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КТ-ангиографические признаки тромбоэмболии легочной артерии: клиническое наблюдение

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Аннотация: Представлен клинический случай массивной двусторонней тромбоэмболии легочной артерии у пациентки 77 лет с развитием дыхательной недостаточности. По данным КТ-ангиографии установлены признаки значительного поражения легочного сосудистого русла и нарушения легочной гемодинамики. Представленный клинический случай демонстрирует высокую диагностическую ценность КТ-ангиографии в выявлении массивной ТЭЛА, определении распространенности поражения и оценке тяжести состояния пациента, что имеет ключевое значение для выбора дальнейшей лечебной тактики.

Ключевые слова: тромбоэмболия легочной артерий (ТЭЛА), компьютерная томографическая ангиография (КТ-ангиография), седловидная тромбоэмболия, тромбоз легочных артерий, дыхательная недостаточность.

Тромбоэмболия легочной артерии (ТЭЛА) представляет собой одно из наиболее распространенных и клинически значимых сердечно-сосудистых заболеваний, характеризующееся высокой частотой госпитализаций и существенным риском летального исхода. Смертность от которого в последние годы снижается, но заболеваемость увеличивается. Клинические проявления ТЭЛА отличаются значительной вариабельностью и могут варьировать от бессимптомного течения до жизнеугрожающего состояния. По уровню смертности ТЭЛА занимает третье место среди причин смерти госпитализированных пациентов [1], однако в последние годы данный показатель снизился благодаря внедрению более чувствительных методов диагностики и совершенствованию лечебных подходов в соответствии с современными клиническими рекомендациями. Компьютерная

томографическая ангиография с контрастным усилением считается золотым стандартом диагностики у пациентов с подозрением на острую тромбоэмболию легочной артерии в условиях отделений неотложной помощи [2].

Клинический случай. В экстренном порядке в многопрофильную больницу г. Караганды была госпитализирована пациентка 77 лет с подозрением на тромбоэмболию легочной артерии. При поступлении предъявляла жалобы одышку в покое, усиливающуюся при минимальной физической нагрузке, снижение толерантности к физической активности, эпизод потери сознания. Из анамнеза известно, что пациентка проходила лечение в условиях дневного стационара отделения микрохирургии глаза. Ухудшение состояния с появлением вышеуказанных жалоб отмечено после проведенного лечения, в связи с чем самостоятельно обратилась в приемное отделение стационара. В анамнезе перенесенное острое нарушение мозгового кровообращения.

При поступлении состояние пациентки расценивалось как тяжелое, обусловленное развитием дыхательной недостаточности. Для проведения интенсивной терапии и динамического наблюдения пациентка была госпитализирована в отделение анестезиологии, реанимации и интенсивной терапии. При объективном обследовании артериальное давление составило 100/70 мм рт. ст., частота дыхательных движений - 24 в минуту, сатурация 90% на атмосферном воздухе.

По результатам лабораторного обследования отмечалось значительное повышение уровня D-димера до 10 000 нг/мл, что в совокупности с клинической картиной позволило заподозрить тромбоэмболию легочной артерии. С целью верификации диагноза была выполнена КТ-ангиография с внутривенным болюсным контрастным усилением, позволившая подтвердить наличие тромбоэмболического поражения ветвей легочной артерии.

Согласно данным КТ-ангиографии, в просвете легочного ствола на уровне его бифуркации определяется протяженный внутрипросветный дефект контрастирования цилиндрической формы с распространением в правую и левую легочные артерии. Максимальный диаметр тромботических масс достигает 10мм. Плотность тромбоэмболических масс составляет около +110 HU. Тромбоэмболический субстрат характеризуется четкими контурами и окружен контрастным веществом по периферии, формируя типичную КТ-картину острой тромбоэмболии легочной артерии (рисунок 1).

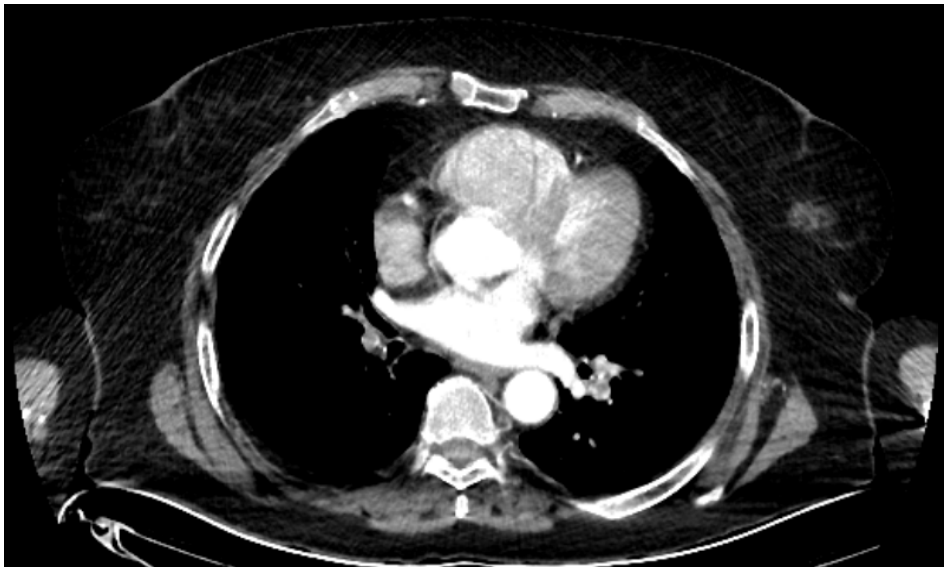

Рисунок 1. КТ-ангиография: седловидная тромбоэмболия легочной артерии на уровне бифуркации легочного ствола.

Тромбоэмболические массы локализуются в центральных отделах легочного артериального русла с вовлечением бифуркации легочного ствола и распространением на магистральные ветви обеих легочных артерий (рисунок 2). Выявленная картина соответствует седловидной тромбоэмболии (saddle pulmonary embolism), являющейся одной из наиболее тяжелых форм эмболического поражения легочного сосудистого русла.

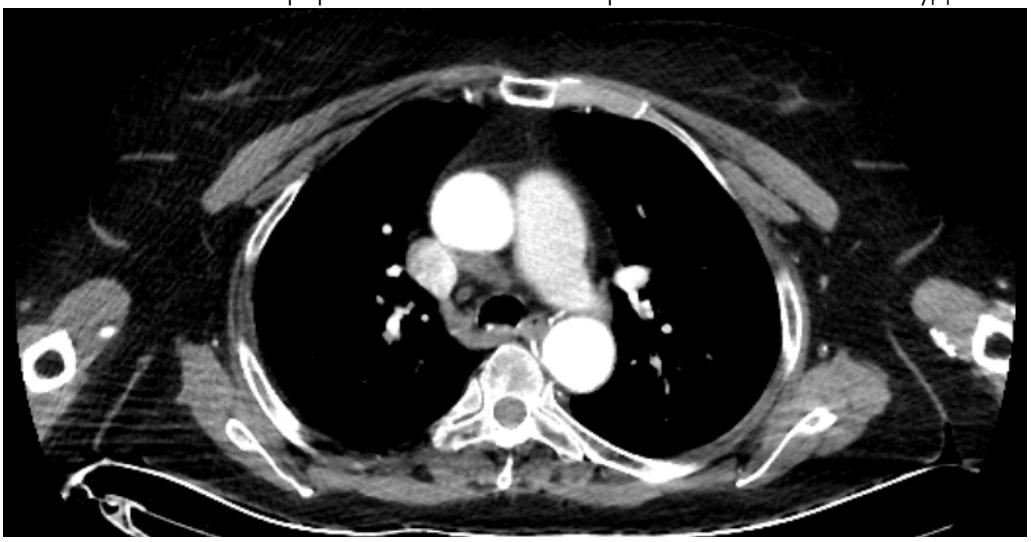

Рисунок 2. Тромбоэмболические массы в магистральных ветвях легочной артерии

Отмечается дальнейшее распространение тромботических масс в долевые и сегментарные ветви обеих легочных артерий с формированием множественных участков субтотальной и полной окклюзии сосудов различного калибра (рисунок 3).

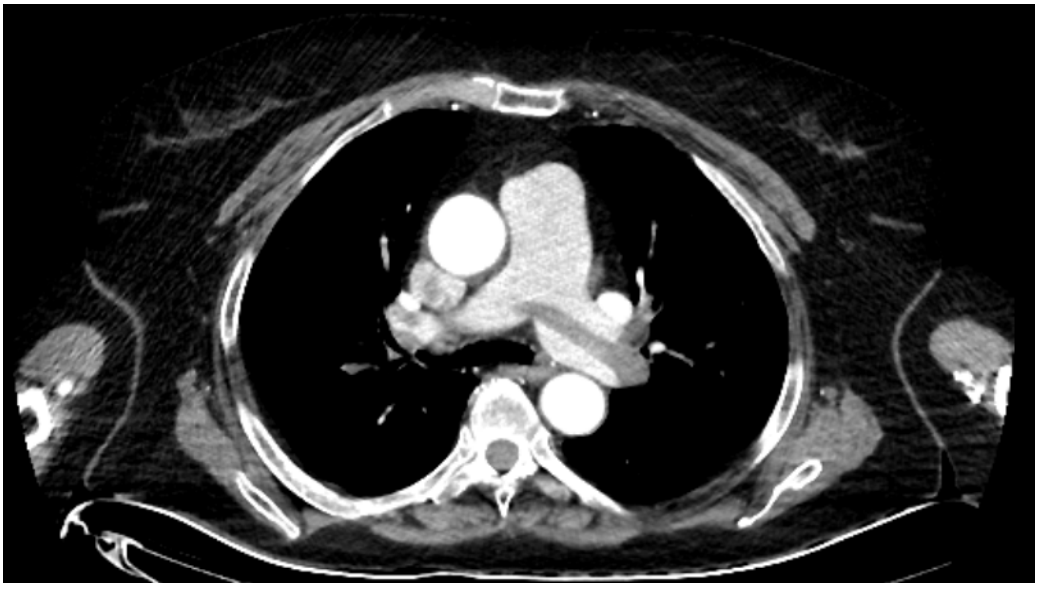

Рисунок 3. Тромботические массы в области бифуркации легочного ствола

Особое внимание обращает значительный объем поражения легочного артериального русла, включающий центральные, долевые и сегментарные сосуды обоих легких. Подобная распространенность тромбоэмболического процесса свидетельствует о высокой эмболической нагрузке и выраженном уменьшении площади функционирующего сосудистого русла малого круга кровообращения.

Легочный ствол расширен до 35 мм, что превышает общепринятые нормативные значения и может рассматриваться как косвенный признак повышения давления в системе малого круга кровообращения. Расширение ствола легочной артерии в сочетании с массивным тромботическим поражением центральных ветвей является дополнительным маркером гемодинамической значимости выявленных изменений.

При оценке органов средостения патологически увеличенных внутригрудных лимфатических узлов не выявлено. Свободная жидкость в плевральных полостях отсутствует. Просвет трахеи, главных, долевых и сегментарных бронхов сохранен, признаков компрессии, деформации или эндобронхиальных образований не определяется.

В легочной паренхиме преимущественно в базальных отделах обоих легких визуализируются линейные участки интерстициального уплотнения. Выявленные изменения имеют неспецифический характер и могут соответствовать хроническим фиброзным, гиповентиляционным либо поствоспалительным изменениям. Участков клиновидной субплевральной консолидации, характерных для инфаркта легкого, зон внутриальвеолярного кровоизлияния, а также очаговых инфильтративных изменений на момент исследования не выявлено.

Таким образом, данные КТ-ангиографии свидетельствуют о наличии массивной двусторонней тромбоэмболии легочной артерии с вовлечением бифуркации легочного ствола, правой и левой легочных артерий, а также долевых и сегментарных ветвей. Выявленные изменения соответствуют картине седловидной тромбоэмболии с высоким объемом эмболического поражения легочного сосудистого русла и признаками нарушения легочной гемодинамики.

Представленный клинический случай демонстрирует диагностические возможности КТ-ангиографии при острой тромбоэмболии легочной артерии. Метод позволил своевременно выявить массивную тромбоэмболию обеих легочных артерий, а также оценить объем поражения сосудистого русла и признаки нарушения легочной гемодинамики. Полученные данные имели решающее значение для подтверждения диагноза, определения степени тяжести заболевания и выбора дальнейшей лечебной тактики. Данный метод остается высокоинформативным методом диагностики ТЭЛА и должна рассматриваться как основной инструмент визуализации при подозрении на данную патологию.

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TOBACCO CONTROL POLICIES: A COMPARATIVE STUDY OF THE EFFECTIVENESS OF PREVENTIVE MEASURES IN CHINA AND KAZAKHSTAN

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Introduction

The relevance of the study of tobacco control policy is due to the persistently low prevalence of tobacco smoking and its negative impact on public health, as well as instability and demographic indicators.

Despite the existence of national tobacco control programs in both China and Kazakhstan, they do not always lead to the desired results. This is due to the insufficient effectiveness of preventive measures and the insufficient involvement of the state in regulating the tobacco market.

With increased anti-smoking policies at the global level, including the WHO Framework Convention on Tobacco Control, a comparative analysis of national strategies is becoming particularly relevant. It allows us to identify successful practices and identify time gaps in the implementation of tobacco control policies.

The purpose of this study is to conduct a comparative analysis of the effectiveness of preventive tobacco control policies in China and Kazakhstan in order to identify the most effective approaches and opportunities for their adaptation.

To achieve this goal, it is necessary to solve the following tasks:

1. To carry out state and preventive measures to combat tobacco smoking in China and Kazakhstan.

2. Evaluate the effectiveness of the implemented policy in terms of reducing the prevalence of smoking and raising public awareness.

The scientific novelty of this study lies in the fact that it offers a comprehensive comparative analysis of the effectiveness of preventive anti-smoking measures in China and Kazakhstan. This takes into account differences in socio-economic conditions, the level of government regulation, and the mechanisms for implementing public health policies in these countries.

Unlike previous studies, this study not only describes anti-smoking programs, but also identifies the factors that determine their practical effectiveness in reducing tobacco use and shaping public awareness.

The study also offers a new perspective on anti-smoking policy, identifying the most effective tools such as legislative restrictions, tax regulation, awareness campaigns, and preventive education programs. In addition, the authors evaluate the possibilities of applying the successful experience of China and Kazakhstan to improve national tobacco control strategies. The results obtained will help to develop practical recommendations aimed at improving the effectiveness of preventive measures in the field of public health.

Literature review

Among Chinese experts, Teh-Wei Hu made a significant contribution to the study of the problem. In his article “WHO Framework Convention on Tobacco Control in China: barriers, challenges and recommendations. Glob Health Promot”, he analyzes the implementation of the WHO Framework Convention in China.

The author concludes that, despite the formalization of international regulations, the pace of development of anti-smoking measures is slowing down due to institutional, economic and social barriers, including the influence of the state tobacco industry. This points to a key problem – the gap between the policy and its actual implementation[1].

The influence of Chinese authors Yang G, Wang Y, Wu Y, Yang J, Wan X. where they examines the scale of the tobacco epidemic and the effectiveness of government policy[2].

The authors notes that there are more than 300 million smokers in China, and the high prevalence of smoking among men poses a serious threat to public health.

According to the authors, possible measures such as the introduction of taxes, bans, and public awareness have potential, but require a strengthened and systematic approach to achieve innovative smoking reduction.

A study was conducted in Kazakhstan, the results of which were presented in the article “The Current State of MPOWER Policies in the Republic of Kazakhstan: Data from the Global Adult Tobacco Survey”, published by Shynar Abdrakhmanova and Zarina Keruenova in 2019[3].

As part of the study, the authors analyzed the effectiveness of the six-day anti-smoking Policy (MPOWER) based on data from the global GATS survey. As a result, it was revealed that progress has been made in Kazakhstan in the field of public awareness and product labeling. However, major issues such as the availability of cigarettes, exposure to advertising, and secondhand smoke remain relevant.

The authors concluded that MPOWER's policy is partially effective, but requires increased control and reduced availability of tobacco products.

In the article “Prevalence and characteristics of tobacco use among adults in Kazakhstan: A cross-sectional National Survey”, published in 2025, Ibrayeva A, Shoranov M, Aipov R, Katarbayev A, Tanabayeva S, Fakhradiyev I. conducted a study that showed that, despite the control measures taken, the smoking rate in Kazakhstan remains high and poses a serious problem for public health[4]. The authors concluded that it is necessary to further develop prevention programs, strengthen public policy and develop targeted measures for various groups of the population.

Thus, the analysis shows that comprehensive tobacco control measures are being implemented in Chinese literature and in Kazakhstan. However, the key problems are the insufficient effectiveness of policy implementation, the high prevalence of smoking in society, and the need to strengthen tax, legislative, and educational measures.

Research shows that comprehensive measures combining strict regulation and active prevention are the most effective. Their practical implementation remains the main task.

Research methodology

The methodological basis of the research is based on a comparative and interdisciplinary approach to the analysis of government policy on tobacco control in China and Kazakhstan. The study aims to identify the effectiveness of preventive measures applied in these countries, as well as to identify factors influencing the reduction in the prevalence of tobacco smoking and related diseases.

The research plan includes several sequential steps. At the first stage, an analysis of international and national regulatory legal acts regulating the anti-smoking policy is carried out. In particular, the provisions of the World Health Organization Framework Convention on Tobacco

Control, national health programs, laws banning smoking in public places, tax instruments and measures regulating the tobacco market are being considered.

At the second stage, a comparative analysis of statistical data on the prevalence of smoking, mortality and morbidity associated with tobacco use in China and Kazakhstan is carried out.

The third stage evaluates the effectiveness of preventive and institutional measures aimed at combating smoking. In particular, educational programs, medical mechanisms to support smoking cessation, and administrative control over compliance with legislation are analyzed.

The official statistical materials of the World Health Organization, the World Bank, the Ministry of Health of the Republic of Kazakhstan, and the National Health Commission of China were used as data sources for the study. The results of the international Global Adult Tobacco Survey (GATS), scientific articles published in international peer-reviewed journals, and analytical reports in the field of public health for the period from 2020 to 2025 were also taken into account.

The time frame of the study covers the period from 2020 to 2025, which allows us to analyze current trends in the development of anti-smoking policy, assess the impact of new restrictive measures and the dynamics of tobacco smoking prevalence after the strengthening of global public health initiatives.

The study uses methods of comparative analysis, content analysis of regulatory documents, statistical analysis of international data, as well as elements of an institutional approach that allow for a comprehensive analysis and assessment of the impact of the state management system and socio-cultural factors on the effectiveness of anti-smoking policy. This comprehensive approach allows for a detailed study and identification of both similarities and differences between China and Kazakhstan in the context of tobacco control.

Results

The first stage of the study included an analysis of government tobacco control policies in Kazakhstan and China, including legislative measures, prevention programs, and institutional regulatory mechanisms. The analysis was based on the provisions of the World Health Organization Framework Convention on Tobacco Control, national health laws, as well as government tobacco prevention programs.

In Kazakhstan, the fight against smoking is carried out through a system of legislative restrictions, including a ban on smoking in public places, an increase in excise taxes on tobacco products, restrictions on tobacco advertising and information and prevention campaigns. In accordance with the Code of the Republic of Kazakhstan “On the Health of the People and the Healthcare system”, there is administrative responsibility for violating anti-smoking legislation. Additionally, the Ministry of Health and the Ministry of Education are implementing educational programs aimed at preventing smoking among young people and adolescents[5-6].

In China, the anti-smoking policy is more centralized and implemented through government programs aimed at limiting smoking in public places, developing educational campaigns and creating “tobacco-free schools”. However, the specificity of the Chinese system lies in the existence of a state tobacco monopoly, which creates certain contradictions between the economic interests of the state and the tasks of public health[7-8].

The following is a brief comparative summary of the main directions of anti-smoking policy in Kazakhstan and China, which makes it possible to visually compare the key institutional and regulatory measures implemented in both countries (in table 1).

Table 1. Comparison of the main tobacco control measures in Kazakhstan and China

Indicator	Kazakhstan	China
Smoking ban in public places	Implemented at the national level	Mainly implemented in major cities
Tax policy	Increase in excise taxes	Gradual increase in excise taxes
Educational programs	Implemented in schools and universities	Large-scale government campaigns
Medical support for smoking cessation	Limited availability	Developed through major clinical institutions
Enforcement of laws	Inconsistent	Varies by region
State tobacco monopoly	Not present	Exists

Source: compiled by author

The results of the first stage of the study allow us to conclude that the anti-smoking policy in Kazakhstan and China is developing within the framework of different institutional models. This directly affects the nature and effectiveness of the measures being implemented.

Although both countries are guided by the standards of the WHO Framework Convention on Tobacco Control, their practical implementation differs significantly. In particular, the level of centralization, control mechanisms and the role of the state in regulating the tobacco market differ.

In Kazakhstan, the fight against smoking is mainly carried out using regulatory and fiscal methods. The legally established ban on smoking in public places, the increase in excise taxes and the restriction of tobacco advertising form the basis of regulation.

It is also worth noting the important intersectoral programs implemented by the Ministry of Health and the Ministry of Education. These programs are aimed at developing a healthy lifestyle among young people.

There is a key problem – inefficiency of law enforcement practice. It is not always possible to ensure stable monitoring of compliance with existing standards, which reduces their real impact on people's behavior.

In China, on the contrary, the anti-smoking policy is characterized by a high degree of centralization and the active participation of government agencies. The country pays great attention to the creation of "tobacco-free schools," mass information campaigns are conducted, and smoking in public places is restricted.

The peculiarity of the Chinese model is that there is a state tobacco monopoly in the country. This creates a structural contradiction between the economic interests of the state and the goals of public health. Because of this, despite the scale of preventive measures, the potential for significant reductions in tobacco use may be limited.

Comparative analysis shows that Kazakhstan has a clearer regulatory framework for smoking bans, but faces difficulties in their implementation and control. At the same time, China has a more developed and centralized preventive infrastructure, but is influenced by institutional constraints caused by economic dependence on the tobacco industry.

Thus, the first stage of the study confirms that the effectiveness of an anti-smoking policy depends not only on the availability of legislative measures, but also on their practical implementation at the institutional level, the level of interdepartmental coordination and structural constraints in the economic system.

At the second stage of the study, statistical data related to the prevalence of tobacco smoking, mortality and morbidity caused by tobacco use were analyzed.

In Kazakhstan, smoking is becoming one of the main causes of premature mortality. According to the World Bank and WHO, about 13.17% of all deaths in the country are related to

tobacco exposure, making it one of the main factors affecting the health of the adult population[9].

About 17,000 people die each year from smoking-related diseases such as lung cancer, cardiovascular and chronic respiratory diseases. At the same time, it is predicted that among current smokers, more than 1.4 million people may face premature death if more serious tobacco control measures are not taken[10].

In Kazakhstan, approximately 16-19% of the adult population smokes. Among men, this figure is significantly higher – about 30-40%, while among women it is less than 10%. Despite the introduction of smoking bans in public places, increased excise taxes, and various campaigns, the effectiveness of the policy remains limited due to insufficient safety controls and high availability of tobacco products.

The situation in China is even more serious. The country is the largest tobacco consumer in the world, and more than 300 million people smoke, which puts a significant strain on the health system (according to WHO and national research). Chinese studies show that smoking causes millions of deaths annually, and the smoking rate among men remains extremely high, exceeding 50% in some age groups (according to GATS China).

The following are comparative epidemiological indicators of the prevalence of tobacco smoking and its consequences in Kazakhstan and China, allowing us to assess the scale of the problem and the key differences between the two countries(table 2).

Table 2. Comparative indicators of smoking prevalence

Indicator	Kazakhstan	China
Adult smoking prevalence	16–19%	Over 25%
Smoking among men	30–40%	Over 50%
Annual smoking-related mortality	17,000 people	Millions of deaths
Main diseases	Lung cancer, COPD, stroke, ischemic heart disease	Lung cancer, COPD, cardiovascular diseases
Key challenges	Weak enforcement of laws	State tobacco monopoly

Source: compiled by author

The results of the study demonstrate that, despite the preventive measures being taken, the smoking rate in both countries remains significant. Cultural traditions, widespread availability of tobacco products and insufficient supervision of compliance with legislation play an important role.

As part of the third stage of the study, the effectiveness of measures aimed at tobacco prevention and control was assessed.

In Kazakhstan, preventive measures are carried out at the level of education, healthcare and the state[11]. Classes on healthy lifestyle formation are held in schools, events dedicated to World No Tobacco Day are organized, and information campaigns aimed at combating the use of electronic cigarettes and vapes are being conducted. There are prevention rooms in medical institutions, but smoking cessation and nicotine replacement therapy programs are still not widely available.

