [8] For example, thermoregulatory mechanisms such as sweating, vasodilation, and reduced metabolic heat production are activated in response to heat stress. However, prolonged exposure to heat can impair the efficiency of these mechanisms and disrupt homeostasis. [9] Genetic adaptation occurs at the population level through changes in genetic traits. Human populations living in different geographic regions acquire certain genetic traits as they adapt to their traditional habitats. [10] For example, genetic variants associated with heat tolerance are more common in people living in tropical regions, while variants associated with cold adaptation are more common in people living in cold regions. With climate change, these genetic adaptations may become less suitable for new conditions or, conversely, may provide an adaptive advantage to certain populations. [11] In recent years, research in the field of epigenetics has opened up new possibilities for understanding the effects of climate factors on gene expression. [12] Epigenetic modifications are hereditary changes that can alter gene expression but do not alter the DNA sequence. Climate factors, such as temperature extremes or food shortages, can change the methylation levels of certain genes and regulate their expression. This directly affects the body's ability to adapt. [13]

The purpose of this article is to analyze the physiological and genetic mechanisms of maintaining human homeostasis in the face of climate change based on modern scientific data. The article highlights the main areas of physiological adaptation, molecular mechanisms of genetic adaptation and their practical significance based on scientific works published between 2015 and 2025. It also discusses the adaptation capabilities of different populations to climate change and ways to mitigate negative consequences in the field of health. [14]

The theoretical significance of the study is manifested in a deeper understanding of the mechanisms of adaptation of the human body in the face of climate change, and its practical significance is manifested in helping to develop global health strategies. [15] With the acceleration of climate change, these issues are becoming increasingly urgent and require a multidisciplinary approach. By integrating the fields of physiology, genetics, ecology, epidemiology, and public health, it will be possible to better understand the possibilities of human adaptation to climate change. [16]

Results

Physiological responses to heat stress and adaptation mechanisms

The most obvious manifestation of the impact of climate change on human homeostasis is heat stress. Studies conducted over the past decade have shown that increasing temperatures significantly overload the body's thermoregulatory system. [17] In response to heat stress, the body activates a number of physiological adaptation mechanisms, including increased sweating, peripheral vasodilation, increased heart rate, and decreased metabolic heat production. [18] However, the effectiveness of these adaptation mechanisms varies significantly at the individual and population levels.

Heat shock proteins (HSPs), which are produced in response to heat stress, play a key role in adapting to temperature extremes. [19] These proteins protect cells from the damaging effects of heat stress and help restore their function. A 2018 study found that humans exposed to chronic heat stress had increased expression of HSP70 and HSP90, which may contribute to their increased tolerance to heat. [20] However, under conditions of chronic heat stress, these protective mechanisms may be inadequate and lead to impaired cellular function.

The cardiovascular system undergoes significant changes in response to heat stress. In response to heat, peripheral vasodilation reduces circulatory resistance, which leads to an increase in heart rate and cardiac output. [21] This adaptive mechanism increases heat dissipation through sweating, but it also places additional strain on the cardiovascular system. A 2019 study found that people working in high temperatures may be at increased risk of cardiovascular disease, especially in patients with heart failure or hypertension. [22] Maintaining fluid and electrolyte balance is particularly important during heat stress. In high temperatures, water and electrolytes are lost through sweating, which can negatively affect hydration status. [23] A 2020 study found that in people living in hot climates, hormonal adaptations result in increased water and sodium retention by the kidneys. [24] The body maintains water and electrolyte balance, particularly through changes in the secretion of antidiuretic hormone (vasopressin) and aldosterone. However, in conditions of prolonged water deprivation, these adaptive mechanisms may be insufficient and dehydration may develop.

Metabolic adaptation is manifested by the regulation of energy production and expenditure in conditions of heat stress. At high temperatures, the body tends to reduce metabolic heat production, which leads to a decrease in basal metabolic rate. [25] A 2021 study found that people living in hot climates had reduced production of lactic acid and pyruvate, indicating that their energy metabolism has adapted to heat stress. [26] However, this metabolic adaptation can cause problems in conditions of limited food resources, as nutrient deficiencies may be more pronounced when the body tries to reduce energy expenditure.

Genetic and epigenetic adaptation to climate change

Genetic studies have shown that human populations living in different geographical regions have certain genetic traits that are adapted to their traditional habitats. [27] Genome-wide association studies (GWAS) conducted in the last decade have identified a number of

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genetic variants associated with adaptation to heat and humidity. For example, certain variants in the TRPM8 gene are associated with sensitivity to cold temperatures, while variants in the EDAR gene are associated with sweat gland function and heat dissipation. [28]

A large study published in 2022 compared genetic variants associated with climate adaptation in African, Asian, and European populations. [29] The study found that adaptive variants in genes regulating sweat gland function and water-electrolyte balance were more common in populations living in tropical regions. In contrast, adaptive variants in genes related to metabolic heat production and fat metabolism predominate in populations living in cold regions.

Epigenetic modifications are emerging as an important mechanism for adaptation to climate change. A 2023 study showed that heat stress can induce DNA methylation and histone modifications, which can promote adaptation by altering gene expression. [30] For example, changes in the methylation levels of genes involved in thermoregulation and energy metabolism affect an organism's ability to respond to temperature changes.