China has a more extensive system of smoking prevention measures, which includes centralized educational programs, medical consultations, and the creation of smoke-free public spaces[12]. However, the high level of social acceptance of smoking among men and the influence of the state monopoly on the production and sale of tobacco products reduce the effectiveness of these measures.

Below is a comparative summary of the effectiveness of preventive tobacco control measures in Kazakhstan and China, reflecting differences in the level of implementation of educational, medical and institutional programs(in table 3).

Table 3. Effectiveness of tobacco control preventive measures

Indicator	Kazakhstan	China
School-based prevention	Implemented unevenly	Large-scale government programs
Medical support	Limited accessibility	Developed in major urban hospitals
Enforcement of smoking bans	Partially effective	Weak at local level
Social perception of smoking	Gradually decreasing	Remains high
Policy effectiveness	Moderate	Limited due to institutional factors

Source: compiled by author

The results of the table demonstrate that the best result is provided by an integrated approach to the fight against smoking, which includes:

a strict legal framework;

high taxes on tobacco products;

permanent work on smoking prevention in educational institutions;

affordable medical care for quitting smoking.

In both countries, there is a gap between formal measures and their actual application, which reduces the overall effectiveness of government tobacco control policies.

Discussion

The results obtained need to be considered in the context of international research, which shows that the effectiveness of an anti-smoking policy depends not only on the availability of formal legislative measures, but also on the quality of their implementation, the sustainability of institutional mechanisms and the level of social support.

In this context, the differences between Kazakhstan and China reflect two different regulatory models. Kazakhstan has a relatively developed regulatory framework and prevention programs are being actively implemented, but their effectiveness is limited by weak control over implementation and uneven implementation in different regions. In China, despite the high centralization and scale of government initiatives, there remains a structural contradiction associated with the tobacco monopoly and the social normalization of smoking, which reduces the overall effect of the measures.. These conclusions are consistent with the results of research by the World Health Organization, which demonstrate that the most stable reduction in the number of smokers is achieved only with an integrated approach that includes strict regulation, high taxes, access to smoking cessation assistance, and consistent public oversight. At the same time, if there is a significant gap between policy and practice, even well-designed programs may not be effective.

Conclusion

A comparative study of anti-smoking policies in China and Kazakhstan revealed that this problem still poses a significant threat to public health in both countries, despite the existence of appropriate laws and preventive measures.

The main conclusion of the study was that the effectiveness of an anti-smoking policy depends not only on the completeness of the legislative framework, but also on the quality of its implementation, the level of control and coordination of actions of various state institutions.

The analysis showed that in Kazakhstan, despite the existence of a relatively strong regulatory framework and preventive initiatives, there is a problem with insufficient control over their implementation. At the same time, in China, large-scale government programs face structural factors such as the influence of the tobacco monopoly and the steady social

normalization of smoking, which prevents the achievement of a sustainable reduction in smoking rates.

As a result, in both countries there is only partial success of the measures taken without a steady decrease in the number of smokers.

From the point of view of political consequences, the most effective measures are:

1. Strengthening control over compliance with legislation.
2. Increasing the tax burden on tobacco products.
3. Increasing access to smoking cessation programs.
4. Strengthening intersectoral cooperation in the field of public health.

Only an integrated approach to the implementation of these measures can significantly improve the effectiveness of the anti-smoking policy in the long term.

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13.

COMPARATIVE ANALYSIS OF PRIMARY HEALTH CARE SYSTEMS IN CHINA AND KAZAKHSTAN: CHALLENGES, PROSPECTS, AND THE POTENTIAL FOR INTEGRATING BEST PRACTICES

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Introduction

The importance of the study is due to the increasing role of primary health care (PHC) as the foundations of the sustainability of national health systems. With the growth of chronic diseases, the aging of the population and the need to increase the availability of medical services, primary health care is becoming a key factor determining the effectiveness of the entire healthcare system.

In recent years, China and Kazakhstan have been carrying out large-scale reforms aimed at the primary health system. However, their development models differ. China is actively implementing integrated and digital mechanisms for the organization of primary health care, while Kazakhstan is developing a multidisciplinary and socially oriented model of primary care based on family medicine and health system reform programs.

Comparative analysis of data systems is becoming especially relevant for identifying problems, evaluating the effectiveness of reforms, and opportunities for mutual learning.

The purpose of the study is to conduct a comparative analysis of primary health care systems in China and Kazakhstan. Identify problems, identify ways to solve them, and consider applying best practices to improve the effectiveness of national health systems.

To achieve this goal, we have to solve the following tasks:

1. To study the theoretical and organizational foundations of PHC systems in China and Kazakhstan.
2. To identify the main problems faced by the medical sector in modern countries.
3. Compare the models of reform and management approaches in the field of primary health care.
4. Identify development prospects and areas for applying best practices.

The scientific novelty of this study lies in a comprehensive comparative analysis of primary health care (PHC) systems in China and Kazakhstan. The emphasis is not only on structural features, but also on managerial, digital and organizational principles that can be adapted to national conditions.

The study systematizes the prospects for the development of best practices in both countries in the context of modern challenges in the field of healthcare.

This study is aimed at deepening the transformations in the first aid system and creating an analytical framework for monitoring health policy in Kazakhstan and other countries with economies in transition.

Literature review

Scientific research on the development of primary health care (PHC) analyzes a key element in improving the effectiveness of health systems, especially in countries undergoing reform.

Special attention is paid to the comparative analysis of the models of Kazakhstan and China, where approaches to the organization of primary care differ.

Almaz Sharman's work describes in detail the Kazakh approach to PHC[1]. The author substantiates the need to move from a biologically oriented model to a personalized, technological and preventive first aid system. He notes the problems of insufficient funding and a weak focus on prevention in Kazakhstan, despite reforms in the field of family medicine and digitalization.

The main conclusion of the study is that the development of primary health care should be based on advanced technologies, communities and a personalized approach to increase the sustainability of the healthcare system.

In the course of a study conducted by the World Health Organization (the Kazakhstan case) and presented in the political and economic analysis of the reform, it was found that Kazakhstan has been actively implementing the multidisciplinary team model in primary health care (PHC) since the 1990s[2].

The team of authors notes that the reforms are based on changes in financing, management and digitalization. There are problems of uneven access to services and staff shortages. The conclusion of the study is that Kazakhstan has implemented a systemic transformation of PHC, but further consideration of management and personnel principles is required to achieve the result.

The Chinese experience of PHC organization is presented in studies on the quality of primary health care and the factors influencing its effectiveness.

A study conducted by Chinese authors such as Zhang K., Wang S., Wang E., and others shows that the quality of primary health care in China varies significantly depending on the region[3]. The main problems are the uneven distribution of resources, insufficient qualifications of personnel related to natural phenomena, as well as the overloaded infrastructure of medical institutions.

The authors of the study conclude that in order to increase the effectiveness of the system, it is necessary to ensure more even financing and support for the first level of healthcare in all territories.

Cai, Chang, et al. shows that the reforms of primary health care (PHC) are aimed at strengthening the family medicine system and reducing the burden on the secondary level of healthcare[4].

The conclusions of these studies note that digitalization and integration of medical services are already increasing accessibility, but there are still problems with workers' trust in the first link and insufficient consistency between levels of medical care.

Recent scientific papers published between 2024 and 2025 indicate that primary health care (PHC) systems Kazakhstan and China are undergoing significant changes due to financial reforms, the introduction of digital technologies, and efforts to improve the availability and quality of services.

According to the World Health Organization (WHO) report “Health Systems in Action: Kazakhstan 2024”, the introduction of the Compulsory Social Health Insurance (CSHI) has become a key step in reforming the health system. This reform is aimed at improving the financial security of the population, increasing the effectiveness of public financing and strengthening primary health care as the first level of the healthcare system.

The report emphasizes that the introduction of SMS has made it possible to reduce personal expenses of citizens and improve access to primary health care services. However,

despite this, problems remain in the healthcare system related to regional differences and staff shortages, especially in rural areas.

The information obtained as a result of the analysis of progress in the field of healthcare financing in Kazakhstan (2025) suggests that the use of a two-tier financing system – a government-guaranteed package of benefits and a social health insurance fund - has contributed to more efficient use of resources and expanded coverage of services.

Despite this, there are problems related to inefficient procurement mechanisms, insufficient cost recovery and fragmentation of funding flows, which negatively affect the quality and sustainability of primary health care[5].

Recent scientific papers published in the Central Asian Journal of Global Health between 2024 and 2025 provide important information on the transformation of primary health care in Central Asia.

Researchers such as Qumar and Alaidarova draw attention to the fact that Kazakhstan is moving towards a model of primary health care that is patient-centered and supported by digital technologies[6],[7]. Electronic medical records, telemedicine, and integrated healthcare systems are actively used within this model.

These studies also point to problems that still exist. Among them are the uneven development of digital infrastructure, the shortage of medical personnel, and differences in the quality of care between urban and rural medical institutions.

Additional international studies have also identified similar trends in China's primary health care. The reforms focus on strengthening local health centers, expanding the “family doctors by contract” model, and introducing advanced digital platforms to manage patient flow.

Research, including the work of Kumar and others conducted in 2024-2025, shows that China is successfully applying a centralized and technology-oriented approach to increase efficiency and reduce the burden on hospitals. Problems remain related to public confidence in the primary health care system and regional disparities between the developed eastern provinces and the less developed western regions.

The study of the materials allows us to conclude that Kazakhstan and China are striving to introduce modern models of primary health care. These models involve financial transformation, the integration of digital technologies and the strengthening of the role of primary health care.

Both systems still face challenges related to ensuring equal access to medical care, staffing shortages, and sustained implementation of reforms. This creates the conditions for conducting a comparative analysis and identifying successful practices that can be used in both countries.

An analysis of Kazakh and Chinese studies shows that both countries are actively reforming the PHC system, but using different approaches. Kazakhstan focuses on multidisciplinary teams, digitalization and the development of family medicine, while China focuses on scaling access, removing traditional and digital platforms.

A common problem is the uneven quality of services and the shortage of staff. Both experiences demonstrate a high potential for mutual exchange practices, especially in the field of digital technology and first-line organization.

Research methodology

Within the framework of this study, two main methods of scientific analysis were used: the case method and the comparative method. These methods have made it possible to comprehensively study the primary health care system in China and Kazakhstan.

The case study method was used to study in detail the models of PHC organizations in individual countries. The choice of objects for this comparative study was based on the principles of representativeness and structural diversity. In Kazakhstan, megacities such as Almaty and Astana were chosen because they are home to the country's largest multidisciplinary primary health care organizations and have the highest level of digitalization of healthcare and the

implementation of reforms. Additionally, rural outpatient clinics were included to assess differences in access to medical care and staffing. In China, Beijing and Shanghai were chosen because of their well-developed community-based healthcare systems, extensive digital integration, and the introduction of "family doctors by contract" programs. Rural district health centers were included to assess the regional disparity between the eastern and western provinces. This comparative approach made it possible to analyze both highly developed urban primary health care systems and less well-resourced rural health facilities in both countries.

The use of the case method allowed us to identify typical problems in each country, such as regional changes in China or the lack of a preventive focus in Kazakhstan. The unique management solutions used in each system were also identified.

The comparative method is used to identify similarities and differences in the PHC models of the two countries. Based on the collected data, an analysis of key parameters is carried out, such as organizational structure, accessibility of medical services, the level of digitalization, management efficiency and quality of medical care.

This method allows you to determine which elements of the system are most effective and can be adapted in another country. The comparative analysis reveals common problems such as staff shortages and uneven access to services, as well as differences in strategies such as centralization and digitalization in China and family medicine reform in Kazakhstan.

Results and discussion

The results of the study of the primary health care system (PHC) In Kazakhstan and China, the results were obtained as a result of a thorough analysis of various sources and empirical data. The research is based on official reports from the Ministry of Health, analytical materials from international organizations such as the World Health Organization, as well as statistical data and the results of scientific publications on PHC reforms in modern countries.

As part of the study on Kazakhstan, typical primary health care organizations were considered, which are located at different levels and in different regions of the health system. Among them are urban polyclinics, such as large multidisciplinary polyclinics in Almaty and Astana, rural outpatient clinics and family health centers.

Special attention was paid to institutions that participate in government digitalization programs. These institutions use electronic medical records, appointment systems, and dental consultations in electronic form.

The study included a study of the burden on general practitioners, an analysis of the staff, an assessment of the availability of services to the public, as well as a study of the level of preventive work, such as medical examinations and screening examinations.

The examination of particular urban primary healthcare systems revealed significant variations in the execution of healthcare reforms across the chosen cities in Kazakhstan and China. By considering the cases at the city level, we were able to discern not only national trends but also distinctive institutional practices and regional disparities within each healthcare system.

In Astana, the modernization of primary healthcare has been closely linked to the expansion of multidisciplinary family health centers and the implementation of compulsory social health insurance mechanisms. Astana is one of the most advanced cities in Kazakhstan in terms of healthcare digitalization, with electronic medical records, integrated patient databases, and online appointment systems. However, despite these advancements, primary healthcare organizations in Astana continue to face significant workloads for general practitioners. According to healthcare statistics and regional estimates, the average number of patients per general practitioner in large urban polyclinics is approximately 2,200-2,500, far exceeding recommended workload standards. This workload limitation affects consultation time and the effectiveness of preventive care. The shortage of general practitioners in some urban facilities is estimated to be 15-20% of staffing requirements, contributing to physician burnout and longer waiting times for patients[8].

In Almaty, the primary healthcare institutions exhibit a higher level of integration between primary and specialized medical services due to the presence of large multidisciplinary medical organizations. However, the rapid urbanization and migration from rural areas have significantly increased the demand on urban polyclinics. The implementation of compulsory social health insurance has expanded the range of available consultations, preventive examinations, and laboratory diagnostics, further increasing the number of patients visiting PHC facilities. Despite the active implementation of telemedicine and electronic prescription systems, disparities in healthcare accessibility persist between central and peripheral districts of the city.

The upgrading of primary healthcare in Kazakhstan has been bolstered by substantial government funding for rural healthcare infrastructure. According to official government data, over 646 new rural healthcare facilities, including outpatient clinics, feldsher-obstetric stations, and medical posts, have been constructed as part of the national program to modernize rural healthcare. This project is anticipated to enhance healthcare accessibility for approximately one million rural residents and narrow the gap in access to medical services across different regions.

A comparison of these data made it possible to identify the main problems: the shortage of medical workers in rural areas, the excessive burden on specialists and the low effectiveness of preventive measures.

As part of the China study, special attention was paid to the work of community Health centers in large cities such as Beijing and Shanghai, as well as rural clinics and Township Health Centers.

The researchers studied institutions that were integrated into digital healthcare platforms, including electronic medical record systems and telemedicine. They analyzed such aspects as the availability of primary care, the distribution of patients between the levels of the healthcare system, the level of public confidence in family doctors, as well as the effectiveness of “contract family doctors” programs.

Regional differences were also considered, in particular, a comparison of more developed eastern regions with less well-off western territories of China.

Thus, the results of our study are based on a comparison of data obtained from different types of primary care facilities in the two countries. We analyzed both urban and rural primary health care (PHC) organizations, which allowed us to obtain a representative picture of their functioning.

The application of the case method provided a deep understanding of the internal structure and problems of each system. And thanks to the variety of medical institutions studied, we were able to identify both general national trends and regional features of primary care development.

The examination of the situation in Beijing uncovered a highly centralized and technologically advanced model for managing primary healthcare. Beijing has established a vast network of community healthcare facilities that serve as gatekeepers within the healthcare system. According to official city statistics, by 2023, Beijing had 364 community health service centers and 1,636 community health service stations, employing approximately 45,700 healthcare professionals. During the same period, the number of visits to community healthcare facilities increased by 28.2% compared to the previous year, indicating a growing demand for primary healthcare services[9].

A unique aspect of Beijing's primary healthcare system reform is the widespread adoption of family doctor contract services. According to official statistics, approximately 42% of Beijing's permanent residents currently have family doctor contracts, with coverage for elderly citizens and patients with chronic conditions exceeding 90%. The expansion of these contracts has enhanced the continuity of care and improved communication between community health centers and tertiary hospitals. Additionally, Beijing has implemented unified digital platforms for referrals and

appointments, allowing primary healthcare providers to more effectively coordinate consultations with higher-level hospitals.

In Shanghai, the implementation of PHC reform is a leading example of healthcare digitalization in Asia. Shanghai has successfully integrated electronic health records, mobile healthcare platforms, telemedicine systems, and AI-powered appointment technologies into its community healthcare services.

According to the Shanghai Municipal Health Commission, approximately 44% of permanent residents have signed up for family doctor contracts, and among the elderly and patients with chronic conditions, the coverage rate has reached 84%. Currently, more than 11 million residents are enrolled in the contracted family doctor system[10].

Shanghai has also made substantial advancements in chronic disease management through the integration of digital monitoring systems for patients with hypertension and diabetes. Research suggests that the implementation of unified electronic referral systems and digital patient management platforms has reduced outpatient waiting times by approximately 30-40% in several community healthcare facilities.

However, despite these technological achievements, the Chinese primary healthcare system still faces institutional issues related to public trust. Many patients still prefer to seek specialized consultations directly at secondary and tertiary hospitals, which undermines the gatekeeping role of community health centers and contributes to hospital overcrowding.

The comparative study reveals that Kazakhstan and China have chosen distinct approaches to the development of their healthcare systems. In Kazakhstan, the focus is on patient-centered family medicine, ensuring continuity of care, and making healthcare services accessible to all. In contrast, China emphasizes digital governance, centralized management, and the ability to scale up healthcare systems.

Despite these differences, both countries face similar structural issues, such as a shortage of medical personnel, disparities between urban and rural areas, the growing prevalence of chronic diseases, and the increasing burden of aging populations.

The results indicate that the fusion of supplementary approaches could substantially enhance the resilience and efficacy of primary healthcare systems in both nations. Kazakhstan could learn from China’s approach to digital healthcare infrastructure, centralized referral systems, and the integration of telemedicine. Conversely, China could strengthen public confidence and a preventive approach to primary healthcare by incorporating aspects of Kazakhstan’s family medicine model, which emphasizes long-term relationships between physicians and patients and the continuity of care.

Kazakhstan's healthcare system has been the introduction of the compulsory social health insurance system, which has been fully operational since 2020.

This financing model was developed with the aim of creating a more stable, fair, and socially oriented healthcare system in which responsibility for paying for medical services is shared between the State, employers, and citizens.

Unlike the previous system, where the budgetary approach prevailed, the Incorporate Social Health Insurance provided an additional source of funding for primary health care (PHC), which significantly improved both the availability and quality of medical services.

First of all, the introduction of compulsory medical insurance has led to an increase in the volume of medical care available to the population at the primary health care (PHC) level. Due to the increased funding, the list of consulting and diagnostic services, preventive examinations and screening programs has been expanded.

Now the population can get access to specialist consultations, laboratory diagnostics and dynamic monitoring of chronic diseases without significant direct costs. It is especially important that the introduction of compulsory medical insurance has created financial incentives for early

detection of diseases and follow-up of patients, which has contributed to strengthening the preventive direction in the healthcare system.

The compulsory health insurance system has also increased the importance of primary health care (PHC) as a patient's first contact with the healthcare system. As part of the reform, a model of family medicine was introduced, based on the attachment of the population to general practitioners. This allowed for more continuous medical monitoring, improved coordination between different levels of medical care, and reduced the number of unjustified calls from citizens to hospitals and specialized centers. Thus, PHC began to perform not only a curative, but also a coordinating function in the healthcare system.

Compulsory Social Health Insurance has made an important contribution to improving the quality of medical services. Additional financial resources have enabled the introduction of modern digital technologies such as electronic medical records, electronic appointment systems, and telemedicine consultations. These innovations have contributed to more effective patient flow management, reduced waiting times, and improved control of chronic diseases.

The has introduced payment mechanisms for medical organizations based on the results of their activities. This created incentives to improve the quality of care and preventive work, which in turn improved the overall quality of medical care.

Despite the positive impact of the Incorporate Social Health Insurance, significant structural problems remain in the system. One of the most acute is the uneven access to medical services between urban and rural areas.

In large cities such as Almaty and Astana, the population has the opportunity to use modern medical facilities and digital services. At the same time, there is a shortage of general practitioners in rural areas, limited diagnostic infrastructure and a low level of medical facilities.

These factors reduce the effectiveness of the implementation of the Incorporate Social Health Insurance principles at the regional level, which requires further attention and efforts on the part of the state.

After the Compulsory Social Health Insurance, the availability of medical services has increased significantly, which has led to an increased burden on primary health care (PHC) doctors.

With the growing flow of patients and the shortage of medical personnel, especially general practitioners and family doctors, specialists are experiencing an overload. This, in turn, negatively affects the quality of consultations, reduces patient admission time and limits opportunities for full-fledged preventive work. The shortage of medical personnel is particularly acute in rural and remote regions of the country.

The effectiveness of incorporate Social Health Insurance largely depends on the level of digital integration of medical institutions and the effectiveness of system management. Despite significant progress in the development of e-health, differences in the level of digital technology adoption remain between regions. This leads to uneven access of the population to modern medical services and affects the overall effectiveness of the primary health care system.

Thus, the incorporate Social Health Insurance has become a key factor contributing to the transformation of primary health care in Kazakhstan. This financing model has made it possible to strengthen the financial stability of the healthcare system, improve citizens' access to medical services, and increase the focus on disease prevention.

Nevertheless, unresolved personnel, infrastructure and regional problems remain on the way to further development of the system. This indicates the need for comprehensive structural reforms aimed at reducing territorial inequality, strengthening human resources and further digitalization of healthcare.

The introduction of compulsory social health insurance system has helped strengthen the role of primary health care organizations as the first link in the interaction of the population with the healthcare system. Despite the positive aspects related to financial accessibility, systemic

problems remain, such as the disparity in access between urban and rural areas, the overload of general practitioners and the shortage of staff in remote regions.

The compulsory social health insurance model reflects Kazakhstan's transition to a more sustainable and patient-oriented healthcare financing system.

In Kazakhstan, there is a problem of limited access to specialized specialists and diagnostic services in rural outpatient clinics. Patients are forced to contact district or regional centers, which leads to an increase in the time required to receive care. Despite the introduction of telemedicine, its use is limited due to infrastructural and personnel problems.

China has a system of “contract family doctors” in urban community health centers. Residents sign a contract with a primary care doctor and receive a basic package of medical services. This model helps to reduce the burden on hospitals of the second and third levels. The level of public confidence in such doctors remains insufficiently high, and patients often bypass the primary care.

Within the framework of this study, a case related to the digital integration of medical services in large cities of China was considered. As part of this case, the practice of using electronic platforms for making appointments, maintaining medical data, and referring patients between system levels was analyzed.

The results of the study showed that digitalization significantly improves the efficiency of patient flow management and reduces waiting times. However, this process also increases the gap between developed and less well-off regions, where such technologies are less implemented.

The analysis of this case revealed four specific situations:

1. Overload of doctors in urban polyclinics in Kazakhstan.
2. Limited availability of medical care in rural regions of Kazakhstan.
3. Lack of trust in family doctors in China.
4. High efficiency of digital solutions in Chinese cities.

These cases form the empirical basis for subsequent comparative analysis and allow us to determine the areas of borrowing best practices.

A comparative analysis of PHC approaches in Kazakhstan and China shows that the differences between these countries are not limited to organizational aspects. They also affect system management.

In Kazakhstan, the healthcare system is patient-oriented, which is reflected in the development of family medicine and ensuring territorial accessibility. This country has problems with a shortage of staff and limited resources, especially in rural areas.

In China, the emphasis is on system scalability, digitalization, and centralized patient flow management. This makes it possible to increase efficiency, but it can lead to problems with trust in primary care and regional inequality.

Comparing specific cases allows us to identify the most effective elements of each system that can be adapted as part of the integration of best practices(table 1).

Table 1 – The comparative analysis

Factor	PHC in Kazakhstan	PHC in China
Organizational structure	Family health centers, polyclinics, rural outpatient clinics; focus on general practitioners	Community health centers, contract-based family doctor system, strong role of the state
Accessibility of healthcare services	High in urban areas, limited in rural regions; dependent on infrastructure	High in cities due to scalability, but significant regional disparities
Level of digitalization	Implementation of electronic systems and telemedicine, but uneven development	High level of digitalization, integrated patient management platforms
Management efficiency	Limited due to physician overload and staff shortages	High due to centralized management and digital solutions
Quality of healthcare	Depends on physician workload; strong in long-term patient monitoring	Higher in cities; weaker in rural areas due to unequal resource distribution
Key problems	Physician overload, staff shortages, weak preventive care	Low trust in primary care, regional disparities, hospital overload
Strengths	Patient-centered approach, development of family medicine	Digitalization, scalability, efficient patient flow management

Source: compiled by author on the data [11-14]

The comparative analysis presented in the table demonstrates that the primary health care systems in Kazakhstan and China are developing in different directions, reflecting the specifics of the national health strategies of these countries.