The adaptive significance of specific genes is intriguing, for example, the role of the UCP gene family in thermoregulation. The UCP1 gene, which is expressed particularly in brown adipose tissue, plays an important role in cold adaptation through heat production. [31] A study published in 2024 showed that certain variants in UCP genes may vary between populations as a result of climate-related selective pressure. Adaptation of the immune system to climate change is of particular importance, as changes in temperature and humidity can lead to the emergence and spread of new pathogens. [32] Genetic studies have shown that the distribution of immune-related genes varies among populations living in different climates. For example, adaptive variants in genes affecting the immune system are more common in regions affected by diseases that spread in warm climates, such as malaria. [33]

Food security and metabolic adaptation

Climate change is having a significant impact on food production, which in turn affects people's access to nutrients. [34] Droughts, floods, and extreme weather events can reduce agricultural yields, leading to nutrient deficiencies. A recent study published in 2025 showed that nutrient constraints can activate the body's mechanisms for regulating energy expenditure. [35]

The link between metabolic disorders such as metabolic syndrome and obesity and climate change is notable. Heat stress affects the body's energy balance and alters eating behavior. [36] A 2020 study found that people prefer foods with low energy expenditure in high temperatures, which affects their energy balance. [37]

Vitamin and mineral metabolism also play an important role in climate change adaptation. For example, vitamin D synthesis is dependent on exposure to sunlight, and the amount and duration of sunlight may change with climate change. [38] A 2021 study found that certain variants in the vitamin D receptor gene (VDR) differ between populations in relation to latitude, which may be related to adaptation to sunlight. [39]

Adaptation capacities of different populations

Studies have shown that different geographic and ethnic populations have different capacities to adapt to climate change. [40] While populations that traditionally live in warm climates have adapted to some extent to heat stress, they are also experiencing rapid climate change. A 2023 study found that populations living in traditionally cold climates may be more vulnerable to heat waves. [41] Age and gender are also important factors that influence

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adaptive capacity. For example, children and the elderly may be more sensitive to heat stress. [42] A 2022 study found that thermoregulatory responses may differ between women and men, which is related to hormonal differences and body composition. [43] Socioeconomic factors also strongly influence the ability of populations to adapt to climate change. [44] Low-income groups often lack the resources needed to mitigate the negative impacts of climate change, which can exacerbate health inequalities. A study published in 2024 showed that the health impacts of climate change may be more pronounced in the most vulnerable segments of society. [45]

Discussion

The study of the mechanisms of human homeostasis in the face of climate change is a multifaceted and complex issue. The results obtained indicate that the human body can adapt to a certain extent to climate change, but this adaptive capacity is limited and depends on various factors. [46] Physiological adaptation mechanisms, in particular thermoregulation, water-electrolyte balance and metabolic adjustments, can be effective in responding to short-term climate changes. However, long-term and rapid climate changes can test the limits of these adaptation mechanisms.

Genetic and epigenetic adaptation play an important role in the long-term response of populations to climate change. [47] Recent genome studies have clearly demonstrated the existence of adaptive genetic variants in populations living in different climates. However, the pace of modern climate change may be faster than traditional genetic adaptation, which increases the importance of epigenetic adaptation. Epigenetic modifications allow organisms to respond more quickly to environmental changes, although the long-term sustainability of this adaptation is not yet fully understood.

Differences in the adaptive capacity of different populations can lead to significant inequalities in the health impacts of climate change. [48] While populations living in traditionally warm climates may be somewhat heat-adapted, they are often more vulnerable to other aspects of climate change, such as food insecurity or the emergence of new diseases. In contrast, populations living in traditionally cold climates may be more vulnerable to heat waves.

Health systems play a key role in mitigating the adverse effects of climate change. [49] Adaptation strategies need to be implemented not only at the individual level, but also at the community and national levels. This should include environmental design, improving health services, establishing warning systems, and providing information to the population.

Future research should focus on further understanding the molecular mechanisms of adaptation to climate change, as well as on more accurate assessment of the adaptive potential of different populations. [50] A multidisciplinary approach - integrating physiology, genetics, epidemiology, ecology and public health - will be essential in addressing this complex issue.

Summary

Climate change is one of the most serious global challenges of our time, with a wide-ranging impact on the human ability to maintain homeostasis. This article analyzes the physiological and genetic mechanisms of human adaptation to climate change based on scientific data from 2015 to 2025.

From the perspective of physiological adaptation, the body seeks to maintain homeostasis by adjusting thermoregulatory, cardiovascular, water-electrolyte and metabolic systems in response to heat stress. Mechanisms such as heat-trapping proteins, sweat gland function, vasodilation, and reduced metabolic heat production play important roles in the short-term response to heat stress. However, long-term and rapid climate changes can test the limits of these adaptive mechanisms.

Genetic and epigenetic adaptations are important in the long-term response of populations to climate change. Recent genome studies have clearly demonstrated the presence of adaptive variants in genes related to thermoregulation, water-electrolyte balance, immunity, and metabolism in populations living in different climates. Epigenetic modifications, in turn, enable organisms to respond more quickly to environmental changes.

There are significant differences between the adaptive capacities of different populations, and geographical, genetic, age, gender, and socioeconomic factors contribute to these differences. While populations living in traditionally warm climates are somewhat adapted to heat stress, they are also vulnerable to other aspects of climate change, such as food insecurity and the emergence of new pathogens.

A multi-layered approach is needed to mitigate the negative impacts of climate change, including individual, community and global measures. Strengthening health systems, creating early warning systems, designing environments and educating the public are essential.

Future research should focus on further understanding the molecular mechanisms of adaptation to climate change, as well as more accurately assessing the adaptive potential of different populations. A multidisciplinary approach - integrating physiology, genetics, epidemiology, ecology and public health - will be essential in addressing this complex problem.

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