Kazakhstan adheres to a more patient-oriented model based on the development of family medicine and long-term patient monitoring. However, its effectiveness is hampered by the high workload on doctors and staffing shortages, especially in rural areas.

At the same time, China has made significant strides in the field of digitalization and centralized management. This ensures high controllability of the system and efficient distribution of patient flows. However, there are problems with the population's trust in primary care and significant regional disparities in the quality of medical care.. The table clearly demonstrates that each country has both strengths and systemic limitations. Comparing these two countries reveals their complementary potential. Kazakhstan can use the Chinese experience of digital integration and management, and China, in turn, uses the Kazakh approach to the development of family medicine and increasing the role of primary care in providing continuous medical care.

A comparative analysis of the primary health care (PHC) systems of Kazakhstan and China, presented in the table, revealed both strengths and systemic limitations in both models. Kazakhstan is focused on the development of family medicine and a patient-centered approach, while China is characterized by high efficiency of digitalization and centralized management, but faces problems of trust and regional inequality.

Based on these results, a SWOT analysis was conducted, which allowed us to systematize the identified problems, prospects and threats(table 2). The potential of integrating the best practices of the two countries to increase the effectiveness and sustainability of PHC systems was also substantiated.

Table 2 – SWOT analysis

Strengths	Weaknesses
Primary health care systems in both countries have significant advantages. In Kazakhstan, in particular, the patient-centered model of family medicine is actively developing. Multidisciplinary teams are being formed to provide comprehensive monitoring of the population. Compulsory Social Health Insurance has contributed to strengthening financing mechanisms for primary health care, improving accessibility of services, and expanding preventive medicine programs in Kazakhstan. In China, the focus is on a high level of digitalization of healthcare, an extensive network of community-based medical centers, and an effective centralized patient flow management system. Both countries demonstrate active government support for reforms in the primary health system.	There are serious problems in Kazakhstan, such as a shortage of medical personnel, excessive workload of primary care physicians, insufficient attention to preventive measures, and uneven access to medical care in urban and rural areas. Despite the positive results of the Compulsory Social Health Insurance implementation, the disparity in access to primary health care services between urban and rural regions remains significant. In China, however, there are problems related to the low level of public confidence in primary health care, significant disparities in the quality of services in different regions, and overloading of secondary and tertiary hospitals due to direct patient treatment.
Opportunities	**Threats**
The prospects for the development of healthcare in Kazakhstan and China are related to the introduction of digital technologies and the integration of medical information systems. Kazakhstan can use the Chinese experience in creating digital platforms, managing patient flows and telemedicine services. In turn, China can adopt the Kazakh model of family medicine, which enhances the role of primary health care and strengthens public confidence. The development of joint training programs for medical personnel and the exchange of management practices. This will allow both countries to improve the quality of medical care and improve the level of medical care.	The main threats to health systems are the increasing burden on them as a result of the aging of the population and the growing number of chronic diseases. In Kazakhstan, there is a risk of increasing regional inequality and an outflow of medical personnel, while in China, there is a risk of reducing the effectiveness of reforms due to lack of trust in primary care and overloading of large medical institutions. High cost of digital transformation and the need for constant infrastructure upgrades.

Source: compiled by author

The SWOT analysis allowed us to comprehensively consider the key problems, prospects and opportunities for integrating best practices in the primary health care (PHC) systems of Kazakhstan and China.

The analysis showed that both countries face serious institutional and organizational difficulties. In Kazakhstan, this is reflected in a shortage of qualified personnel, an overload of doctors and insufficient preventive focus. In China, however, the low level of trust in primary health care, regional inequality and hospital congestion are serious problems. Currently, the

problem of inequality in access to medical services in rural areas is being addressed within the framework of the national project “Modernization of healthcare in rural areas”.

According to official sources, more than 646 new primary health care facilities have already been built under the project, including outpatient clinics, field obstetric centers and medical posts[15].

The project is expected to improve access to primary health care for approximately one million rural residents and reduce differences in access to health services between regions.

In addition, the modernization of district hospitals and the development of telemedicine infrastructure are aimed at strengthening the interaction between rural and urban health systems.

These weaknesses point to the need for structural reforms and a stronger role for primary health care as the coordinating level of the healthcare system.

The SWOT analysis has clearly identified development opportunities that are primarily related to digital transformation and the strengthening of primary health care. Kazakhstan has the potential to implement more advanced digital solutions and patient flow management systems that have already been tested in China. In turn, China can strengthen its humanistic and preventive orientation by developing family medicine based on the Kazakh model. This shows that our models complement each other, and there is a space for sharing successful practices.

The most significant result of the SWOT analysis was the discovery of the potential for integrating best practices. We are talking about the possibility of combining two approaches: the Kazakh patient-oriented model and the Chinese digital management system. Such integration can create a more sustainable, efficient, and technologically advanced model of primary health care (PHC) that simultaneously ensures the availability, quality, and coordination of medical care.

As a result of the comparative analysis, it can be concluded that Kazakhstan and China are developing unique but potentially compatible models of primary health care (PHC).

Kazakhstan focuses on the continuity of medical care, family medicine and an individual approach to patients. China also demonstrates high efficiency in the field of digital integration and centralized healthcare management.

Combining the best practices of both systems can lead to the creation of more sustainable, affordable, and technologically advanced PHC systems.

In particular, Kazakhstan can benefit from China's experience in digital healthcare infrastructure and patient flow management. At the same time, China can adopt elements of the Kazakh model of family medicine aimed at building trust and continuity of medical care.. The study shows that for successful PHC reform, it is necessary not only to upgrade infrastructure and introduce digital technologies, but also to strengthen trust between system participants, develop human resources and ensure equal access to services in different regions.

Conclusion

The study revealed that primary health care systems in China and Kazakhstan are developing according to different but complementary models. Kazakhstan strives to create a patient-oriented system based on family medicine and comprehensive patient care. At the same time, China demonstrates the high efficiency of digitalization, centralized management and scalability of medical services.

Comparative analysis, case method, and SWOT analysis allowed for a comprehensive study of this topic. As a result, key issues such as staffing shortages, regional inequality, and system overload were identified. In addition, prospects were identified, including digital transformation, the development of primary care and the strengthening of prevention. The potential of integrating the best practices of the two countries was also assessed.. The results of the study showed that it is possible to increase the effectiveness of primary health care (PHC) by combining the best practices of the two models. Technological solutions developed in China can be adapted in

Kazakhstan, and the experience of family medicine accumulated in Kazakhstan will strengthen the humanistic and preventive nature of the Chinese healthcare system.

The practical significance of the study lies in the fact that its results can be used to develop strategies for reforming primary health care. They can help improve family medicine models, introduce digital technologies, and improve patient flow management. The recommendations of the study can also be used in the work of health authorities to optimize resources, reduce the burden on doctors and increase the availability of medical care for the population.

The theoretical significance of the study lies in the expansion of scientific understanding of the comparative analysis of health systems. It deepens the understanding of primary health care (PHC) organization models in countries with different levels of socio-economic development and systematizes the factors influencing the effectiveness of primary care.

The research expands existing scientific knowledge by combining case analysis, comparative approach and SWOT methodology within a single topic.

The prospects for further development of the topic are related to a deeper study of digital healthcare platforms, an assessment of the effectiveness of telemedicine, and an expansion of comparative analysis to include other countries with different PHC models. This will make it possible to form more universal recommendations for the global development of primary health care in the face of growing demographic and epidemiological challenges.

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Geological and Mineralogical Sciences

ДИСТАНЦІЙНІ ОЦІНКИ ПАРАМЕТРІВ ГЛИБИННИХ ФЛЮЇДНИХ СИСТЕМ ПРИ ДОСЛІДЖЕННІ ВУЛКАНІЧНИХ СТРУКТУР РІЗНОГО ТИПУ (ЗА РЕЗУЛЬТАТАМИ ВИКОРИСТАННЯ ЧР-ТЕХНОЛОГІЙ)

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Вступ

Інтенсивність формування та еволюція вулканічних структур різного типу залежать від періодичності пульсаційних процесів багаторівневих джерел системи глибинних потоків флюїдів, з якими пов'язане існування магматичних камер та висока активність дегазації надр.

Використання частотно-резонансних (ЧР) досліджень дає змогу отримати додаткову (і незалежну) інформацію про взаємозв'язок цих процесів з природними явищами в багатьох структурах в широкому діапазоні глибин літосфери [Yakymchuk, 2024; Якимчук, 2021, 2022, 2024].

Нижче наведені результати досліджень деяких вулканічних структур різного типу (грязьові і магматичні вулкани Середземного, Чорного та ін. морів), для яких отримані нові дані про глибинну будову і особливості ймовірного розташування джерел їх формування.

Методи досліджень

У складі сумарного електромагнітного сигналу на земній поверхні значну частку становить компонента літосферного походження, а розподіл інтенсивності випромінювання вздовж профілів має впорядковану структуру, в значній мірі пов'язану із будовою та динамікою Землі, що дає можливість отримати інформацію про структуру геосередовища [Шуман, 2008]. Блок однорідної речовини створює електромагнітне випромінювання пропорційне концентрації речовини. Лінійно поляризована хвиля із заданою частотною характеристикою, що несе інформацію про структуру речовини, не поглинається середовищем, а її інтенсивність не зменшується з відстанню. Характерна електромагнітна хвиля певним чином реєструється на космічному знімку, що дозволяє застостосовувати нові методи і технології при дослідженні глибинної будови локальних і регіональних структур Землі [Якимчук та ін, 2022; Шуман, 2011].

Експериментальні дослідження проведені з використанням технології, яка включає модифіковані методи ЧР декодування супутникових та фотознімків та вертикального електрорезонансного зондування розрізу.

Для опису реалізованих процедур інструментальних вимірів використовувались фотознімки зразків осадових та магматичних порід. Особливості та можливості використаних методів, а також методика проведення вимірювань наведені в [Yakymchuk et al, 2024].

Нові результати досліджень окремих вулканічних структур різного типу

Грязьовий вулкань Бореаліс

У норвезькому секторі Баренцева моря довгий час дослідженим був лише один грязьовий вулкан - Хакон Мосбі, але влітку 2023 року на глибині майже 400 м було виявлено новий грязьовий (300 м ×25 м) вулкан **Бореаліс** (Рис. 1), який є результатом катастрофічного (із великою кількістю метану) виверження (18 000 років тому) [Panieri et al, 2024].

Резонансні відгуки на газових частотах зареєстровані в інтервалах 166-511 м і 882-1131 м, а також в інтервалі 1,131-10,0 км. Сигнали можуть вказувати на наявність глибокого міграційного каналу та викидів газу в атмосферу, що підтверджується сучасними процесами виверження газу в кратері грязьового вулкану Бореаліс.

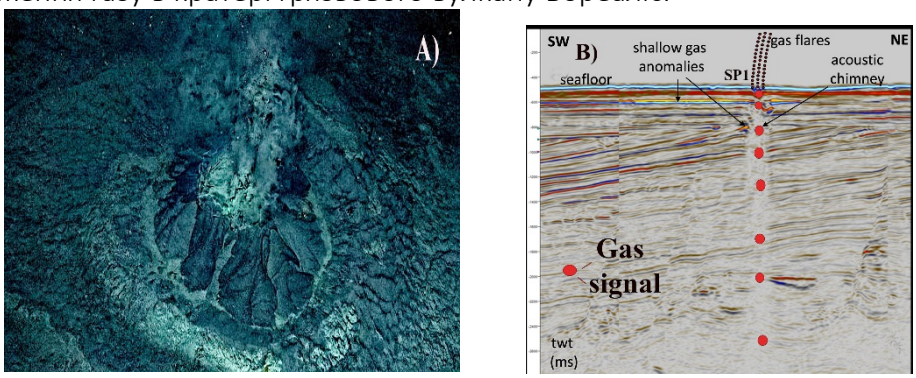

Рис. 1. Грязьовий вулкан Бореаліс: рельєф дна (**A**) та результати сканування (**B**) за допомогою FR-технології [Panieri et al, 2024, simplified].

На частотах газогідратів відгуки при скануванні розрізу отримані до глибини 400 м. Виявлення скупчень газу та джерел дегазації на глибинах, що перевищують потужність осадового чохла, свідчить про додаткове надходження глибинного газу та існування процесів дегазації, які можуть пояснити масштаби утворення полів сипів і покмарків в різних структурах Світового океану.

Вулканічні структури Середземного та Чорного морів

Грязьові вулкани вперше були виявлені у східній частині Середземного моря понад 40 років тому. За останні 15 років вже понад 60 з них були виявлені на внутрішній частині Середземноморської агломерації (на південь від Калабрії) на глибинах 150-2750 м [Carmicaoa et al, 2020; Loher et al., 2018; Panieri et al, 2013; Camerlenghi et al.,1992].

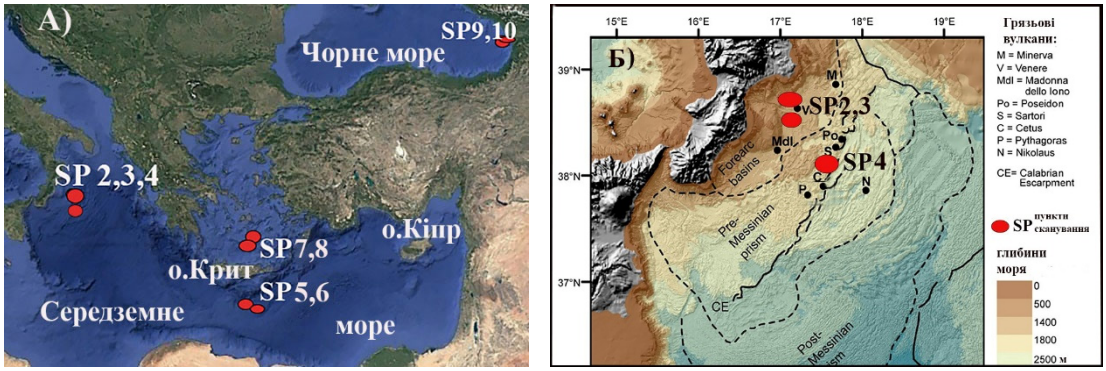

Рис. 2. Розташування пунктів (А) частотного сканування (SP, червоні еліпси) в Середземному та Чорному морях; (Б) - тектонічна схема розташування грязьових вулканів у переддуговому басейні.

Сейсмічні дані показали існування серії тектонічних порушень в межах Калабрійської дуги, і було висловлено припущення, що виявлені насуви могли забезпечити формування шляхів вертикальної міграції для флюїдів грязьового вулканізму [Panieri et al, 2013].

Грязьові вулкани Венере. Екструзивні конуси грязьових вулканів висотою до 100 м лежать на глибині 1500 м в Іонічному морі, за 30 км на південь від узбережжя Калабрії. Характерною особливістю цього поля грязьових вулканів є існування зануреної кальдери, обмеженої кільцеподібною зоною розлому, чітко вираженою структурами донного рельєфу (рис. 3,А).

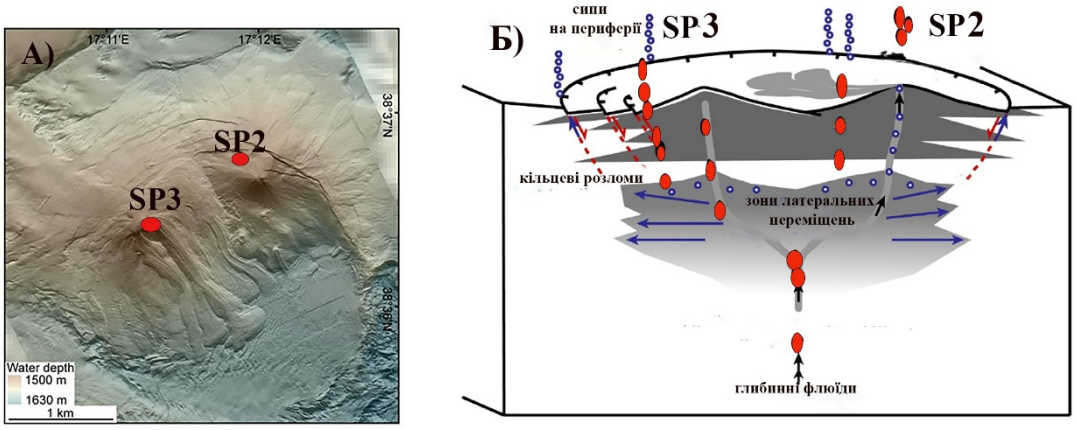

Рис. 3. Рельєф дна (А) грязьового вулкана Венере у переддуговому басейні; (Б)- концептуальна модель вулкана Venere, що включає канал з грязьовою брекчією, насиченою газом, міграція якого відбувається вздовж кільцевих розломів (короткі сині стрілки вздовж червоних пунктирних ліній) [Loher et al., 2018].

Сучасні грязьові потоки та постійні викиди газу свідчать про те, що грязьові вулкани Венере є одними з найактивніших, у порівнянні з іншими грязьовими вулканами переддугового басейну. Проведені дослідження свідчать про термогенне походження вуглеводнів, що викидаються цим грязьовим вулканом і їх джерела розташовані на глибині більше 3 км [Loher et al., 2018].

Пункти сканування SP2 та SP3 (рис. 3) розташовані на валу Венере, де було зареєстровано активну дегазацію [Loher et al., 2018]. Для пункта сканування SP2 відгуки були

отримані від доломітів (до 6,5 км) в локальних умовах стиснення, які фіксуються особливостями його частотного сигналу. В пункті сканування SP3 відгуки отримані від другої осадової групи, де залягають грязьові потоки та псаміти (до 7,5 км). Вони теж свідчать про існування локальних умов стиснення.

Формування вертикальних шляхів міграції могло бути результатом дії надлишкового тиску або викликано тектонічним напруженням, реактивацією розломів і високою сейсмічністю [Dimitrov, 2003; Loher et al., 2018]. Еволюція активних систем розломів у регіоні спричинила глибинну циркуляцію флюїдів, витіснення та просочування газу [Panieri et al, 2013; Ceramicola et al., 2020].

Пункт сканування SP4 (рис. 4) розташований на вулкані Сарторі. У цій точці сканування сигнали були отримані від сьомої осадової групи (до 4,0 км). Тут відомо шість окремих фаз виверження грязьової брекчії, вік яких складає понад 56 тис. років, але в останні 10000 років переважає лише флюїдна активність [Doll et al., 2023]. Також були отримані сигнали від вуглеводнів, які вказують на їх можливе термогенне та глибинне походження. Ізотопний склад метану, визначений у вулканічному полі Сарторі, є результатом суміші метану з кількох джерел [Loher et al., 2018].

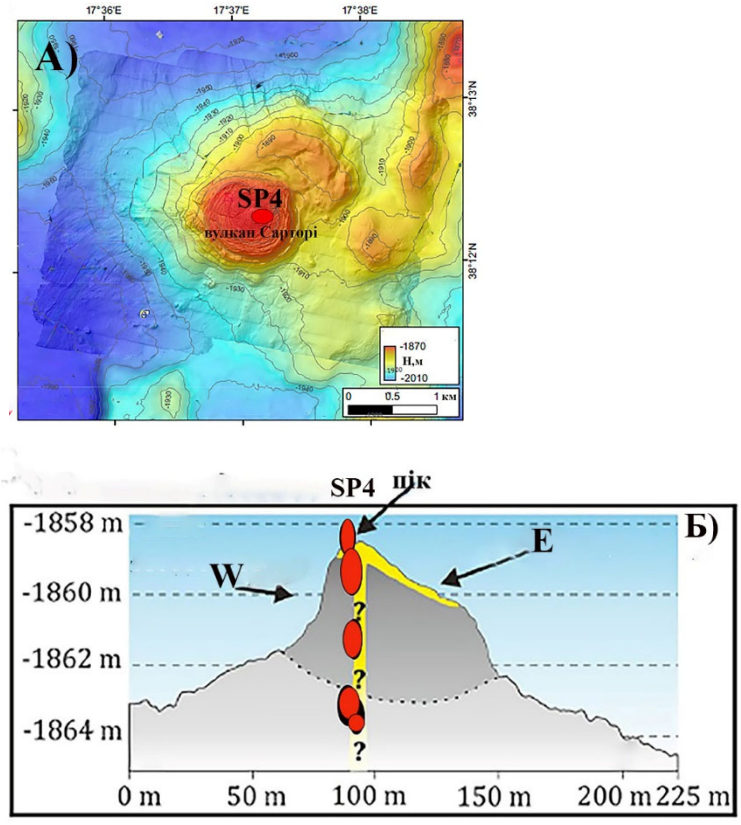

Рис. 4. Схематична модель вулкана Sartori (А); (Б) – широтний профіль через вулкан з піком у його наймолодшій частині [Doll et. al, 2023].

Поля вулканів Олімпія (рис. 2) розташовані на відстані біля 150 км від південного Криту [Huguen et al., 2004]. Це найбільш відоме поле грязьових вулканів на Середземноморському хребті (понад 6000 км^2). Поле цих грязьових вулканів складається з кількох структур (рис. 5), найбільшими з яких є грязьові вулкани Геленджик та Наполі.

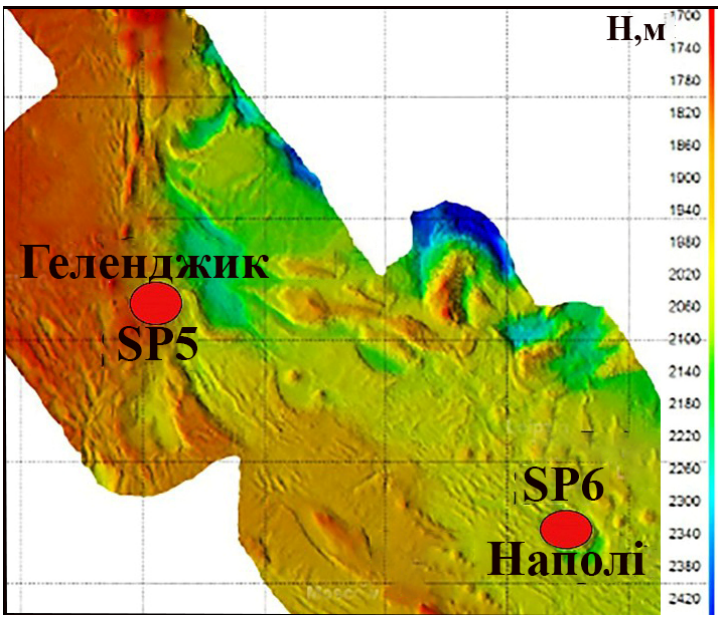

Рис. 5. Цифрова модель батиметрії поля грязьового поля вулканів Олімпія [Nikitas et al., 2021, спрощено] з пунктами сканування SP5, SP6.

Результати сканування свідчать про існування локальних умов стиснення в межах поля грязьових вулканів Олімпія (Геленджик та Наполі), як і в інших частинах Середземноморського хребта.

Грязьовий вулкан Геленджик має асиметричний поперечний переріз, його найбільша довжина сягає 10 км, він розташований поблизу основного тектонічного уступу району (рис. 5). Потужний горизонт осадових порід (до 5,5 км), за даними частотного зондування, може бути перспективним для вуглеводнів, оскільки тут існують умови та джерела для утворення нафти та газу [Nikitas et al., 2021].

Результати зондування вказують на наявність вуглеводневих відгуків, що є критерієм їх нафтогазоносності, хоча на даному етапі дослідження оцінити перспективність ділянки неможливо.

Аналогічні результати були отримані для ділянки (рис. 6) з грязьовим вулканом Наполі (Napoli), де товщина шару осадів. представленого вапняками, становить близько 6,0 км. Відомо, що поблизу цього вулкана спостерігалися фрагменти карбонатів, а також відомі ділянки активних у часі та просторі просочувань флюїдів [Huguen, et al. 2004]. Для цього району були також отримані сигнали на частотах вуглеводнів, що підтверджує наявність сприятливих умов для більш детальних досліджень поля грязьових вулканів Олімпія.

Вулкани Колумбо (Kolumbo) та Санторіні (Santorini)

Вулканічне поле Крістіана-Санторіні-Колумбо в південній частині Егейського моря (рис. 6) є одним з найбільш небезпечних вулканічних регіонів у світі.

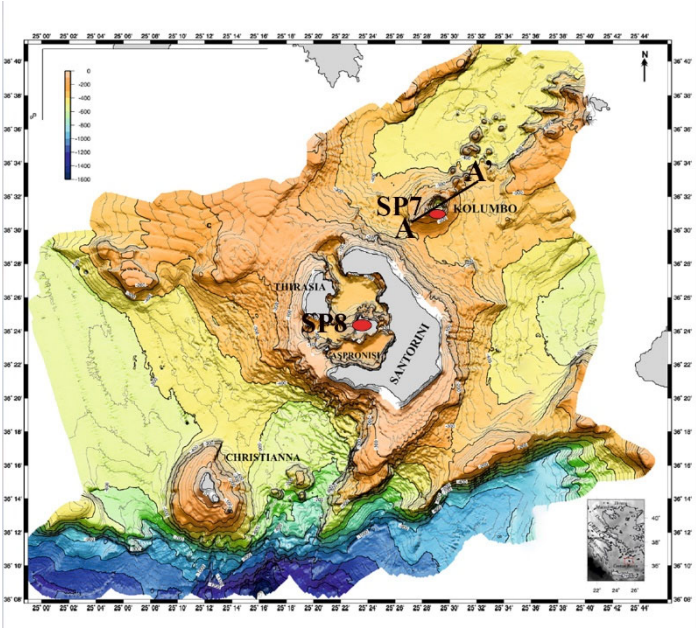

Рис. 6. Схематична карта рельєфу поля вулканів Санторини–Колумбо [Nomikou et al, 2012]. Нанесені пункти сканування SP7, SP8 та профіль A-A' (рис.7).

Вулканічна група Санторіні складається з трьох різних вулканічних структур: острів Крістіана на південному заході, Санторіні посередині та вулканічний ланцюг Колумбо, вирівняний вздовж зони тектонічного розлому північно-східного напрямку [Nomikou et al., 2012].

Утворюючи північно-східну частину цього вулканічного поля, вулканічний ланцюг Колумбо складається з понад 20 підводних вулканічних конусів, для яких відомо лише два великих виверження за останні 360 000 років.

Колумбо є найбільшим та найактивнішим з них (рис. 6), він має висоту ≥1 км та діаметр ≥11 км [Hübscher et al., 2014].

Дослідження швидкості сейсмічних P та S хвиль вказують на існування магматичної камери під вулканом Колумбо, яка простягається на 2-4 км і є окремою та відмінною від магматичного резервуара під головним островом Санторіні [Bohnhoff et al., 2006]. Магми Колумбо походять з окремого, більш збагаченого мантійного джерела порівняно з вулканом Санторіні [Klaver et al., 2016].

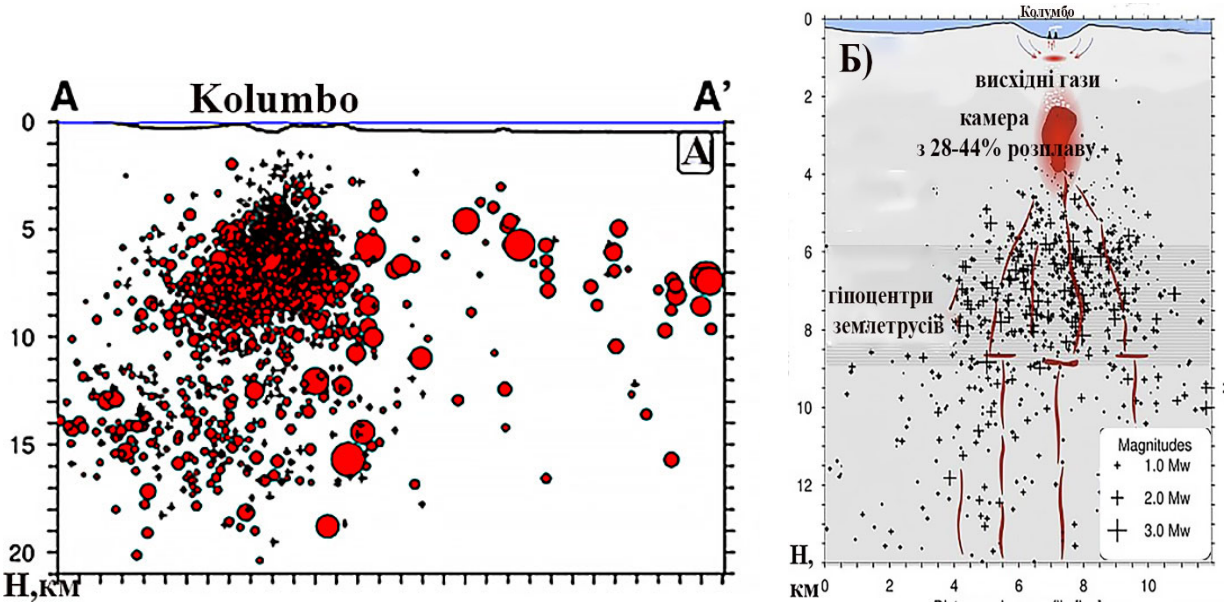

Рис. 7. Глибинний розріз (**А**) через вулкан Колумбо (*профіль А-А' на рис.6)* з гіпоцентрами землетрусів поблизу профіля; **Б-** модельний розріз магматичної системи вулкану Колумбо [Scmidt et al, 2022].

Результати сканування пункту SP7 (рис. 6) показали, що для вулкана Колумбо характерні процеси дегазації з виділенням і міграцією в атмосферу водню. Сигнал на частотах базальтової магми не фіксувався в інтервалі глибин 0-13.0 км протягом 3 хв вимірювань, а в інтервалі глибин 13-99 км він не фіксувався протягом 250 с. Ці результати можуть свідчити про активну локальну розломну діяльність на глибині до 5 км і відсутність великих магматичних камер в глибинному розрізі флюїдної системи вулкана Колумбо або істотно інший склад резервуару магми під цим вулканом, корінь якого зафіксовано на глибині 99 км.

Вулкан Санторіні розташований на острові Тіра поблизу перетину рифтових систем Егейського моря (рис. 6, 8). Він є найбільш активним вулканом поля вулканів Колумбо-Санторіні.

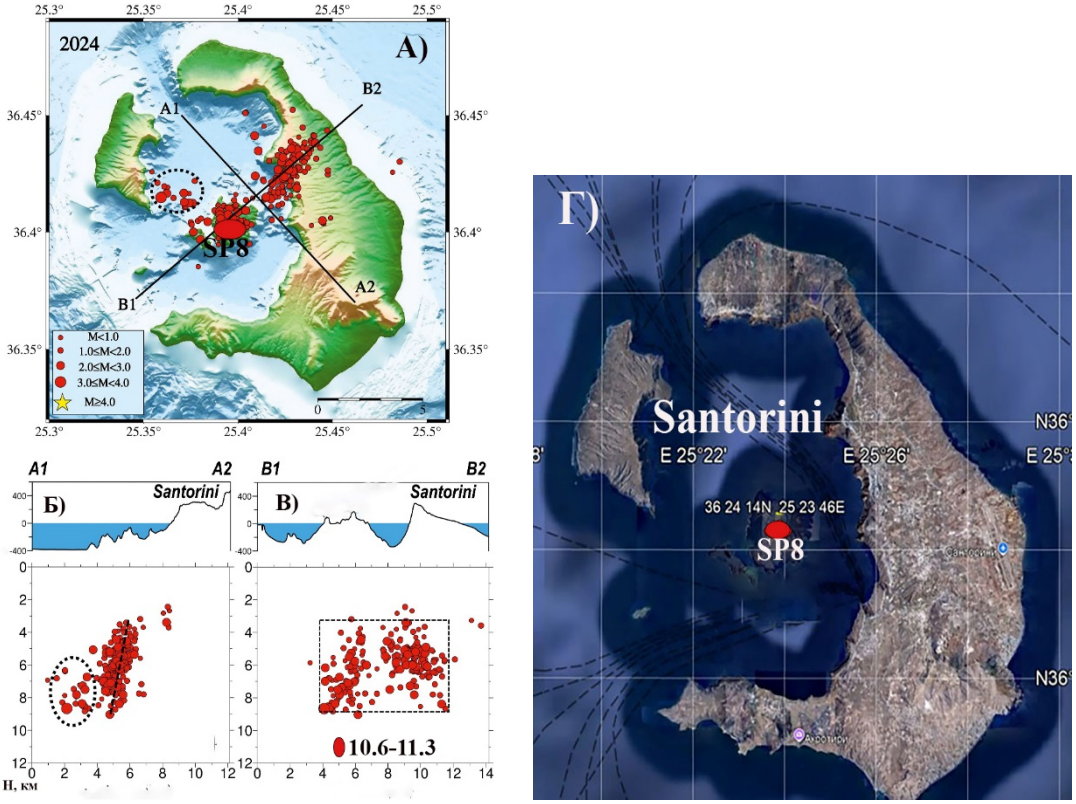

Рис. 8. Вулкан Санторіні на о.Тіра: схематичний рельєф кальдери з епіцентрами землетрусів 2024 року і розташуванням профілів **А-А', В-В'**(**А**); **Б, В-**гіпоцентри землетрусів вздовж профілів з нанесеним положенням розплавленої магми за даними ЧР сканування [Papazachos et al, 2025]; **Г** - положення пункту сканування SP8 в кальдері вулкану.

За останні 360000 років відомо більше двох сотень його вивержень, однак про просторово-часову еволюцію, тектонічний контроль флюїдних систем та магматизму цих підводних вулканів та реальність сейсмічної небезпеки інформації недостатньо [Scmidt et al, 2022; Papazachos et al, 2025].

Скануванням розрізу з кроком 5 см спільний сигнал із розплавленими базальтами зафіксовано в інтервалі глибин 10.641 км – 11.31 км (рис. 8).

При обробці знімка ділянки (рис. 8,**г**) сигнал на частотах базальтової магми не фіксувався в інтервалі глибин 13-470 км протягом 350 с вимірювань.

Результати сканування показали існування суттєвих відмінностей глибинних розрізів вулканів, які підтвержують припущення про різні джерела постачання магми в цих структурах. Тому ці результати дають додаткові дані про структуру флюїдних систем поля вулканів Санторіні-Колумбо.

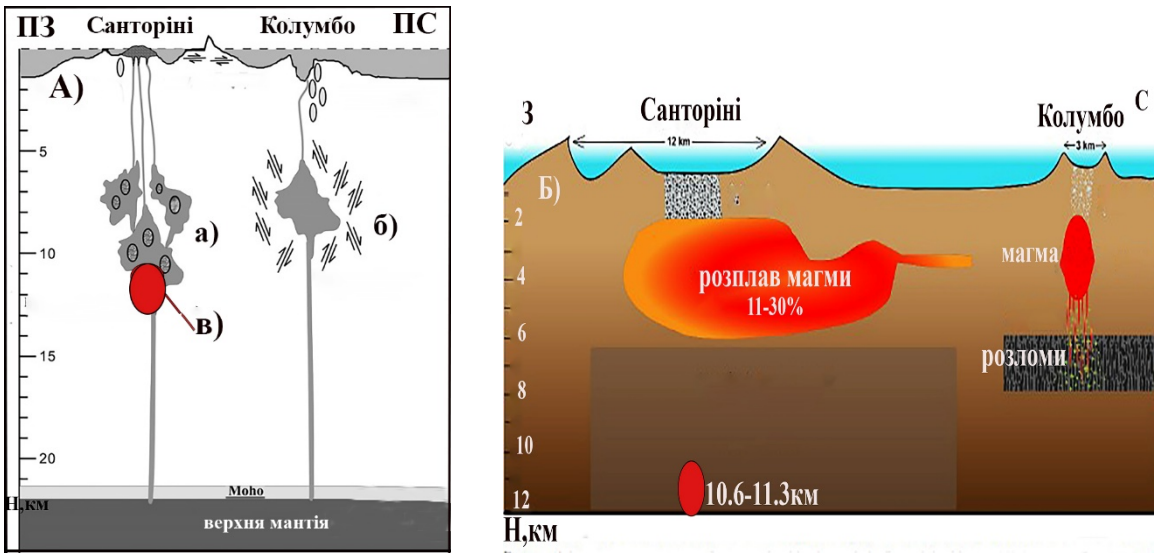

Рис. 9. Схематична модель (А) глибинного розрізу поля вулканів Санторіні-Колумбо [Dimitriadis et al, 2009]: а - магма із значними домішками корових компонентів; б - резервуар з молодою магмою, (піднятою прямо з мантії) та інтенсивним розвитком нормальних розломів і сейсмічності; в - магматична камера за даними ЧР сканування; Б - схематична модель [Hufstetler et al, 2024] вулканів з ймовірними резервуарами магми l

Запропоновані моделі глибинного розрізу поля вулканів Санторіно-Колумбо (рис. 9) не є єдиними для цього регіону. В роботі [Autumn et al, 2025] розглядаються інші ймовірні моделі розвитку флюїдної системи цих вулканів (рис.10).

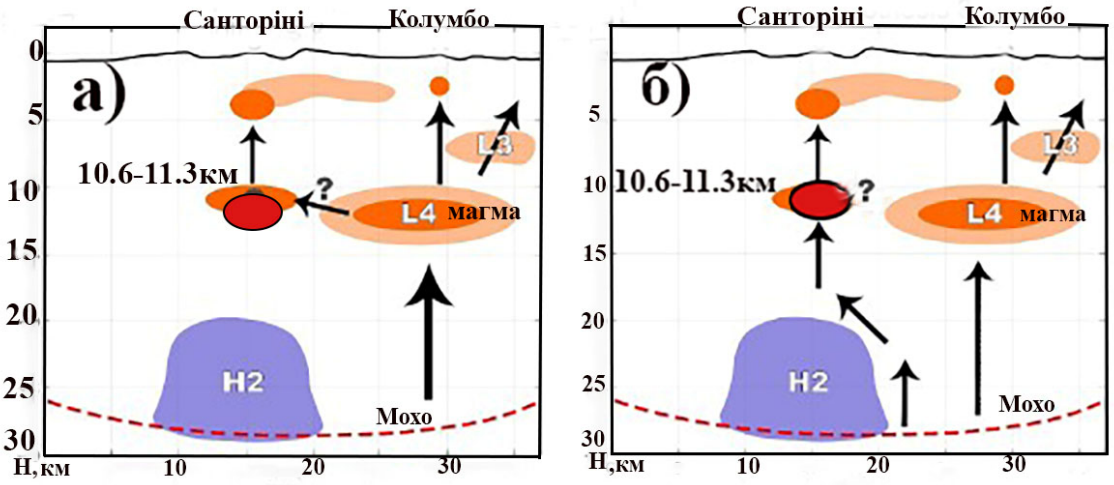

Рис. 10. Ймовірні моделі (а,б) глибинної будови поля вулканів Санторіні-Колумбо [Autumn et al, 2025] за результатами досліджень землетрусів 2025 року. Н2 - високошвидкісні тіла в розрізі кори; L3, L4 – ймовірні магматичні камери флюїдної системи. Червоні еліпси - резервуари магми за даними ЧР сканування; стрілками показано напрямок підйому глибинних флюїдів.

Автори [Autumn et al, 2025] вважають найбільш ймовірною модель (рис.10, б), в якій вулкани Санторіні та Колумбо мають окремі флюїдні системи транспортування магми з мантії. Результати ЧР сканування показали, що в земній корі існує магматична камера на глибині 10.5-11.3-13 км, яка позначена цими авторами знаком питання (рис.10). В кальдері вулкана Санторіні розплав піднімається з окремого мантійного джерела нижче області

високої швидкості (H2) у нижній корі вздовж краю цієї області до резервуара у середній корі на глибині від 8 до 15 км під Санторіні [Autumn et al, 2025].

Окрема флюїдна система та мантійне джерело для вулкана Санторіні дозволяє швидко поповнювати неглибоку магматичну камеру на глибині 3–5 км, а також пояснює відмінності в мікроелементах та радіогенних ізотопах між вулканами Санторіні та Колумбо [Hufstetler et al, 2024].

Також була досліджена глибинна будова вулкану о. Десепшн у протоці Брансфілд (Західна Антарктика) та отримані нові додаткові дані про структурні особливості флюїдної системи та розташування магматичних камер вулкану, схожого на вулкан Санторіні.

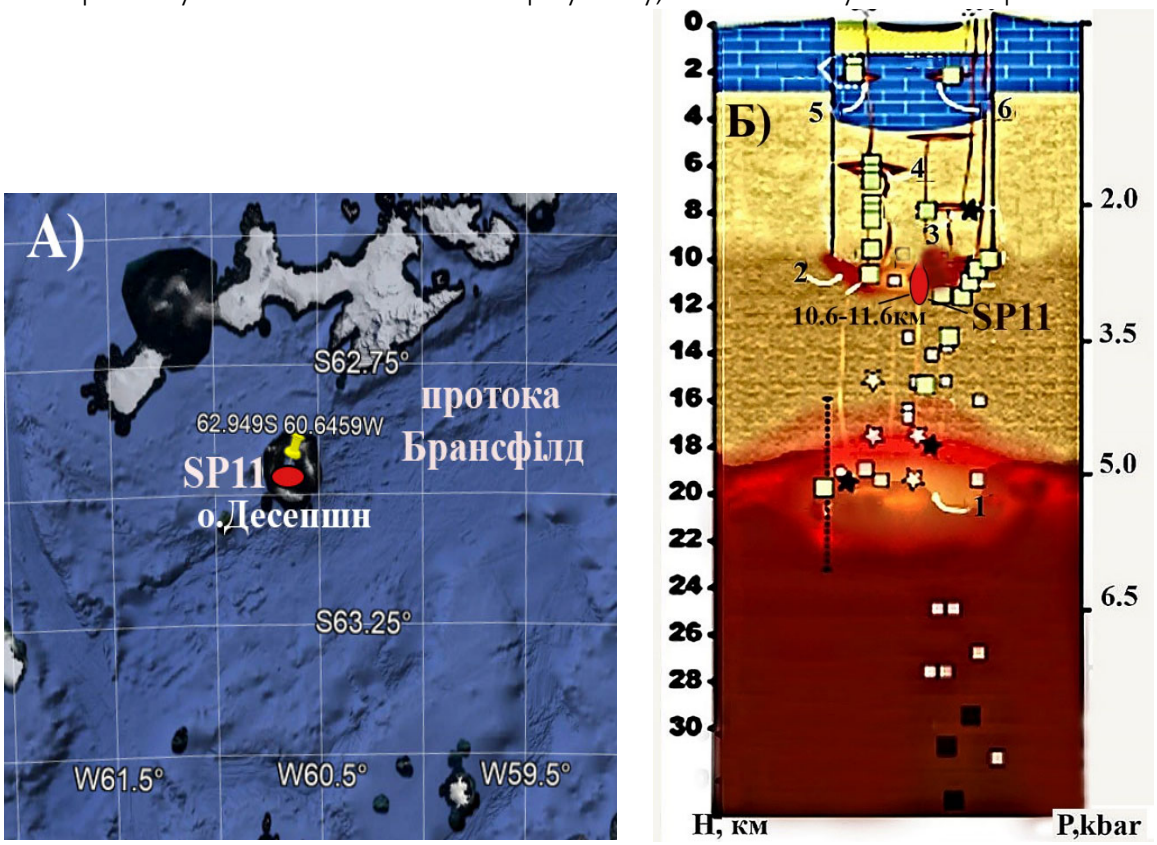

Рис. 11. Острів Десепшн та пункт сканування SP11 (А) на космічному знімку протоки Брансфілд (Західна Антарктика); Б - принципова схема формування магмо-газо-флюїдної системи у верхній частині літосфери о. Десепшн [Geyer et al, 2019, спрощено]. Цифрами (1-6) показано положення локальних магматичних камер - складної мережі окремих резервуарів змінного розміру та складу (цифри 2-6).

Магми, що живлять частину системи магмопідведення о. Десепшен (камера 1), можуть підніматися безпосередньо з мантії або з магми на межі кори та мантії (25-30 км) поблизу розділу Мохо.

Для крупного знімка ділянки (рис. 11) спільний сигнал із 6-ою групою магматичних порід (габро і базальти) зафіксовано на поверхні, та на глибинах 57, 99, 217 км. Корінь базальтового вулкану зафіксовано на глибині 217 км.

При обробці знімка локальної ділянки (рис. 11) спільний сигнал на частотах базальтової магми не фіксувався в інтервалі глибин 0-10.0 км протягом 200 с (3 хв 20 с) вимірювань. Він почав фіксуватися з 4 с вимірювань в інтервалі глибин 10.0-13.0 км. Скануванням розрізу з кроком 5 см спільний сигнал із розплавленими базальтами зафіксовано в інтервалі глибин 10.642 км – 11.557 км (таб. 1), в інтервалі глибин 13-217 км протягом 200 с (3 хв 20 с) вимірювання він не фіксувався.

Таб.1. Результати сканування.

Амплітуда	Глибина (100м)	Крок	Речовина	Порода
0	115,570000	0,005	лава	базальти
80	114,600000	0,005	лава	базальти
60	114,455000	0,005	лава	базальти
40	112,620000	0,005	лава	базальти
20	110,345000	0,005	лава	базальти
40	109,605000	0,005	лава	базальти
20	106,425000	0,005	лава	базальти

Існуванням магматичної камери з частково розплавленою речовиною під кальдерою можна пояснити особливості формування геотермальних аномалій та систем тріщин з активною міграцією флюїдів у приповерхневих водах.

Еволюційна модель надходження магми у верхні горизонти земної кори та глибинна структура вулкана Десепшн є предметом досліджень. Якщо порівняти дані ВЕРЗ з результатами сейсмо-томографічних досліджень [Prudencio et al, 2015; BenZvi T. et al, 2007], то можна знайти загальні характеристики будови верхньої частини земної кори о. Десепшн, одержані різними методами. Насамперед це стосується кальдери, де розміри магматичної камери розплавленої речовини, визначені морфологією інтенсивної аномалії зниженої швидкості, близькі до розмірів зони зниженого опору за даними ВЕРЗ. Мозаїчний розподіл аномалій швидкості значною мірою збігається з наявністю неоднорідності розрізу кальдери за геоелектричними даними (суттєві коливання потужності осадів, включення дайок та зони можливого прогріву). Ми припускаємо, що цей розріз характеризує проміжну приповерхневу камеру, розігрітий газо-вулканічний матеріал в яку надходить з більш глибоких джерел в літосфері. Можлива глибина магматичної камери вулкана Десепшн становить 25-30 км.

Системи магматичного насичення розрізу подібної конфігурації були відомі і для інших кальдер світу (вулкан Санторіні). Формування невеликих магматичних резервуарів може бути пов'язане з регіональними та локальними розломами, що контролюють утворення кальдери.

Східна частина Чорного моря

В південно-східній частині Чорнго моря в грузинській частині континентального схилу (рис.12) було проведено серію досліджень (поля сипів Печорі та Колхеті).

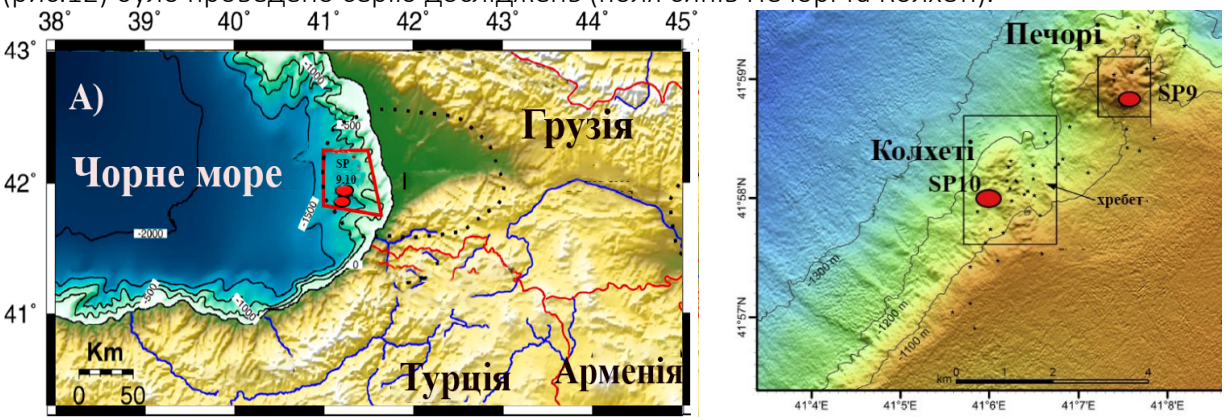

Рис. 12. Пункти сканування SP9, SP10 в південно-східній частині Чорного моря (А); Б - положення пунктів сканування в грузинській частині континентального схилу [Körber et al, 2014].

Континентальний схил в районі Батумі характеризується складною системою каньйонних хребтів східно-західного простягання. Численні газові витоки відомі на вершинах або схилах хребтових структур на глибинах 850-1200 м [Шнюков и др., 2013; Körber et al, 2014].

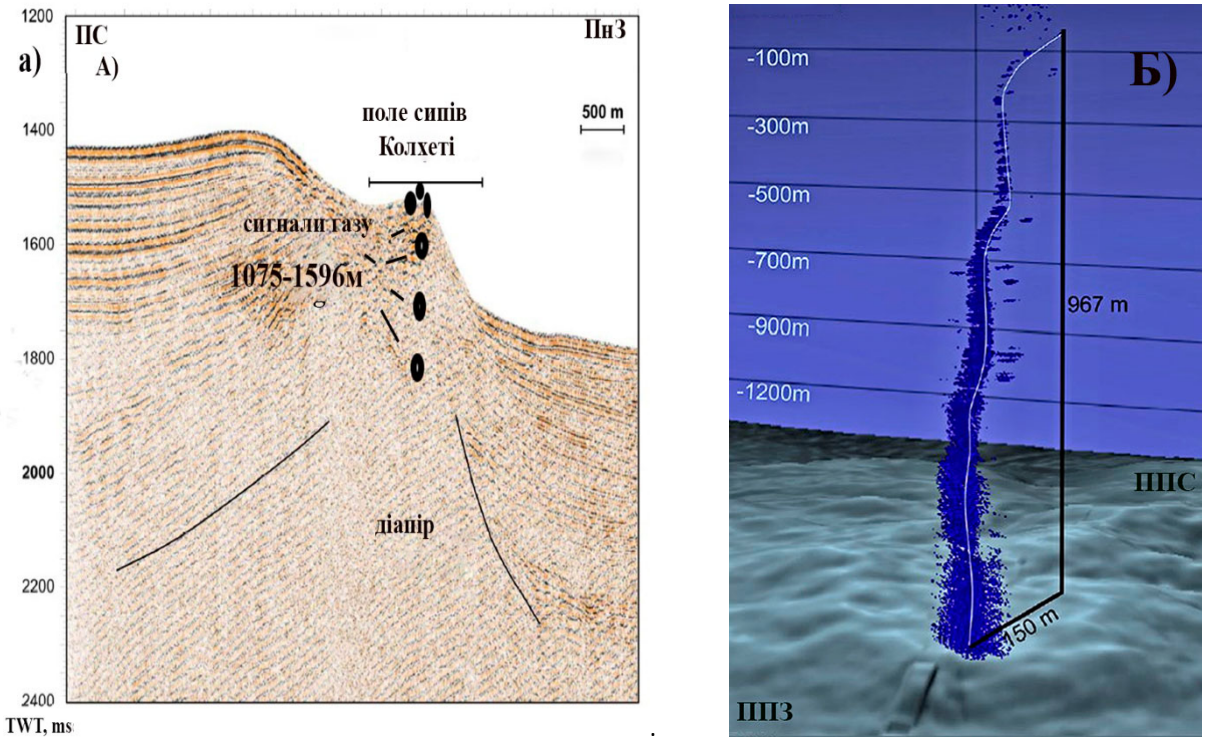

Рис. 13. Сейсмічний розріз (А) of Colkheti seep [Wagner-Friedrichs, M., 2007, спрощено] з результатами ЧР сканування (SP10); Б – газовий факел над полем сипів Печори [Körberet al, 2014].

У пункті сканування SP10 (рис. 13) зафіксовано газовий сигнал на глибинах 1075 м - 1596 м (подальше зондування не проводилося). Для SP9 (рис. 12, Печори) отримано сигнали газу на глибинах: 1221 м – 1522 м, 1673 м – 2226 м. Підтверджено також процес активної дегазації на обох ділянках.

Глибини залягання вуглеводнів для точок сканування є орієнтовними, їх можна уточнити під час детальних досліджень.

Ділянки з нафтовими плямами у східній частині Чорного моря.

Нафтові плями природного та антропогенного походження були виявлені на поверхні моря (рис. 14) у південно-східній частині Чорного моря [Mityagina et al, 2016].

Дослідження показали, що покриті нафтою газові бульбашки не зазнають подальших геохімічних змін під час проходження та досягають поверхні моря менш ніж за 2,5 години. Нафта та газ розділяються на поверхні моря, що призводить до утворення нафтових плям та виходу газу в атмосферу [Mityagina et al, 2016].

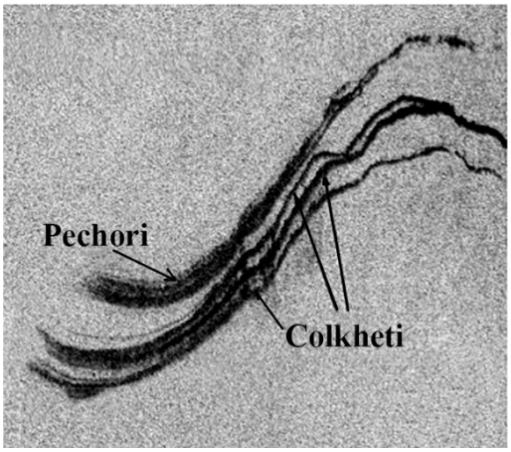

Рис.14. Нафтові сліки на поверхні моря в районі проявів сипів Колхеті та Печорі в південно-східній частині Чорного моря [Mityagina et al, 2016].

Виходячи з розмірів нафтових плям на поверхні моря, візуалізованих за допомогою дистанційного зондування, поля сипів Колхеті та Печорі є найпотужнішими в Чорному морі щодо викидів нафти. Автори зазначають [Körberet al, 2014]. що глибина залягання відповідних газо- та нафтонасичених порід залишається значною мірою невідомою.

Але проведені експерименти за допомогою використання ЧР технологій показали, що вперше отримані для сліків ймовірні глибини просочування змінюються в широкому інтервалі від 500 м до 5000 м (відгуки з глибини формування: 570-920 м; 1090-1900 м; 3000-3490 м; 4510-5290 м).

Висновки

В статті показані можливості використання ЧР-технологій для дистанційної оцінки формування багаторівневої флюїдної системи в вулканах різного типу, що дозволило отримати нові (в тому числі і кількісні) дані про особливості тектоно-магматичних процесів утворення і розміщення окремих магматичних камер в земній корі грязьових і вулканічних структур, вплив тектонічних факторів на функціонування глибинної імпульсної дегазації [Кутас, 2020].

Отримані дані для вулкнів східної частини Середземного моря (Сарторі, Венере. Санторіні, Колумбо та ін) доповнюють сучасні уявлення про глибинну флюїдну систему та процеси дегазації в цих структурах кількісними параметрами, що дозволяє звузити коло гіпотез про особливості їх формування.

Наведені матеріали підтверджують глибинний характер утворення полів сипів, локалізують області міграції метану в атмосферу, а також доповнюють дані про зв'язок процесів дегазації з накопиченнями глибиннх вуглеводнів.

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Pedagogical Sciences

Сравнительный анализ систем подготовки педагогов Финляндии и Казахстана

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Аннотация. В статье представлен сравнительный анализ систем профессиональной подготовки будущих учителей Финляндии и Казахстана в контексте современных вызовов глобального образовательного пространства. Рассматриваются исторические предпосылки формирования национальных моделей педагогического образования, особенности отбора абитуриентов, структура образовательных программ, исследовательская подготовка будущих учителей, организация педагогической практики и механизмы обеспечения качества образования. Особое внимание уделено феномену академической автономии финских университетов и ее влиянию на формирование профессиональной ответственности педагога. На основе изучения опыта университета Ювяскюля выявлены факторы эффективности финской модели подготовки учителей и определены перспективные направления их адаптации в системе высшего образования Республики Казахстан.

Ключевые слова: педагогическое образование, профессиональная подготовка будущих учителей, Финляндия, Казахстан, академическая автономия, профессиональная ответственность, университет Ювяскюля, образовательная политика.

Введение. В условиях стремительной трансформации общества, цифровизации образовательной среды и изменения требований к профессиональным компетенциям педагога особую актуальность приобретает проблема совершенствования систем профессиональной подготовки учителей. Сегодня учитель выступает не только транслятором знаний, но и организатором образовательной среды, исследователем, наставником и проводником социальных изменений. В связи с этим вопросы качества педагогического образования становятся одним из ключевых факторов устойчивого развития национальных систем образования.

На протяжении последних двух десятилетий Финляндия стабильно демонстрирует высокие результаты в международных исследованиях качества образования и рассматривается мировым педагогическим сообществом как пример эффективной образовательной политики. Значительный интерес вызывает не столько организация школьного образования, сколько система подготовки педагогических кадров, которая является фундаментом устойчивости всей образовательной системы страны.

В Казахстане за последние годы также реализован ряд масштабных реформ, направленных на модернизацию педагогического образования. Введены обновленные образовательные программы, профессиональный стандарт педагога, новые механизмы

оценки качества образования и цифровые инструменты обучения. Однако сохраняется потребность в дальнейшем совершенствовании системы подготовки педагогических кадров с учетом лучших международных практик и национальных особенностей.

Особую ценность представляет изучение опыта Финляндии не с позиции механического заимствования отдельных образовательных технологий, а с точки зрения понимания системных факторов, обеспечивающих высокое качество подготовки учителей. В этой связи актуальным становится сравнительный анализ двух моделей педагогического образования, позволяющий выявить как общие тенденции развития, так и принципиальные различия в подходах к формированию профессиональной компетентности педагога.

Целью исследования в рамках данной статьи является выявление особенностей систем профессиональной подготовки будущих учителей Финляндии и Казахстана.

Вопросы интеграции исследовательской компоненты в процесс подготовки будущих учителей широко освещены в трудах западных исследователей (L. Shulman [1], H. Niemi [2], J. Toom [3]). Различные аспекты реформирования казахстанской высшей педагогической школы и адаптации международного опыта анализируются в работах отечественных ученых (Ш.Т. Таубаева [4], А.К. Кусаинов [5] и др.). Тем не менее, кросс-культурные сопоставления конкретных институциональных кейсов (в частности, университета Ювяскюля как эталона исследовательской модели) с казахстанскими реалиями через призму данных TALIS и PISA остаются фрагментарными.

Научная новизна исследования заключается в экспликации системных барьеров (когнитивного диссонанса между университетской подготовкой и школьным комплаенсом), сдерживающих импликацию исследовательской парадигмы в педагогическое поле Казахстана, и обосновании того, что ключевым предиктором эффективности реформ является трансформация внутренней академической культуры вузов и школ.

Методология исследования. В основу исследования положен компаративистский (сравнительно-педагогический) подход, направленный на детекцию и экспликацию структурно-функциональных детерминант систем подготовки педагогических кадров в Финляндии и Республике Казахстан. С целью обеспечения триангуляции данных и повышения валидности результатов был развернут комплекс взаимодополняющих методов: системно-структурный и сравнительный анализ нормативно-правовых актов, регулирующих сферу высшего образования (ГОСО РК, Закон «О статусе педагога», финские рамочные стандарты); контент-анализ репрезентативных образовательных программ и силлабусов дисциплин; вторичный анализ эмпирических данных международных сравнительных исследований в области подготовки учителей (включая отчеты TALIS, ЮНЕСКО, ОЭСР) [9].

Верификация теоретических положений осуществлялась посредством дескриптивного анализа институциональных практик, зафиксированных авторами методом включенного наблюдения в ходе научно-образовательной стажировки на базе университета Ювяскюля (*University of Jyväskylä*).

Эмпирическую базу исследования составили: архитектоника и содержательное наполнение образовательных программ Института педагогического образования университета Ювяскюля; профильные образовательные программы ведущих педагогических университетов Казахстана по направлению «Подготовка учителей начальных классов» (ПМНО); корпус релевантных научных публикаций, индексируемых в международных наукометрических базах данных, по проблематике *research-based teacher education* (исследовательски ориентированного педагогического образования).

Примененный методологический конструкт позволил провести кросс-культурное сопоставление инвариантных и вариативных компонентов профессиональной подготовки учителей, а также выявить системные факторы, детерминирующие траекторию профессионального становления будущего педагога.

Результаты. Дифференциация национальных моделей педагогического образования позволила выявить глубокие дивергентные тенденции между финской (рефлексивно-исследовательской) и казахстанской (модернизируемой академической) системами по ряду ключевых векторов.

Рассматривая селекцию и академические требования (Пререквизиты к поступающим) мы обнаруживаем, что механизмы селекции на входе в профессию в исследуемых странах демонстрируют принципиально разную методологическую природу. Так, в Финляндии входной барьер базируется на многоступенчатом фильтре. Первая ступень - это национальный межуниверситетский экзамен *VAKAVA*, оценивающий способность абитуриентов критически анализировать научные тексты. Вторая ступень – институциональные собеседования, групповые дискуссии и симуляционные тесты на базе конкретных вузов. Согласно данным ОЭСР (*OECD, Education at a Glance*), финская модель характеризуется экстремально высоким уровнем конкуренции: средний конкурс на программы подготовки учителей начальных классов составляет от 8% до 10% от общего пула заявителей. Зачисление получает лишь каждый десятый кандидат, проявивший высокий уровень эмпатии, коммуникативной толерантности и некогнитивных *soft skills*.

В Казахстане же доминирующим предиктором отбора долгое время оставался исключительно суммативный балл Единого национального тестирования (ЕНТ). В рамках системной модернизации министерством был предпринят шаг по административному регулированию качества: пороговый балл для зачисления на педагогические специальности был целенаправленно повышен до 75 баллов (при среднереспубликанском минимуме в 50 баллов на другие направления). Несмотря на внедрение специального экзамена, проверяющего склонность к педагогической деятельности, процедура селекции сохраняет преимущественно формализованный, академико-центричный характер.

Это дает основание утверждать, что механический подъем проходного балла в Казахстане отсекает слабо подготовленных абитуриентов, но не решает задачу верификации их ценностно-мотивационных предикторов. Финский опыт доказывает необходимость диверсификации инструментов отбора: система должна оценивать не только прошлые академические заслуги (тесты), но и психологическую готовность к долгосрочному удержанию в профессии.

Анализ архитектоники образовательных программ представляет следующее. В Финляндии образовательный трек представляет собой континуум – интегрированную 5–6-летнюю непрерывную магистратуру. Научно-исследовательская компонента не надстраивается над учебным процессом, а выступает сквозным организующим стержнем с первого семестра. В Казахстане функционирует конвенциональная двухступенчатая модель (бакалавриат – 4 года, магистратура – 2 года). Степень сопряженности научно-теоретической и практической подготовки дифференцируется в зависимости от вуза, обнаруживая признаки дискретности при переходе между уровнями высшего и послевузовского образования.

Данное различие свидетельствует о более высокой преемственности и целостности подготовки в финской системе. Для Казахстана вывод заключается в том, что усиление вертикальной интеграции между уровнями образования и более раннее включение студентов в исследовательскую деятельность способны обеспечить устойчивое развитие профессиональных и аналитических компетенций будущих педагогов.

Исследовательская парадигма подготовки в Финляндии предполагает, что каждый студент осваивает методологию количественного и качественного анализа данных. Магистерская диссертация ориентирована на решение реальных микро- и макропроблем конкретной школы, выступая в роли прикладного клинического исследования.

В Казахстане исследовательская парадигма подготовки зачастую носит декларативный или сугубо теоретизированный характер, демонстрируя слабую корреляцию с реальными дефицитами школьной практики.

Считаем, что стратегическим приоритетом для Казахстана должно стать преодоление изоляции академической науки от школьной реальности. Необходимо переориентировать квалификационные работы будущих учителей на парадигму *Action Research* (исследование действием), формируя специалиста, способного принимать управленческо-дидактические решения на основе доказательных данных (*evidence-based education*).

Анализ институционализации и синергии педагогической практики представляет следующее. В Финляндии практическая подготовка осуществляется на базе специализированных университетских тренировочных школ (*Teacher Training Schools / Harjoittelukoulu*), обладающих статусом клинических лабораторий. Студент погружается в профессиональную среду под супервизией университетского методиста и школьного ментора одновременно.

В Казахстане практика рассредоточена по общеобразовательным школам на основе краткосрочных договоров, где качество наставничества и глубина рефлексии существенно варьируются ввиду высокой загруженности школьных учителей и отсутствия единых стандартов менторинга. Различия в институциональных подходах к сопряжению теоретической и практической подготовки наглядно отражены в схеме компаративного анализа моделей (Рисунок 1).

Институциональные модели практики	
Финляндия	Казахстан
триада «Университет – Школа-лаборатория – Студент»	Дискретная модель «Университет – (договор) – Школа»
интегрированная супервизия – исследование собственной практики	линейное наставничество – адаптивное наблюдение

Рисунок 1. Институциональные модели организации педагогической практики в Финляндии и Казахстане

Сопоставление демонстрирует, что эффективность практической подготовки возрастает при наличии устойчивой институциональной связи между университетом и школой. Для системы педагогического образования Казахстана это подчеркивает важность расширения сети университетских школ и развития наставничества.

Говоря о пределах академической автономии, необходимо отметить, что в Финляндии экстремально высокий уровень децентрализации. Отсутствие инспекций и жестких национальных учебных планов делегирует университетам право самостоятельно моделировать контент образования, оперативно реагируя на изменяющиеся запросы общества.

В Казахстане наблюдается поэтапное расширение академической свободы, однако рамки ГОСО и жесткие требования к структурированию компонентов образовательных программ (обязательные дисциплины, объемы циклов) по-прежнему лимитируют маневренность вузов.

Сравнительный анализ показывает, что академическая автономия способствует более оперативному обновлению содержания подготовки в соответствии с изменяющимися образовательными потребностями. Расширение автономии вузов РК может стимулировать инновации при сохранении национальных требований к качеству подготовки.

Результатом анализа по эволюции профессионального статуса и идентичности является следующее. В Финляндии высокий социокультурный статус профессии базируется на концепте «культуры доверия» (*culture of trust*). Общество априори признает за учителем статус автономного эксперта, обладающего правом на проектирование собственной методической системы.

В Казахстане благодаря принятию Закона «О статусе педагога» [6] материально-правовое положение учителей существенно улучшилось, однако трансформация общественного восприятия от «исполнителя инструкций» к «автономному интеллектуалу» находится в транзитной фазе.

Это различие указывает на тесную связь между качеством подготовки педагогов и их общественным статусом. Дальнейшее повышение престижа педагогической деятельности в РК должно сопровождаться укреплением исследовательской культуры и профессиональной автономии.

Таким образом, компаративный анализ инвариантных характеристик двух моделей показывает, что глубинное различие между ними кроется не столько в содержании учебных планов, сколько в принципах интеграции науки, автономии и практики. Для детального понимания внутренних механизмов функционирования рефлексивно-исследовательской среды необходим анализ конкретного дескриптивного кейса.

Наши наблюдения, зафиксированные в ходе научно-образовательной стажировки на базе Института педагогического образования Университета Ювяскюля (University of Jyväskylä), позволили изнутри изучить импликацию парадигмы *Research-Based Teacher Education* и верифицировать её ключевые детерминанты, представленные ниже.

Рассматривая специфику селекции на уровне вуза, необходимо отметить, что институциональный этап отбора в университете Ювяскюля полностью автономен. В ходе стажировки нам удалось зафиксировать, что после общенационального теста *VAKAVA* университет разворачивает собственный уникальный пул симуляционных заданий и психологических интервью, верифицирующих склонность к педагогической эмпатии. Вуз отбирает студентов не по объему заученной информации, а по их способности к критическому мышлению и коммуникативной толерантности, что коренным образом меняет вектор профессионального отбора уже на старте.

Этот подход находит свое прямое продолжение в содержательном наполнении обучения, где внутривузовская архитектоника программ отражает принципиально иной уровень интеграции. Интегрированный 5-летний трек магистратуры в Институте спроектирован на принципах декустомизации и междисциплинарности. Наблюдение за учебным процессом показало, что учебные модули формируются на стыке когнитивной психологии, нейронаук и цифровой дидактики. Это обеспечивает непрерывность и целостность формирования профессиональных компетенций без искусственного разрыва между бакалавриатом и магистратурой, характерного для дискретных моделей.

Описанная архитектоника служит фундаментом для глубокого погружения в науку, благодаря чему реализация исследовательской парадигмы перестает быть сугубо декларативной. Научная работа студентов в Ювяскюля жестко увязана с методологией *Action Research* (исследование действием). Как показал анализ исследовательских треков, данный компонент встроен в учебный план с первого семестра. Магистерская диссертация здесь не является компиляцией теоретических источников, а представляет собой прикладной клинический проект, направленный на решение конкретных дидактических дефицитов (включая дифференцированное обучение и инклюзивные стратегии) в реальной гетерогенной среде.

Практической же базой для верификации этих исследовательских гипотез выступает синергия педагогической практики, организованная на качественно ином

институциональном уровне. Профессиональная практика реализуется на базе собственной тренировочной школы-лаборатории (*Harjoittelukoulu*). В процессе включенного наблюдения нами была зафиксирована уникальная модель сочетанной, интегрированной супервизии, когда студент находится под одновременным наставничеством профессора-методиста университета и школьного учителя-ментора, превращая каждый проведенный урок в объект совместного глубокого рефлексивного анализа.

В конечном итоге, именно такое сопряжение науки и практики детерминирует институциональную автономию и идентичность субъектов образовательного процесса. Обладая экстремально высокой академической свободой, Институт самостоятельно модернизирует контент программ под запросы общества. Опыт стажировки позволяет утверждать, что эта свобода транслируется и на выпускников: образовательная среда вуза формирует у будущего учителя устойчивую идентичность автономного эксперта, способного принимать ответственные дидактические решения на основе доказательных данных (*evidence-based education*), а не простого исполнителя нормативных директив.

Резюмируя анализ кейса, следует констатировать, что синергетическим результатом функционирования данной образовательной экосистемы становится высокая конкурентоспособность выпускников, что подводит к необходимости макросопоставления данных систем в международном контексте обсуждения результатов.

Обсуждение результатов. Компаративный анализ позволяет констатировать, что феноменальная результативность финской образовательной экосистемы обусловлена ее структурным гомеостазом и синергией. Эффективность модели *research-based teacher education* находит прямое отражение в качестве макрорезультатов школьного сектора, фиксируемых международными мониторинговыми исследованиями.

Существует прямая корреляционная связь между автономией, закладываемой на уровне университета, и результатами школьников в рейтингах PISA. По данным ОЭСР (*OECD, PISA Results*), финские учащиеся стабильно демонстрируют высокие показатели функциональной грамотности (в среднем 484–510 баллов в зависимости от субтеста) при минимальном разрыве между результатами школ с разным социально-экономическим статусом. Это доказывает способность финского учителя, подготовленного как исследователь, автономно адаптировать дидактический контент под нужды гетерогенного класса.

Напротив, в Казахстане, согласно последним отчетам PISA, только около 50% учащихся достигают базового уровня математической грамотности, а в читательской грамотности этот показатель падает до 36%. Кроме того, фиксируется глубокий разрыв (достигающий нескольких лет обучения) между городскими и сельскими школами. Это указывает на дефицит у молодых педагогов компетенций в области дифференцированного обучения и работы с данными [7].

Проблема усугубляется результатами исследования TALIS (*OECD, TALIS Database*), которые обнажают глубокие институциональные барьеры. Ниже представлены ключевые индикаторы, отражающие распределение профессиональной свободы преподавателей [8].

В то время как более 90% финских учителей декларируют абсолютную автономию в выборе методов преподавания и проектирования контента (что является прямым следствием их исследовательской подготовки), казахстанские педагоги, по данным TALIS, сталкиваются с жестким внешним комплаенсом. Более 70% опрошенных учителей в РК указывают на то, что их деятельность жестко регламентирована типовыми учебными планами и административной отчетностью. Это неизбежно влечет за собой рост рутинной нагрузки, снижающий время на творческую и исследовательскую активность преподавателя:

В Финляндии уровень административной нагрузки составляет всего 33%, в то время как средний показатель по ОЭСР равен 49%. Сводные данные сопоставления автономии и нагрузки приведены в таблице 1.

Таблица 1. Сравнительные параметры профессиональной среды педагога по данным TALIS ОЭСР

Страна / Регион	Индикатор автономии (право выбора материалов и контента)	Уровень административной нагрузки (отчетность, рутина)	Основной вектор профессиональной идентичности
Финляндия	Экстремально высокий (>85%) – полное доверие со стороны государства.	Низкий (~33%) – минимум формальных отчетов, фокус на преподавании.	Автономный эксперт, исследователь собственной практики (*Reflective practitioner*).
ОЭСР (среднее)	Высокий (около 78%) – сбалансированная модель.	Средний (49%) – стандартизированная отчетность.	Квалифицированный исполнитель с правом на методическую гибкость.
Казахстан	Умеренный / Транзитный (~38–40%) – преобладание рамочных типовых планов.	Высокий (выше среднего по ОЭСР) – сохраняющийся комплаенс.	Модернизирующийся педагог в условиях жестких нормативных стандартов.

Это создает когнитивный диссонанс: вузы Казахстана пытаются обучать студентов инновационным исследовательским методам (*Action Research*), однако, приходя в реальную школу, молодой специалист попадает в жесткие рамки государственных стандартов, исключающих методический эксперимент. Таким образом, механический трансфер финских технологий без изменения институциональной «культуры доверия» (*culture of trust*) и децентрализации контроля не способен привести к радикальному сдвигу в качестве человеческого капитала.

Заключение (Conclusion). Проведенное сравнительное исследование систем подготовки учителей в Финляндии и Казахстане, подкрепленное изучением опыта университета Ювяскюля и данными международных мониторингов PISA и TALIS, показывает, что главное различие между моделями заключается не в содержании учебных предметов, а в самой организации учебного процесса.

Финская модель представляет собой непрерывное высшее образование в рамках магистратуры, где научно-исследовательская работа является стержнем всего обучения. В то же время казахстанская двухступенчатая модель (бакалавриат и магистратура) все еще сохраняет разобщенность при переходе с одного уровня на другой. Мы приходим к выводу, что исследовательские умения педагога невозможно сформировать простым увеличением часов на дипломную работу; они требуют воспитания особого профессионального мышления. При таком подходе учитель воспринимает любые трудности в классе как научную задачу, которую нужно решать на основе конкретных данных.

Кроме того, анализ данных TALIS и PISA выявил заметное противоречие между теоретической подготовкой в вузе и реальной средой в школах Казахстана. В то время как отечественные университеты стремятся обучать студентов гибким стратегиям работы и методам исследования практики, молодой специалист в школе сталкивается с жесткими рамками, доминированием типовых планов и высокой бумажной нагрузкой, уровень

которой в Казахстане превышает средний показатель по развитым странам (49%). Отсюда следует вывод, что эффективность реформ зависит не от копирования чужих технологий, а от предоставления школам большей самостоятельности. Без перехода от жесткого контроля к атмосфере взаимного доверия исследовательский потенциал выпускников вузов сведется к обычному исполнительству.

Изучение опыта университета Ювяскюля позволило увидеть, что школьная практика должна быть тесно связана с университетской наукой. В финском кейсе тренировочная школа при вузе работает как лаборатория, где теория и практика постоянно дополняют друг друга. Ключевым фактором успеха здесь выступает тесное взаимодействие цепочки «университет – школа-лаборатория – студент» под двойным руководством со стороны вузовского методиста и школьного учителя. Для Казахстана это означает необходимость ухода от формального наставничества по краткосрочным договорам к созданию постоянных университетских базовых школ. Именно совместное руководство позволяет превратить практику из простого наблюдения в глубокий анализ собственной деятельности.

Сравнительный анализ результатов PISA также показал, что способность финской системы сокращать разрыв между слабыми и сильными школами напрямую связана с готовностью учителей к инклюзивному образованию. В университете Ювяскюля умение работать в неоднородных классах встроено в методику преподавания каждого предмета. Для преодоления разрыва в качестве образования между городскими и сельскими школами Казахстана приоритетом должно стать обучение будущих педагогов методам дифференцированного обучения, что позволит учителю гибко менять материал под особенности конкретного класса.

В теоретическом плане данное исследование доказывает, что механическое копирование внешних правил (например, повышение проходного балла ЕНТ до 75 или введение профессиональных стандартов) без изменения внутренней культуры учебных заведений не ведет к автоматическому росту грамотности школьников. Практическая значимость выводов заключается в том, что модернизировать систему педагогического образования в Казахстане нужно через изменение характера студенческих научных работ, закрепление за передовыми школами статуса университетских баз и превращение школьных наставников в квалифицированных педагогов-супервизоров.

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The Role of English in the Career of a Modern Coach or Athlete

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Abstract

English has become an essential tool for communication and professional development in modern sport. The purpose of this study is to examine the role of English in the careers of athletes and coaches in the context of increasing internationalization of sport. The research is based on an analysis of scientific literature, sports communication practices, and the author's personal experience as a competitive boxer who has participated in international tournaments. The findings demonstrate that English facilitates communication during international competitions, provides access to professional educational resources, supports interaction with international media, and expands career opportunities. The study concludes that English should be considered a key professional competence for athletes and coaches in the contemporary global sports environment.

Keywords: English language, sport communication, international competitions, coaching, professional development, athletes, sports education.

Introduction

Modern sport has become a global phenomenon that connects athletes, coaches, officials, journalists, and fans from different countries. International competitions, training camps, exchange programs, and sports organizations require effective communication among people representing various linguistic and cultural backgrounds. In this context, English has become the dominant language of international communication (Crystal, 2012).

Globalization has significantly transformed the sports industry. Athletes frequently participate in international tournaments, while coaches increasingly collaborate with foreign specialists and sports organizations. According to Maguire (2011), the globalization of sport has increased the importance of intercultural communication and language competence among sports professionals.

The purpose of this article is to examine the role of English in the professional careers of modern athletes and coaches and to demonstrate its practical value through both academic sources and the author's personal experience.

Methodology

This study employs qualitative research methods. The research is based on:

- analysis of scientific and educational literature related to sports communication and globalization;
- comparative analysis of the role of English in international sports environments;
- reflective analysis of the author's personal experience as a boxer participating in international competitions.

These methods allow for the examination of both theoretical and practical aspects of English language use in sport.

The Author’s Professional Experience

The practical significance of English in sport can be demonstrated through the author's personal experience. As a competitive boxer competing in international tournaments, the author

has traveled abroad and interacted with athletes, coaches, referees, and organizers from various countries.

In many situations, English served as the only common language available for communication. Knowledge of English helped the author understand competition regulations, communicate with foreign athletes, ask for information, and navigate unfamiliar environments. During training camps and international events, English enabled the exchange of experiences with athletes from different countries and the establishment of professional contacts.

These experiences confirm that English is not merely an academic subject but an important professional tool in the daily life of modern athletes.

English in International Competitions

International competitions are among the most important components of modern sport. Athletes regularly participate in world championships, continental tournaments, Olympic qualification events, and international training camps.

English is widely used during these events. Competition schedules, technical regulations, accreditation procedures, and official announcements are frequently available in English. Referees, organizers, volunteers, and journalists often use English as their primary language of communication.

Athletes with English-language skills generally experience fewer communication difficulties and demonstrate greater confidence in international settings. Effective communication allows them to focus more fully on performance rather than logistical challenges.

English and Sports Education

Professional development is an essential aspect of successful athletic and coaching careers. Many scientific publications, coaching manuals, educational platforms, and online courses are available primarily in English.

According to Pedersen (2020), access to international educational resources contributes significantly to professional growth in sport. Coaches who understand English can study modern training methodologies, sports science research, and innovative coaching strategies.

Similarly, athletes can access information related to sports nutrition, psychology, injury prevention, rehabilitation, and performance optimization. Consequently, English serves as a gateway to current scientific knowledge and evidence-based practice.

Communication in International Teams

Modern professional sports teams often include players and coaching staff from different countries. In such environments, effective communication is essential for teamwork and success.

English frequently functions as a common language within multicultural teams. It allows players to understand tactical instructions, coordinate actions during competitions, and build positive relationships with teammates.

Effective communication contributes to team cohesion, minimizes misunderstandings, and improves overall performance. Therefore, language competence should be viewed as an important component of professional sports preparation.

English and Sports Media

The development of global media has increased the importance of communication skills among athletes and coaches. Television broadcasts, international interviews, press conferences, podcasts, and social media platforms have become integral parts of modern sport.

As noted by Rowe (2004), media communication plays a central role in shaping athletes' public image and professional reputation. Many international interviews are conducted in English because they are intended for a global audience.

Athletes who can communicate confidently in English are better able to interact with journalists, represent their countries and teams, and engage with international fans. Such communication may also attract sponsorship opportunities and increase professional visibility.

Technology in Modern Sport

Technological innovations continue to transform sports training and performance analysis. Athletes and coaches increasingly rely on digital platforms, wearable technologies, statistical software, and video analysis systems.

Most technological tools used in sport employ English terminology and interfaces. Understanding English therefore enables athletes and coaches to utilize these technologies more effectively and stay informed about international developments in sports science.

As sports technology continues to evolve, English proficiency becomes increasingly valuable for professional success.

English Learning among Student-Athletes in Kazakhstan

Based on the author's observations as a student at the Kazakh National University of Sport, attitudes toward English language learning vary considerably among student-athletes.

Many first-year students do not initially view English as an essential component of their professional education. Their primary focus is often directed toward athletic training and specialized sports subjects. Consequently, English may be perceived as a secondary academic discipline.

However, students who participate in international competitions frequently develop a different perspective. Personal experience abroad often reveals communication difficulties and demonstrates the practical value of English in real-life situations. As a result, many athletes become more motivated to improve their language skills after participating in international events.

These observations suggest that sports universities should place greater emphasis on practice-oriented English courses designed specifically for future athletes and coaches.

Challenges of Learning English

Despite its importance, learning English can be challenging for athletes and coaches. Intensive training schedules, frequent travel, and physical fatigue often reduce the time available for language study.

Some athletes also experience anxiety when communicating in a foreign language and may be reluctant to speak because they fear making mistakes. Nevertheless, regular practice and exposure to authentic communication can gradually increase confidence and competence.

Modern educational technologies, including mobile applications, online courses, and communication with foreign teammates, provide effective opportunities for language learning even within demanding athletic schedules.

Conclusion

The findings of this study demonstrate that English has become an essential professional competence in contemporary sport. It facilitates communication during international competitions, provides access to scientific and educational resources, supports effective interaction with media, and contributes to career development.

The author's personal experience in international boxing competitions confirms the practical significance of English in real sporting contexts. Athletes who possess English language skills are better prepared to participate successfully in the global sports community.

Therefore, English language education should be regarded as an important component of the professional preparation of future athletes and coaches. Developing language competence can significantly enhance both sporting performance and long-term career opportunities.

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Technical Sciences

Antioxidant capacity of sweet clover, St. John's wort and purslane extract mixtures assessed by ABTS assay

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Abstract

The development of plant extract compositions with high radical scavenging activity is a promising approach for creating natural antioxidant ingredients for functional foods. This work evaluated individual extracts of sweet clover (*Melilotus officinalis*), St. John's wort (*Hypericum perforatum*) and purslane (*Portulaca oleracea*), as well as their binary and ternary compositions, using the ABTS assay with expression of results as Trolox equivalent antioxidant capacity (TEAC, µmol TE/g dry weight). Among the individual extracts, St. John's wort and sweet clover demonstrated higher antioxidant activity, 88.74 and 85.65 µmol TE/g, respectively, whereas purslane showed 70.35 µmol TE/g. The binary compositions had increased TEAC values compared with most single extracts, and the St. John's wort + purslane combination showed one of the highest values at 94.16 µmol TE/g. The ternary composition with an equal ratio of 33:33:33 demonstrated the maximum antioxidant activity, reaching 99.38 µmol TE/g. These findings indicate that combining the studied plant extracts can enhance antioxidant potential and support their use as natural functional ingredients for fermented dairy products and other food systems.

Keywords

ABTS assay; TEAC; plant extracts; sweet clover; St. John's wort; purslane; antioxidant activity; extract composition

Introduction

The development of functional dairy products using secondary metabolites derived from plant material cultivated *in vitro* represents a promising direction in contemporary food biotechnology because it combines the goals of improving nutritional and biological value, broadening the range of health-oriented dairy systems, and identifying sustainable sources of natural bioactive ingredients (Kandyliari et al., 2023; Pant et al., 2021; Wawrosch & Zotchev, 2022). In recent years, interest in functional dairy foods has increased markedly as consumers and manufacturers have shifted attention toward products that provide benefits beyond basic nutrition and may help address oxidative stress and related metabolic disturbances (Kandyliari et al., 2023; Nistor et al., 2018). Within this context, fermented dairy products, especially yogurt and yogurt-like matrices, are widely regarded as effective carriers of plant-derived bioactive compounds because of their broad acceptance, favorable sensory properties, and technological compatibility with herbal and phenolic extracts (Kandyliari et al., 2023; Nistor et al., 2018; Zouari et al., 2024).

The functionality of such products is closely associated with the presence of plant secondary metabolites, including phenolic acids, flavonoids, tannins, terpenoids, and other phytochemicals that exhibit antioxidant, anti-inflammatory, antimicrobial, and potentially health-promoting

properties (Pant et al., 2021; Sharma et al., 2023; Wawrosch & Zotchev, 2022). These compounds are increasingly incorporated into dairy systems as natural ingredients because they can enhance antioxidant capacity, improve oxidative stability, and in some cases modify rheological behavior, water-holding capacity, texture, and overall product quality (Herrera et al., 2023; Nistor et al., 2018; Zouari et al., 2024). Their use also aligns with the current demand for natural alternatives to synthetic antioxidants and with the broader clean-label trend in functional food design (Kandyliari et al., 2023; Zouari et al., 2024).

At the same time, the conventional use of field-grown or wild-harvested plant raw materials as sources of bioactive compounds is associated with substantial limitations (Sharma et al., 2023; Wawrosch & Zotchev, 2022). The composition of plant tissues depends strongly on genotype, developmental stage, season, climate, soil conditions, environmental stress, harvesting practices, and post-harvest handling, which results in considerable variation in the concentration and profile of target metabolites (Wawrosch & Zotchev, 2022). For the food industry, and particularly for the design of standardized functional ingredients, such variability is problematic because it complicates process reproducibility, dosage justification, quality consistency, and reliable prediction of biological performance in the final product (Sharma et al., 2023; Wawrosch & Zotchev, 2022). In addition, large-scale harvesting of medicinal or food plants from natural populations may threaten biodiversity, while open-field cultivation requires substantial land, water, and seasonal resources (Wawrosch & Zotchev, 2022).

Against this background, the biotechnological production of secondary metabolites through plant cells, tissues, and organs cultivated *in vitro* has attracted increasing attention as an alternative source of valuable phytochemicals (Pant et al., 2021; Sharma et al., 2023; Wawrosch & Zotchev, 2022). Recent reviews emphasize that *in vitro* systems can provide a more predictable, year-round, and potentially scalable route for obtaining bioactive compounds than conventional extraction from whole plants (Pant et al., 2021; Sharma et al., 2023).Their main advantages include independence from seasonality and weather conditions, tighter control over biomass quality, the possibility of directing metabolite biosynthesis through medium composition, plant growth regulators, and elicitors, and improved opportunities for standardization (Sharma et al., 2023; Wawrosch & Zotchev, 2022). Depending on the target compounds, different systems can be employed, including callus cultures, cell suspension cultures, adventitious root cultures, hairy root cultures, and micropropagated plant biomass generated under controlled conditions (Pant et al., 2021; Sharma et al., 2023).

The literature increasingly indicates that *in vitro* plant biotechnology is no longer relevant only to pharmaceutical applications, but is also becoming important for the production of ingredients intended for the food and nutraceutical sectors (Sharma et al., 2023; Verpoorte et al., 2008). Secondary metabolites produced in controlled plant culture systems may serve as natural antioxidants, pigments, aroma-active compounds, preservatives, or multifunctional ingredients with additional physiological potential (Sharma et al., 2023; Verpoorte et al., 2008). From the perspective of food formulation, one of the most significant advantages of this approach is the possibility of selecting or inducing biomass with a desired phytochemical profile, thereby creating extracts with higher compositional reproducibility than many conventionally sourced plant materials (Wawrosch & Zotchev, 2022).

Fermented dairy products are particularly suitable matrices for the incorporation of such ingredients (Kandyliari et al., 2023; Nistor et al., 2018). Yogurt is characterized by high nutritional value, digestibility, consumer familiarity, and technological flexibility, which allows plant extracts to be added before fermentation, during fermentation, or after gel formation, depending on the desired functional and technological outcome (Kandyliari et al., 2023; Nistor et al., 2018). In addition, the dairy protein-fat matrix does not simply act as a passive carrier; it can influence the stability, release, transformation, and sensory perception of plant metabolites, making the

interaction between phytochemicals and fermented milk systems an important research topic in its own right (Kandyliari et al., 2023; Stoupi et al., 2024).

A growing body of evidence demonstrates that the enrichment of yogurt and related dairy products with plant extracts can significantly enhance their antioxidant properties (Herrera et al., 2023; Kandyliari et al., 2023; Nistor et al., 2018). In the study by Nistor et al. (2018), the addition of aqueous extracts from wild herbs improved antioxidant indicators and affected the physicochemical and rheological characteristics of yogurt during storage, showing that herbal fortification can modify both functionality and technological performance. More recently, Kandyliari et al. (2023) reported that aqueous extracts and plant-derived byproducts can be effectively used for the fortification of kefir, cream cheese, yogurt, and vegan yogurt; importantly, the authors evaluated not only antioxidant and phenolic content but also the bioaccessibility of these compounds after *in vitro* digestion. This is especially relevant because the nutritional significance of phytochemical enrichment depends not only on the initial concentration of compounds in the food matrix, but also on their stability and transformation during gastrointestinal digestion (Kandyliari et al., 2023; Stoupi et al., 2024).

The value of plant-derived ingredients for dairy applications has also been demonstrated in studies involving specific botanical sources. Herrera et al. (2023) showed that yogurt fortified with extracts from strawberry tree and hawthorn had improved antioxidant capacity and additional functional properties while maintaining acceptable consumer-related characteristics; the hawthorn treatment was especially notable for high total phenolic content and strong antioxidant performance according to ABTS and ORAC assays. Likewise, Zouari et al. (2024) found that the incorporation of a peppermint phenolic extract markedly increased the antioxidant activity of yogurt, improved resistance to lipid peroxidation, and preserved acceptable physicochemical and sensory attributes during cold storage. Other studies likewise indicate that plant extracts may affect not only antioxidant potential, but also texture, syneresis, acidity, microbiological quality, and fatty acid composition in fermented dairy products (Herrera et al., 2023; Nistor et al., 2018; Zouari et al., 2024).

Despite these advances, most published studies on plant-enriched dairy systems still rely on extracts obtained from conventionally grown, harvested, or wild plant materials, whereas the use of secondary metabolites derived from *in vitro* cultivated plant biomass remains far less explored in food technology (Kandyliari et al., 2023; Sharma et al., 2023). This gap is important because *in vitro* systems offer the potential to produce more standardized extracts and to support the rational design of functional foods with targeted phytochemical composition and predictable antioxidant properties (Sharma et al., 2023; Wawrosch & Zotchev, 2022).For dairy science, this opens the possibility of moving beyond empirically selected herbal additives toward more controlled ingredient systems based on biotechnologically generated plant metabolites (Wawrosch & Zotchev, 2022).

Phenolic compounds and flavonoids are of special interest in this regard because they are among the most significant plant secondary metabolites associated with antioxidant activity (Kandyliari et al., 2023; Wawrosch & Zotchev, 2022). The review by Wawrosch and Zotchev (2022) describes plant cell and tissue cultures as alternative sources of high-value secondary metabolites, including phenylpropanoids, flavonoids, phenolic acids, and related compounds, and emphasizes that their production can be enhanced by elicitation and medium optimization.Similarly, Sharma et al. (2023) highlighted the potential of tissue culture systems to generate compounds of interest for pharmaceutical, cosmetic, agricultural, and food applications. Accordingly, the use of extracts obtained from *in vitro* cultivated plant materials in dairy technology lies at the intersection of two rapidly developing areas: plant biotechnology and functional fermented food design (Kandyliari et al., 2023; Sharma et al., 2023).

An additional consideration in the development of functional dairy products is the compatibility of the plant-derived ingredient with the protein-colloidal structure of milk (Nistor et al., 2018; Stoupi et al., 2024). Phenolic compounds can interact with caseins and whey proteins, and such interactions may influence the apparent antioxidant response, the release of phytochemicals during digestion, and the structural and sensory properties of the final product (Kandyliari et al., 2023; Stoupi et al., 2024). The addition of plant extracts may also alter acidification kinetics, gel formation, water retention, and storage stability, which means that technological development requires integrated evaluation of chemical, microbiological, rheological, and sensory parameters rather than antioxidant analysis alone (Herrera et al., 2023; Nistor et al., 2018).

Dose optimization is another critical issue. Increased extract concentration does not always translate into proportional improvement in functional performance because the final outcome depends on color intensity, herbal flavor, bitterness, astringency, physical stability, and the fate of bioactive compounds in the dairy matrix during processing and storage (Herrera et al., 2023; Stoupi et al., 2024; Zouari et al., 2024). In the case of *Cistus creticus* leaf extract, Stoupi et al. (2024) showed that enrichment can improve antioxidant properties while maintaining satisfactory physicochemical quality only within a suitable concentration range. Similar observations were reported for peppermint extract, where moderate addition levels delivered substantial antioxidant benefits without causing unacceptable sensory deterioration (Zouari et al., 2024).

These considerations become even more important when the added ingredient is derived from *in vitro* cultivated plant biomass, because such extracts may contain elevated or selectively enriched levels of specific metabolites (Sharma et al., 2023; Wawrosch & Zotchev, 2022). As a result, the design of dairy technologies based on these ingredients requires justification of the introduction stage, evaluation of effects on starter culture performance, and assessment of stability during refrigerated storage (Herrera et al., 2023; Nistor et al., 2018). A recent study on yogurt supplemented with aqueous extracts of medicinal plants reported increased total phenolic content and antioxidant activity relative to the control throughout storage, highlighting the importance of monitoring functional changes over time (Benloucif et al., 2025).

Another important issue is the bioaccessibility of secondary metabolites within the dairy matrix. High phenolic content or strong antioxidant activity measured directly in the product does not necessarily guarantee physiological effectiveness after consumption (Kandyliari et al., 2023; Stoupi et al., 2024). For this reason, studies that incorporate simulated *in vitro* digestion and, in some cases, colonic fermentation are becoming increasingly important, because they provide insight into the stability, release, and transformation of plant-derived compounds under gastrointestinal conditions (Kandyliari et al., 2023; Stoupi et al., 2024; Tzima et al., 2025).Such approaches are particularly relevant for products enriched with phenolic extracts, since interactions with proteins, pH changes, and enzymatic hydrolysis may significantly alter the antioxidant profile after ingestion (Stoupi et al., 2024; Tzima et al., 2025).

The use of *in vitro* cultivated plant raw materials also creates opportunities for targeted modulation of extract composition. In plant biotechnology systems, the accumulation of desired metabolites can be adjusted through the selection of carbon sources, mineral nutrients, plant growth regulators, temperature and light conditions, and biotic or abiotic elicitors such as methyl jasmonate and salicylic acid (Sharma et al., 2023; Wawrosch & Zotchev, 2022). This capability is highly valuable for designing functional ingredients with a defined antioxidant profile and for improving batch-to-batch consistency in food applications (Wawrosch & Zotchev, 2022). In the long term, this approach may support a transition from the empirical use of plant extracts as generic additives toward the development of scientifically designed phytochemical compositions with controlled contents of key bioactive compounds (Sharma et al., 2023; Wawrosch & Zotchev, 2022).

Taken together, the available literature clearly indicates the relevance of research focused on the development of functional dairy products using secondary metabolites derived from plant materials cultivated *in vitro* (Kandyliari et al., 2023; Nistor et al., 2018; Pant et al., 2021; Sharma et al., 2023). On the one hand, numerous studies show that plant extracts can enhance antioxidant activity and may improve several technological and consumer-relevant properties of fermented dairy products (Herrera et al., 2023; Nistor et al., 2018; Zouari et al., 2024). On the other hand, reviews in plant biotechnology demonstrate that *in vitro* systems are realistic and increasingly sophisticated tools for obtaining valuable secondary metabolites, especially phenolic compounds, in a controlled and sustainable manner (Pant et al., 2021; Sharma et al., 2023; Wawrosch & Zotchev, 2022). However, the integration of these two fields—the biotechnological production of plant metabolites and the technology of fermented dairy systems—remains insufficiently developed, which defines the scientific novelty and practical importance of research in this area (Kandyliari et al., 2023; Sharma et al., 2023).

Therefore, the development of technologies for functional dairy products incorporating secondary metabolites from *in vitro* cultivated plant raw materials can be regarded as both scientifically justified and technologically important (Kandyliari et al., 2023; Sharma et al., 2023). Such work may broaden the raw-material base available for functional dairy manufacturing, improve the reproducibility of ingredient composition, and enable more precise control over the biological properties of final products (Nistor et al., 2018; Wawrosch & Zotchev, 2022). For food science and dairy technology, this direction provides a strong platform for creating new fermented milk products with predictable antioxidant characteristics, improved functional profiles, and enhanced added value for health-oriented consumers (Herrera et al., 2023; Kandyliari et al., 2023; Zouari et al., 2024).

Materials and Methods

Materials

The plant materials used in the study were sweet clover (*Melilotus officinalis*), St. John's wort (*Hypericum perforatum*), and purslane (*Portulaca oleracea*), selected because these species are recognized as sources of phenolic compounds and other antioxidant phytochemicals relevant to functional dairy product development. Individual extracts of the three plants were prepared in advance and then used for the formulation of mixed extract systems.

Preparation of extract compositions

Three ternary extract compositions were prepared by combining sweet clover, St. John's wort, and purslane extracts in different proportions. The studied ratios were 35:35:30, 35:30:35, and 40:25:35, representing the percentage contribution of sweet clover, St. John's wort, and purslane extracts, respectively, in each mixed formulation. In addition to the ternary formulations used for yogurt enrichment, the antioxidant activity of the individual extracts and selected binary and ternary compositions was evaluated separately by the ABTS assay to compare their TEAC values and identify the composition with the strongest radical scavenging capacity.

Determination of antioxidant activity

The antioxidant activity of plant extract compositions was determined using the ABTS radical cation decolorization assay, and the results were expressed as Trolox equivalent antioxidant capacity (TEAC). For quantification, a Trolox calibration curve was used, and the antioxidant response of the samples was converted into Trolox equivalents. The final values were expressed as µmol TE/g, which allowed direct comparison of the antioxidant capacity of the control yogurt, yogurt enriched with plant extract mixtures, individual extracts, and mixed extract compositions.

Statistical presentation

The antioxidant activity data were presented as TEAC values in µmol TE/g and summarized in tabular and graphical form for comparative interpretation. The graph prepared from the ABTS

dataset was used to visualize differences among the individual extracts and extract compositions and to support interpretation of the most promising antioxidant formulations.

Results and Discussion

The antioxidant activity of individual plant extracts and their mixtures was evaluated using the ABTS assay and expressed as Trolox equivalent antioxidant capacity (TEAC, µmol TE/g dry extract) shown figure 1. The TEAC values of single extracts ranged from about 70 to 89 µmol TE/g, with St. John's wort and sweet clover showing higher activity than purslane, which is consistent with published data on the phenolic richness of these species (Liu et al., 2018; Pant et al., 2021; Wawrosch & Zotchev, 2022). Mixed formulations generally exhibited higher TEAC values than the individual extracts, indicating additive or synergistic effects between the phenolic constituents of the three plants (Kandyliari et al., 2023; Nistor et al., 2018).

Binary mixtures, particularly the combination of St. John's wort and purslane, showed pronounced antioxidant activity, while the highest TEAC was observed for the ternary composition with equal contributions of all three extracts (33:33:33). This confirms that a rational selection of ratios makes it possible to enhance the total radical-absorbing potential of phytomixtures, which is in good agreement with data on other plant compositions used as natural antioxidants (Herrera et al., 2023; Shori, 2022). Thus, the studied mixtures of extracts of sweet clover, St. John's wort and purslane can be considered as promising compositions for subsequent inclusion in functional food matrices.

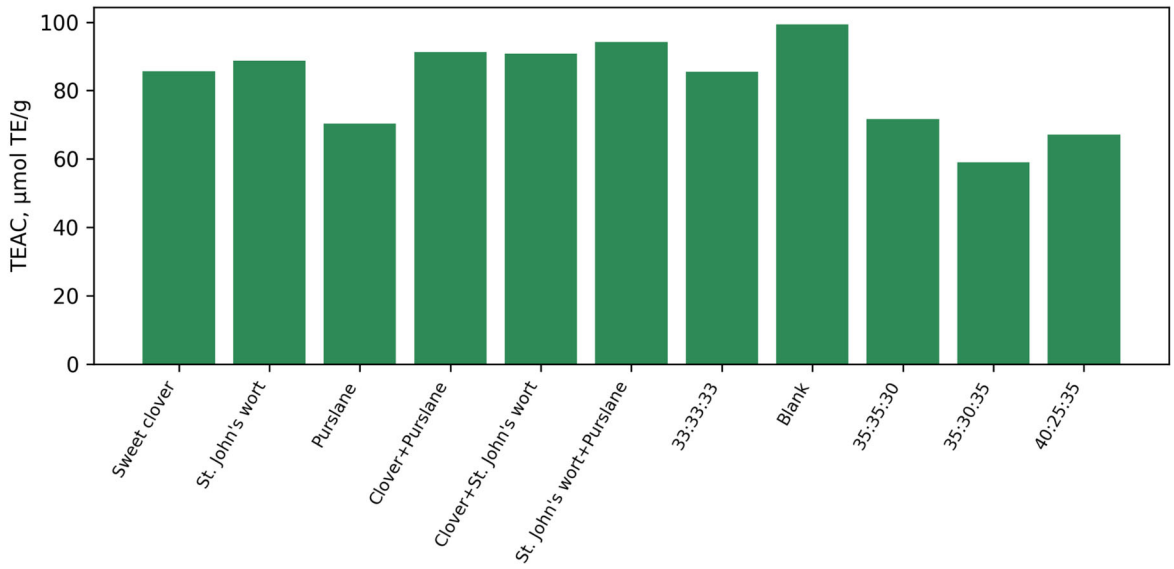

Figure 1 - Antioxidant activity of studied samples

Conclusion

The present study demonstrated that individual extracts of sweet clover, St. John's wort, and purslane possess measurable antioxidant activity, and that their combinations can further enhance ABTS radical scavenging capacity expressed as TEAC. Mixtures of the three extracts generally showed higher TEAC values than the single extracts, with the equimolar ternary composition (33:33:33) exhibiting the strongest antioxidant response and several binary blends also outperforming their individual components. These findings indicate that rational blending of medicinal and culinary plant extracts is an effective strategy to obtain phytochemical compositions with improved antioxidant potential, in agreement with previously reported effects of multi-herb formulations in dairy and non-dairy systems (Herrera et al., 2023; Kandyliari et al., 2023). The developed extract compositions can therefore be considered promising natural antioxidant ingredients for subsequent incorporation into fermented dairy matrices and other functional food prototypes.

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Reduction of CO2 Emissions and Energy Consumption through Cement Minimization in Cement-Plastic Composite Masonry Blocks

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Abstract
The construction sector is one of the largest consumers of energy and raw materials and is responsible for a substantial share of global greenhouse gas emissions. Cement production is especially important in this context because it requires high-temperature processing and releases carbon dioxide both through fuel combustion and limestone calcination. The present paper evaluates the potential reduction of CO2 emissions and energy consumption achieved through cement minimization in cement-plastic composite masonry blocks incorporating recycled plastic waste and alternative mineral fillers. The proposed approach combines material substitution, lightweight composite design and improved thermal performance of building envelopes. Experimental data obtained for recycled plastic-mineral composite blocks indicate that an optimized composition can reduce material density and thermal conductivity while maintaining compressive strength suitable for lightweight masonry applications. A simplified environmental assessment is used to estimate cement-related CO2 savings and operational energy benefits associated with lower heat transfer through wall elements. The results demonstrate that reducing cement content by approximately 30-35% and incorporating recycled plastic waste can contribute to lower embodied emissions, improved resource efficiency and reduced building energy demand. The developed concept supports circular economy principles and provides a practical pathway for low-carbon construction materials in regions where plastic waste accumulation and energy efficiency remain important environmental challenges.
Keywords: cement minimization; CO2 reduction; recycled plastic; composite masonry blocks; energy efficiency; circular economy; low-carbon construction

1. Introduction

Modern construction faces two closely connected challenges: the need to reduce greenhouse gas emissions and the need to improve the energy performance of buildings. Conventional masonry and concrete products are widely used because of their durability and structural reliability; however, their production is associated with significant consumption of cement, mineral resources and energy.

Cement is a critical component of many building materials, but it is also one of the most carbon-intensive materials. CO2 is emitted during clinker production as a result of fuel combustion and the chemical decomposition of limestone. Therefore, reducing cement consumption in non-load-

bearing and lightweight masonry products represents an important opportunity for lowering embodied carbon.

At the same time, plastic waste accumulation has become a major environmental problem. Large quantities of plastic waste remain uncontrolled, especially in regions where recycling infrastructure is limited. Incorporating recycled plastic into construction materials can reduce environmental pressure and transform waste into a useful engineering resource.

This study presents an approach based on cement-plastic composite masonry blocks, where part of the conventional mineral-cement matrix is replaced or modified by recycled plastic and alternative mineral fillers. The aim is to achieve a balance between reduced cement use, improved thermal insulation and acceptable mechanical performance.

2. Research Aim and Objectives

The aim of the research is to evaluate the environmental and energy benefits of cement minimization in recycled plastic composite masonry blocks and to demonstrate their potential for low-carbon construction applications.

The main objectives are:

- to analyze the role of cement reduction in decreasing embodied CO2 emissions;
- to evaluate the use of recycled plastic waste as a functional component of composite masonry blocks;
- to determine the relationship between density, thermal conductivity and cement-plastic composition;
- to assess the potential reduction of building heat losses through lower thermal conductivity;
- to formulate practical recommendations for the application of low-carbon composite blocks in energy-efficient buildings.

3. Materials and Concept of the Composite Block

The investigated composite masonry blocks are based on recycled plastic waste, reduced cement content and locally available mineral fillers. The recycled plastic component contributes to lower density and reduced thermal conductivity, while mineral fillers provide dimensional stability and mechanical resistance. Cement is used as a binding component in reduced quantities compared with conventional cement-based masonry materials.

The general concept of the material is presented in Table 1. The exact composition may be adjusted according to local raw materials, required strength class and thermal performance targets.

Component	Function in composite block	Expected environmental effect
Reduced cement content	Binding and structural contribution	Lower clinker-related CO2 emissions
Recycled plastic waste	Lightweight phase and thermal resistance component	Waste utilization and lower density
Crushed brick / mineral filler	Skeleton and dimensional stability	Use of local or secondary mineral resources
Porous structure / air cavities	Additional thermal resistance	Reduced heat transfer through wall element

Table 1. Functional role of components in cement-plastic composite masonry blocks.

4. Methodological Approach

The evaluation combines experimental observations, simplified thermal calculations and an environmental assessment of cement reduction. The following parameters were considered:

density, thermal conductivity, compressive strength, cement content, recycled plastic content and wall thermal transmittance.

The environmental benefit was assessed through the reduction of cement mass in the block. The simplified cement-related CO2 reduction can be expressed as:

CO2_saved = (m_c,ref - m_c,new) x EF_c

where CO2_saved is the avoided cement-related carbon dioxide emission, m_c,ref is the cement mass in the reference block, m_c,new is the cement mass in the optimized block, and EF_c is the emission factor of cement production.

The thermal benefit was estimated using the wall thermal transmittance relation:

U = 1 / (R_si + delta/lambda + R_se)

where U is the thermal transmittance, delta is wall thickness, lambda is thermal conductivity, and R_si and R_se are internal and external surface thermal resistances.

For energy saving estimation, the following simplified relation may be used:

Q_saved = (U_ref - U_new) x A x HDD x 24 / 1000

where Q_saved is annual heating energy saving, A is wall area, HDD is heating degree days, and U_ref and U_new are thermal transmittance values of the reference and improved wall systems.

5. Results and Discussion

The experimental and analytical results indicate that replacing part of the conventional cement-mineral matrix with recycled plastic and controlled porosity reduces density and thermal conductivity. Optimized recycled plastic composite blocks reached density values in the range of approximately 650-710 kg/m3 and thermal conductivity values close to 0.10-0.17 W/mK, depending on composition and porosity.

Table 2 summarizes the typical performance ranges used for the assessment. These values represent a realistic engineering range for lightweight masonry blocks based on the conducted experimental program.

Parameter	Reference cement-based masonry	Optimized cement-plastic composite block
Density	Higher than 900 kg/m3	650-710 kg/m3
Thermal conductivity	0.25-0.45 W/mK or higher	0.10-0.17 W/mK
Cement consumption	100% reference level	Approximately 30-35% lower
Recycled plastic utilization	Not included	Included as functional component
Thermal performance	Medium	Improved
CO2 impact	Higher	Reduced

Table 2. Comparative assessment of reference and optimized masonry block systems.

The reduction of cement content is particularly important because every kilogram of cement avoided contributes to lower embodied carbon. In addition, the improved thermal properties of the composite block may reduce heating demand during the service life of the building. Therefore, the developed material provides both embodied and operational environmental benefits.

6. Cement Reduction and CO2 Saving Scenario

A simplified scenario was developed to illustrate the environmental effect of cement minimization. If the cement content in a composite block is reduced by approximately 35% compared with a conventional reference block, the cement-related CO2 emissions are reduced proportionally. This calculation is conservative because it considers only cement reduction and does not fully account for additional benefits associated with improved thermal performance and waste plastic utilization.

Scenario	Relative cement content	Relative cement-related CO2 emissions	Estimated reduction
Reference block	100%	100%	0%
Composite block with moderate reduction	80%	80%	20%
Optimized composite block	65%	65%	35%

Table 3. Simplified cement-related CO2 reduction scenario.

The results show that cement minimization is an effective strategy for reducing the embodied carbon of masonry products. When combined with recycled plastic utilization and lower thermal conductivity, the total environmental benefit becomes broader than cement reduction alone.

7. Energy Performance of Wall Elements

The thermal performance of a masonry wall depends on the thermal conductivity of the block and the wall thickness. For a 0.30 m thick wall element produced from optimized composite blocks, the calculated thermal transmittance may reach approximately 0.35-0.40 W/m2K when hollow cavities and surface resistances are taken into account. Such values are relevant for energy-efficient external wall applications.

Wall system	Wall thickness	Thermal conductivity / system behavior	Approximate U-value
Conventional masonry wall	0.30 m	Higher heat transfer	Above optimized target
Solid composite block wall	0.30 m	lambda approximately 0.15-0.17 W/mK	Approximately 0.45-0.55 W/m2K
Hollow composite block wall	0.30 m	Improved thermal resistance through cavities	Approximately 0.35-0.40 W/m2K

Table 4. Thermal performance scenario for wall elements based on composite blocks.

The results indicate that the material has potential not only as a low-carbon masonry product but also as a component of energy-efficient building envelopes. Reduced U-values lead to lower heating demand, which is especially important in buildings with large wall areas and long heating periods.

8. Circular Economy and Resource Efficiency

The proposed technology supports circular economy principles by transforming recycled plastic waste into a functional construction material. This reduces the need for primary raw materials and diverts plastic waste from uncontrolled accumulation. The use of local mineral fillers further improves resource efficiency by reducing transportation needs and enabling regional material cycles.

The environmental logic of the proposed material can be summarized as follows: plastic waste is transformed into a lightweight thermal resistance component; cement consumption is reduced; thermal performance is improved; and operational energy demand decreases during building use.

Environmental aspect	Contribution of proposed material
Plastic waste management	Recycled plastic is used as a construction material component
Cement reduction	Lower cement content decreases embodied CO2
Energy efficiency	Reduced thermal conductivity lowers heat losses
Local resource use	Mineral fillers can be obtained locally
Circular economy	Waste is converted into a functional product

Table 5. Environmental benefits of cement-plastic composite masonry blocks.

9. Limitations and Future Research

The present assessment is based on experimental performance ranges and simplified environmental calculations. For full industrial implementation, additional investigations are required. Future work should include long-term durability testing, fire resistance evaluation, freeze-thaw performance, water absorption analysis, large-scale wall tests and life-cycle assessment. More detailed CO2 calculations should include cement production, plastic processing, transportation, manufacturing energy and operational energy savings over the building service life.

10. Conclusions

1. Cement minimization in composite masonry blocks represents an effective strategy for reducing embodied CO2 emissions in construction materials.
2. Recycled plastic waste can be incorporated as a functional component of lightweight composite blocks, contributing to lower density and improved thermal performance.
3. Optimized cement-plastic composite blocks may achieve density values of approximately 650-710 kg/m3 and thermal conductivity values of approximately 0.10-0.17 W/mK.
4. A cement reduction of approximately 30-35% provides a proportional decrease in cement-related CO2 emissions.
5. Hollow composite block wall systems with a thickness of 0.30 m can achieve U-values of approximately 0.35-0.40 W/m2K, supporting energy-efficient building envelope applications.
6. The proposed material contributes simultaneously to plastic waste recycling, cement reduction, energy efficiency and circular economy objectives.
7. Further research should focus on durability, fire resistance, industrial production and complete life-cycle assessment.

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LoRaWAN: A Mathematical Study of Simple-Signal Modulation Transforms and Realizing CSS (Chirp Spread Spectrum) by Means of FM

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Abstract. LoRa, the physical layer beneath LoRaWAN, owes its long range and robustness to chirp spread spectrum (CSS) modulation, in which each symbol is a linear-frequency-modulated sweep. This article explores very basic modulation schemes mathematically to reveal the formal linkages among them and demonstrates that CSS is not an unusual method but a unique version of frequency modulation (FM) with a linear-frequency-ramp message. Beginning from the instantaneous-phase expression for a complex sinusoid, we develop the chirp signal, illustrate the up-chirp and down-chirp as a complex-conjugate pair, and demonstrate that using a linear modulating function into the FM formula produces the LoRa chirp phase. The cyclic frequency shift of a LoRa symbol's data bearing also equates to an offset or a phase break of the modulating ramp, which can be recovered as a single tone by a conjugate de-chirping receiver. Based on these foundations, we will describe how to create a CSS-like signal by driving an FM modulator with a chirp baseband, mapped to available hardware (the SX1276/SX1278/LR1276 transceivers and the STM32F103 host). Finally, we present an analogical hypothetical application that injects such a baseband into the FM channel of a standard UHF voice radio. We conclude with a symbolic, purely qualitative analysis of the distortion that occurs when a linear-frequency-modulated signal is created by means of an FM chain. The material presented here is entirely theoretical; it has no numerical measurement.

Keywords: LoRaWAN, modulation, transmission, frequency, channel.

0. Brief Methodology

This research examines families of simple modulation techniques for carrying information on a radio carrier. These modulation techniques will be examined in conjunction with each other, rather than separately; using a common analytic framework that allows us to express one modulation technique in terms of others. Specifically, we seek to provide the justification of the transition from frequency modulation (FM) to the chirp spread-spectrum (CSS) modulation which underlies the Lora and subsequently the LoraWan protocols [1],[2].

The mathematical tools employed are basic and have been kept so: the instantaneous phase and instantaneous frequency of a complex exponential, the time integral linking a modulating function to the phase of a frequency modulated (FM) signal, and the complex conjugate relating an up-chirp to a down-chirp. The key formulae were based upon the standard treatment of radio-engineering signals provided in [22] and the methods for interpreting signals described in [23], while the fundamental principles of modulation are based on those presented in [4]. The CSS description has been constructed from both the physical layer analysis in [20] and the study of transmitting chirps in [21], and verified against independently developed LoRa receiver implementations [8], [10], [11], [16]. The hardware mapping was performed using a published integration of LR1276/SX1276 with STM32F103 [19], and also utilizing the SX1278 datasheet [9].

We explicitly state our position regarding the result at the start. A chirp is defined in the radar literature [23] as a linearly frequency modulated signal and is thus well known and accepted. Therefore, our contribution does not describe or prove this relationship but provides a pedagogical development of this relationship through the use of instantaneous phase, a constructive method to achieve this relationship, and a study of realizing and distorting this relationship into accessible transceivers and radio hardware.

Our purposefully limited scope.We analyze and explain the signal relationships (and thus do not simply restate) and limit our contribution to the modulation transformation and its hypothetical implementation. There is no actual prototype being measured so there are no numbers associated with the distortion analysis of Section 3. Coding, interleaving, whitening, and media access [13],[14] are all outside the present discussion. Quantitative link budgets and interference evaluation [3],[12] are also outside the scope of this work. Additionally advanced spatial processing extensions including multi-antenna channel management [17] and high resolution direction finding of radio signals [18] are also beyond the scope of the single channel approach used in this work.

1. Introduction: LoRa Modulation Compared with FM

LoRaWAN is a low-power, wide-area networking standard based upon the LoRa physical layer which is a proprietary technique developed by Semtech using Chirp Spread Spectrum along with Frequency Shift Keying to encode symbols into the frequency shift [20]. LoRa's popularity for the Internet of Things can be attributed to several characteristics. First, LoRa provides protection against Multipath Fading and Doppler Effect. Second, LoRa's constant envelope nature results in efficient operation of the Power Amplifier, while also providing a natural ranging ability due to its Linear Frequency Modulation [1][20]. The same characteristics as above result in LoRa having the appearance of being similar to Ordinary FM when examined more closely. Therefore, a description of how these two schemes compare is necessary to provide a basis for everything else discussed below. Figure 1 illustrates both schemes simultaneously. In FM, the Instantaneous Frequency of the Carrier is a function of the arbitrary message. In CSS, however, the Instantaneous Frequency is a straight line that moves through a specified bandwidth during each symbol. If the message

sent via FM is a straight line corresponding to the straight-line movement in CSS then the two waveforms will be identical.

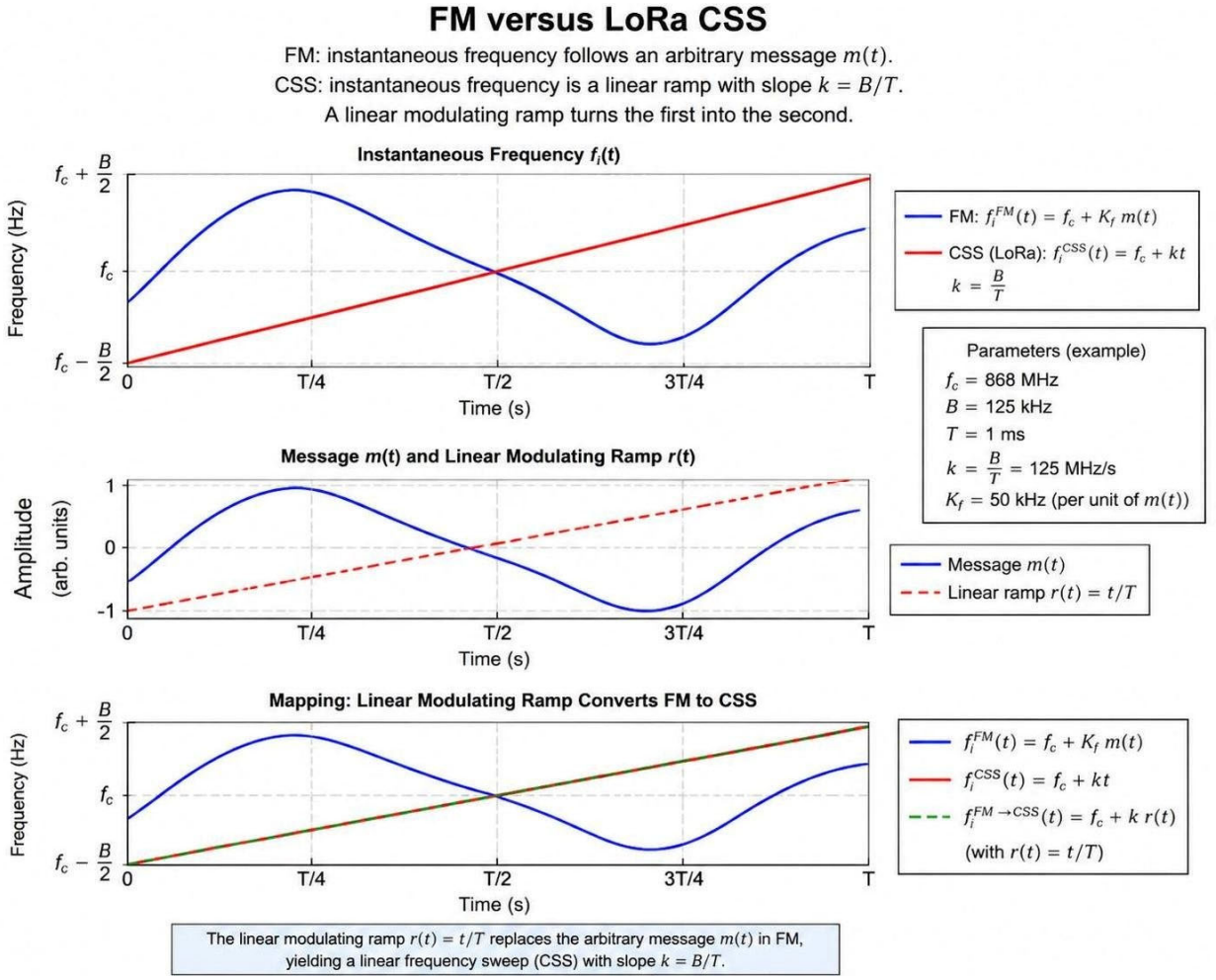

Figure 1. Comparison of FM and LoRa CSS. In FM the instantaneous frequency follows an arbitrary message m(t); in CSS it is a linear ramp of slope k = B/T. A linear modulating ramp turns the first into the second.

1.1. Related work and positioning

Research into Chirp Spread Spectrum has taken place along two primary axes: as a method of modulation to characterize both its error rate and spectral behavior; and as a waveform that receivers will need to decode. Both Reynders and Pollin have developed the theory behind CSS as a method of long range modulation with specific regard to its potential performance [8] ; Ghanaatian et al. were able to analyze and implement the entire LoRa Digital Receiver [10] ; Knight and Seeber used their knowledge of software defined radio to develop a reverse engineered version of LoRa's physical layer [11] ; Leushin was one of the first authors to detail the operational parameters, properties and noise tolerance of LoRa as a form of modulation [16] . The techniques for transmitting signals via chirps proposed by Senatorov (using a break in phase technique that LoRa also utilizes) belong in the same category of analysis/decoding as those described above [21]. This paper takes an entirely different approach. Instead of either characterizing or decoding a previously produced CSS signal, it seeks to explain how such a signal could be synthesized from a simpler modulating signal, and views the transformation of FM to CSS as the subject matter being explored and as the basis for developing a new hardware implementation.

1.2. The simple signal: instantaneous phase and frequency

The most fundamental signal in this discussion is the complex sinusoid, written, ignoring amplitude, as $x(t) = e^{\,j(2\pi f t+\theta)}$ [20], [22]. Its argument is the instantaneous phase

$$\varphi(t) = 2\pi f\, t + \theta,$$

and the instantaneous frequency is the scaled derivative of that phase, $f_{\mathrm{inst}}(t) = 1/2\pi\ \mathrm{d}\varphi/\mathrm{d}t$. Two parameters of the phase can be modulated to carry data. Holding frequency fixed and stepping the phase θ through a discrete set gives phase-shift keying (PSK); holding the phase reference fixed and stepping the frequency gives frequency-shift keying (FSK). CSS is reached by allowing the frequency itself to vary linearly within the symbol, which is to say by promoting the phase from a linear to a quadratic function of time.

1.3. The LoRa chirp

A LoRa symbol is a chirp whose instantaneous frequency increases (or decreases) linearly across a bandwidth B during the symbol time T. Writing the start frequency as f_0 and the chirp rate as $k = B/T$, the instantaneous frequency is

$$f(t) = f_0 + \frac{B}{T}\,t, \qquad 0 \le t < T.$$

Because the phase is the integral of 2π times the instantaneous frequency, integrating from 0 to t gives

$$\varphi(t) = 2\pi\left[f_0\,t + \frac{B}{2T}\,t^2\right],$$

and the real transmitted waveform is $s(t) = \cos\varphi(t)$, a signal whose phase is quadratic in time. The factor $B/2T$ in the quadratic term is exactly one half of the chirp rate $k = B/T$, the slope of the instantaneous-frequency line; the one-half appears because differentiating the quadratic phase returns the factor of two. The chirp rate is fixed by the requirement that each symbol span the bandwidth B once over the duration T and return to its starting frequency, so that consecutive symbols stay separable and inter-symbol interference is contained [20]. When $k > 0$ the waveform is an up-chirp; when $k < 0$ it is a down-chirp. Figure 2 shows the two as time-frequency lines of opposite slope.

The spreading factor SF connects the symbol to the number of bits it carries. With $M = 2^{\mathrm{SF}}$ distinct cyclic frequency positions, each symbol conveys SF bits, and bandwidth, symbol time and alphabet size obey $B\,T = M$ [20]. The practical data symbol is encoded as a cyclic shift of the basic chirp: the sweep starts at a frequency offset $f_m = m\,B/M$, $m = 0, \ldots, M-1$, and wraps around the band, which the receiver detects after de-chirping [20], [21]. Table 1 collects the resulting parameters for the $B = 125$ kHz channel commonly used in the regional sub-GHz bands [21].

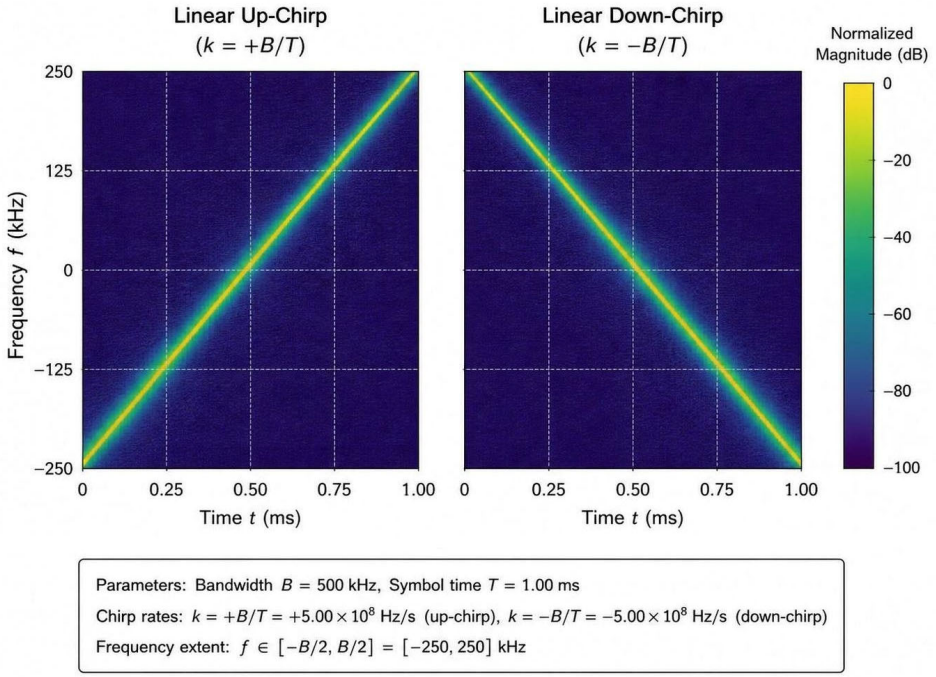

Figure 2. Spectrogram representations of the linear up-chirp (k = +B/T) and down-chirp (k = -B/T). Each sweeps the bandwidth B once over the symbol time T; the two form a complex-conjugate pair.

Table 1. LoRa parameter relations for a $B = 125$ kHz channel: symbol time $T = 2^{SF}/B$, chirp rate $k = B/T$, and approximate bit rate after [21].

SF	$T = 2^{\mathrm{SF}}/B$ (ms)	$k = B/T$ (kHz/ms)	Bit rate (bit/s)
7	1.024	122.1	3418 – 6836
8	2.048	61.0	1953 – 3906
9	4.096	30.5	1099 – 2197
10	8.192	15.3	610 – 1221
11	16.384	7.6	336 – 671
12	32.768	3.8	183 – 366

1.4. Frequency modulation

An FM signal carries the message $m(t)$ in the instantaneous frequency of the carrier. With carrier frequency f_c and frequency sensitivity k_f, the standard expression is [4], [22]

$$s(t) = \cos\left(2\pi f_c\, t + 2\pi k_f \int_0^t m\,(\tau)\,\mathrm{d}\tau\right),$$

whose instantaneous frequency is $f_c + k_f\, m(t)$. The message enters the phase through its time integral; this single fact is the lever for the whole argument, because integration turns a linear message into a quadratic phase, and a quadratic phase is precisely what a chirp has.

1.5. Conjugate values and the modulation transform

Two observations complete the bridge. The first concerns the conjugate structure of chirps. In complex-baseband form the up-chirp is $c_{\uparrow}(t) = e^{\,j\pi kt^2}$ and the down-chirp is $c_{\downarrow}(t) = e^{-j\pi kt^2}$; they are complex conjugates of one another, $c_{\downarrow}(t) = \overline{c_{\uparrow}(t)}$. This is not a cosmetic symmetry. The LoRa receiver exploits it directly, as Section 1.6 shows: multiplying an incoming up-chirp by a locally generated down-chirp cancels the quadratic phase and leaves a pure tone whose frequency is the symbol offset [20], [11]. The conjugate pair is thus both the alphabet of the preamble, up-chirps followed by down-chirps, and the engine of demodulation [20].

The second observation is the substitution itself. Let the FM message be a linear ramp over the symbol, $m(t) = \alpha t$. Its integral is $\int_0^t \alpha\,\tau\,\mathrm{d}\tau = \alpha t^2/2$, so the FM phase of Eq. (4) becomes

$$\varphi_{\mathrm{FM}}(t) = 2\pi f_c\, t + 2\pi k_f\, \frac{\alpha t^2}{2} = 2\pi f_c\, t + \pi k_f \alpha\, t^2.$$

Expanding the bracket in Eq. (3) gives the chirp phase as $\varphi(t) = 2\pi f_0 t + \pi(B/T)t^2$, which we place beside the FM phase Eq. (5). The two are identical term by term once we identify the FM carrier with the chirp start frequency, $f_c \leftrightarrow f_0$ — more precisely, the carrier coincides with the lower edge of the band while the data-bearing offset f_m is carried within f_0 — and identify the FM parameters with the chirp rate through

$$k_f\, \alpha = \frac{B}{T} = k.$$

In words: An FM Modulator fed with a linear ramp will produce a chirp and the chirp rate is the product of frequency sensitivity (k_f) and ramp slope. Selecting the ramp slope such that $k_f\alpha$ = B / T results in the LoRa chirp rate exactly. Therefore, CSS represents a specific form of FM where the modulation signal is a linear sweep. The data-bearing cyclic shift can be easily carried over from LoRa to FM. A constant delay of the ramp start and/or a discontinuity in the modulation function as well as corresponding phase breaks represent the symbol offset fm and the encoding of m [21] by LoRa respectively. One precision has to be made: The pure, non-modulated chirp corresponds to true Linear Frequency Modulation (FM). However, a data bearing symbol is represented by a wrapped saw-tooth message of two linear ramps joined together at the point of wrapping; hence, the equivalence above applies per segment instead of being continuous throughout one ramp. The given equivalence is the main outcome of this paper and justifies the solution presented below.

1.6. Demodulation by conjugate de-chirping

The conjugate structure of Section 1.5 also fixes how a symbol is recovered, and writing the few lines of algebra makes the "conjugate values" concrete. A received symbol carrying offset f_m on an up-chirp is, in complex baseband,

$$r(t) = e^{\,j(2\pi f_m t + \pi k t^2)}.$$

The receiver multiplies it by the conjugate reference, the local down-chirp $\overline{c_{\uparrow}(t)} = e^{-j\pi k t^2}$, which cancels the quadratic phase:

$$y(t) = r(t)\,\overline{c_{\uparrow}(t)} = e^{\,j2\pi f_m t}.$$

What remains is a pure tone at the offset frequency f_m. Sampling $y(t)$ over the symbol and taking the discrete Fourier transform concentrates its energy in a single bin,

$$Y[\mu] = \sum_{n=0}^{M-1} e^{\,j2\pi f_m n T_s}\; e^{-j2\pi\mu n/M} \quad \overset{\text{peak}}{\rightarrow} \quad \mu = m,$$

so the symbol decision is the index of the largest magnitude bin [20], [11]. The same operation run with a local up-chirp instead detects the down-chirps of the preamble; the conjugate pair therefore serves detection, synchronization and data recovery alike.

2. Final Modulation Principle and Technical Solution

The process described in section 1.5 for creating a CSS like symbol can be accomplished by utilizing a generic FM modulator and a baseband signal generator capable of producing a linear frequency ramp with slope equal to k_f α=B/T. The ramp will begin at an offset determined by the encoded symbol as shown in Figure 3.

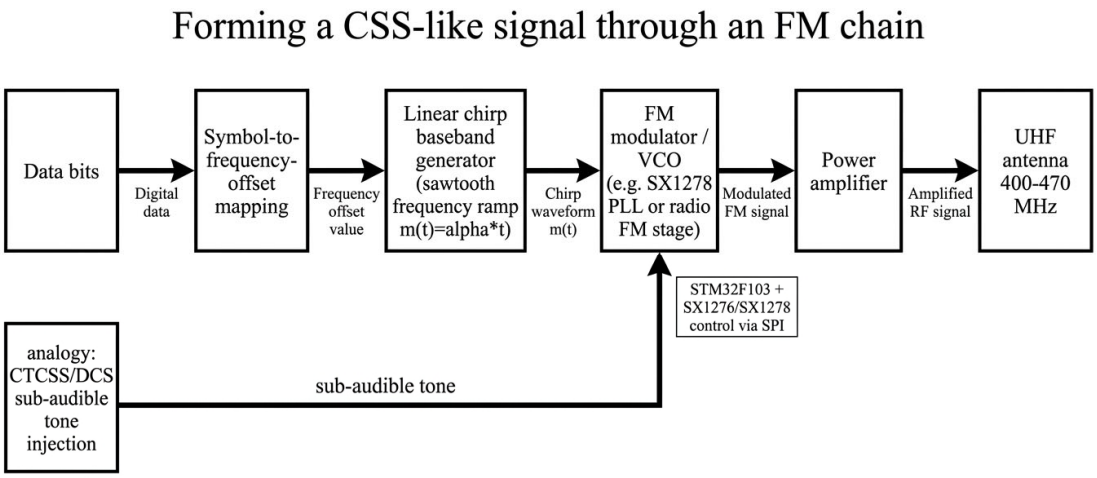

Figure 3. Block diagram of the technical solution: data bits set the frequency offset of a linear chirp baseband, which drives an FM modulator (VCO) and the RF stage. The lower branch shows the CTCSS/DCS sub-audible-tone analogy used in Section 3.

If we read this chain from left to right, first the data bits are grouped into symbols (using the same bit-to-symbol mapping used in LoRa) and mapped to an initial offset value which is equivalent to the "symbol-to-shift" function of LoRa. Next, a chirp baseband generator generates a linear sawtooth ramp m(t)=αt based on the previously generated offset and confines it to the bandwidth. The ramp generates the output of the FM modulator. That output will then create a linear (constant envelope) frequency modulation which is used to create a linear frequency chirp at the carrier. It is the linear nature of the carrier that allows efficient operation of the power amplifier and is due to the linear nature of FM not the addition of a new constant envelope.

A simple micro controller (STM32F103C8) and sub GHz transceiver are the hardware components on the digital side. The documentation provided for using the LR1276/SX1276 module with the STM32F103C8 board shows communication through SPI to expose the radio directly. This provides a way to send data packets wirelessly by defining the bandwidth, spreading factor and code rate [19] when sending data. Since the SX1276 family has a LoRa modem integrated into it that creates the chirp internally, it can achieve sensitivity levels several decibels greater than those achieved with FSK for a similar link [9],[19]. In this research the transceiver will play two primary functions. As a LoRa modem it represents the reference method for creating the chirp that the FM constructed chirp must emulate. When acting as an FM modulator, it is also where the generated chirp baseband would be applied. The STM32F103 microprocessor hosts the map of symbols to offsets and generates ramps for symbols that need them. Both of these tasks are relatively easy to accomplish with a 32 bit processor that will communicate with the transceiver over SPI [19].
The principle, stated once more in compact form, is that the chirp is the integral image of a linear message under FM. Any device that can generate an adequate frequency modulated (FM) signal has the potential to produce a waveform similar to a CSS-type signal, as long as it is capable of providing enough amplitude variation (deviation), and a linear relationship between input signal and output frequency. The design challenges are therefore removed from the use of specialized silicon for CSS generation and placed into two different areas; the first being the quality of the base band ramp used, and the second being the linearity of the FM section that will be analyzed in terms of distortion in Chapter 3

3. Hypothetical Application and Distortion Analysis

If CSS is FM with a linear-ramp message, then an FM transmitter that was never intended for LoRa might nonetheless be coaxed into emitting a chirp. This section sketches such a hypothetical application and then examines, symbolically, the distortions it would incur.

3.1. Bridging ready-made boards to conventional radios

This idea will work just like Sub-Audible Signaling. Most FM Radios have already been doing something similar by adding additional waveforms to the signal that they use to transmit speech, these include Continuous Tone-Coded Squelch (CTCSS), Digital Coded Squelch (DCS), and a lot of other types of tones and codes that help radios communicate only when needed. These waveforms get transmitted at frequencies that are lower than those used for the voice. Since the modulator has no preference about what gets fed to it (voice, music, etc.) you could easily feed a baseband version of a chirp to that same point where you would normally feed your voice. The only differences are how wide the bandwidth of each type of waveform is and why you want to send them.

There is one thing to keep in mind before we build our application, since that one thing will determine what kind of application we can develop. That one thing is the bandwidth of the modulating path on a typical FM Voice Radio. A typical FM Voice Radio's modulating path only allows the transmission of waveforms less than several KHz in bandwidth. As shown in Table 1, a typical LoRa chirp sweeps through a bandwidth many times larger than that. So while a typical FM Voice Radio can be made to modulate a very small portion of a LoRa chirp onto its audio passband (i.e., make it behave somewhat like CTCSS), it can't possibly produce a complete LoRa symbol (and certainly can't do so in the way required to interoperate with specification compliant LoRa receivers). Therefore, I'm proposing Narrowband CSS-Style Signaling over an FM Voice Channel NOT Interoperability with Specification Compliant LoRa Receivers. Those limitations are explained in detail in Section 3.2.

An example of a commercially available UHF Mobile Radio that might be targeted for modification (to implement this idea) is the Motorola GM300. The GM300 operates in the 400 – 470 MHz band and features an External Modulation Input and a Calibrated FM Deviation — Both of which are all that is necessary to construct the modified FM Voice Channel discussed in Section 2.

In the hypothetical, the SX1278 or Meshtastic board generates the symbol-encoded ramp and timing, the radio provides the FM modulator and power stage, and a CTCSS/DCS-style coupling delivers the baseband to the modulator. This is a thought experiment in feasibility, not a validated build; its value is to expose where the idealized identity of Section 1.5 meets the limits of real hardware.

3.2. Symbolic analysis of distortions in forming a linear-frequency-modulated signal

The clean equivalence $k_f \alpha = B/T$ assumes an FM stage that is wideband, perfectly linear and free of memory, fed by an exact ramp from a perfectly stable reference. Real chains depart from each assumption, and each departure smears the chirp in a characteristic way. The mechanisms below are written symbolically and carry no numerical values; the aim is the structure of the degradation rather than its magnitude in any one device. Throughout, the ideal transmitted symbol is the up-chirp of Eq. (7) and the receiver applies the matched conjugate of Eq. (8).

Band limiting of the modulating path. Let the modulating path have a low-pass transfer function $H_{\mathrm{bb}}(f)$ with effective cut-off W. The ramp $m(t) = \alpha t$ commands an instantaneous frequency excursion up to B, but the realizable swept bandwidth is bounded by what the path passes,

$$B_{\mathrm{eff}} \approx \min\{\, B,\ 2W \,\}.$$

When $W \ll B$, as for a voice radio, the sweep is truncated and the corners of the sawtooth are rounded, so the effective chirp covers only a fraction of the intended band.

Non-linearity of the modulator. A practical voltage-controlled oscillator has a curved frequency-versus-voltage law. Expanding it to second order, the instantaneous frequency under a ramp input is

$$f_i(t) = f_c + k_f \alpha\, t + a_2(\alpha t)^2 + \cdots,$$

so the chirp rate is no longer constant but drifts across the symbol,

$$k(t) = \frac{\mathrm{d}f_i}{\mathrm{d}t} = k_0 + \varepsilon\, t, \qquad k_0 = k_f \alpha, \quad \varepsilon \propto a_2 \alpha^2.$$

De-chirping such a symbol with the ideal conjugate of constant rate k_0 does not cancel the phase completely; the leading residual term is cubic in time, $1/3\,\pi\varepsilon\, t^3$, a nonlinear phase that grows through the symbol. Its energy spreads across neighbouring DFT bins, lowering the matched-filter peak and raising the side-lobes.

Pre-emphasis and de-emphasis. FM voice systems apply a rising pre-emphasis $H_{\mathrm{pe}}(f)$ before the modulator and a complementary de-emphasis at the receiver. Because the chirp maps frequency to time through $f = f_0 + kt$, this frequency weighting becomes a time-varying amplitude on the sweep,

$$A(t) = |\, H_{\mathrm{pe}}(f_0 + kt)|,$$

which converts part of the frequency variation into unwanted amplitude modulation and disturbs the constant-envelope property on which the chirp depends. Up-chirps and down-chirps traverse the emphasis curve in opposite directions and are therefore shaped asymmetrically, which is troublesome for a receiver that treats them as an exact conjugate pair.

Group delay and chirp smearing. Any band-limiting filter has a frequency-dependent group delay $\tau_g(f) = -\mathrm{d}\phi/\mathrm{d}\omega$. Since the chirp presents its frequencies in time order, a component at $f = f_0 + kt$ is displaced by $\tau_g(f)$, and the spread of those displacements across the sweep,

$$\Delta t \approx |\, \tau_g'(f)\,|\, B,$$

broadens the de-chirped response. The once-sharp diagonal of Figure 2 acquires a visible thickness; both symbol detection and the ranging accuracy that motivated CSS degrade.

Reference-oscillator instability. The carrier and the timing both descend from a quartz or temperature-compensated reference whose phase noise $\phi_n(t)$ and slow frequency drift Δf are never zero [5], [6], [7]. The recovered tone of Eq. (8) is then

$$y(t) = e^{\,j(2\pi(f_m+\Delta f)t+\phi_n(t))},$$

so a static offset Δf shifts the detected bin and biases the symbol decision, while $\phi_n(t)$ broadens the peak and limits the processing gain available at the higher spreading factors, where the receiver integrates over the long symbols of Table 1.

Deviation scaling and ramp imperfections. The identity (6) is an equality between two independently set quantities, the FM deviation gain and the baseband ramp slope. A mismatch leaves a residual rate $\Delta k = k_f'\alpha' - k$ after de-chirping,

$$y_{\mathrm{res}}(t) = e^{\,j\pi\Delta k\, t^2},$$

whose peak broadening grows with $\Delta k\, T$, so a conventional LoRa receiver matched to the nominal rate loses correlation gain. If the ramp is synthesized digitally it is a staircase rather than a true line, and the quantization steps add spurious tones and a small periodic non-linearity on top of Eq. (12).

Taken together, Eqs. (10)–(16) say that the idealized FM-to-CSS identity is exact in mathematics and approximate in hardware, and that the quality of a CSS-like signal formed through a general FM chain is governed by modulating-path bandwidth, modulator linearity, emphasis shaping, filter group delay and reference stability. None of these forbids the construction; each defines a budget that a real implementation would have to respect.

Limitations

There are three primary constraints bounding the validity of all the claims presented in this paper. First, and most obviously, there is no prototype build to demonstrate the FM-to-CSS conversion

proposed herein; thus while the mathematical basis for this conversion exists and the applicability of the theory is asserted based upon available components, this has yet to be verified experimentally. Second, as indicated above, Identity (6) $k_f\alpha = B/T$, establishes the relationship between parameters of an ideal wide-band FM transmitter and its corresponding chirp signal. However, Section 3.2 demonstrates that actual implementations will deviate from each of these assumptions, and does so quantitatively via Eqs. (10)-(16). Third, although Eqs. (10)-(16) provide a qualitative description of the deviation of actual implementations from the assumptions underlying Identity (6), they do not quantify the magnitude of the deviations; such quantification remains to be accomplished. Third, the hypothetical application is constrained by the modulating-path bandwidth of commodity voice radios and so addresses narrowband chirp signaling rather than full LoRa interoperability. Removing these limitations calls for a structured measurement campaign with a planned design of experiments [15], pairing simulation of the distortion mechanisms with bench measurement on the SX1276/SX1278 and radio hardware identified above.

Conclusion

We sought to establish a mathematical framework for comparing basic modulation schemes and using that comparison to show how one modulation scheme relates to another. This mathematical basis of our study based on the instantaneous-phase approach indicates that a chirp is essentially a complex sinusoid whose instantaneous phase has a quadratic relationship to time rather than being linear. Further, we found that up-chirps and down-chirps are complementary or complex conjugates. And, importantly, when you integrate over time in the FM equation, what results is that linear information regarding the original message is converted directly to a quadratic representation of that same information - which is described as the relationship defined by identity (6) k_f α=B/T, As a result, LoRa's CSS represents a specific example of FM where the message source produces a linear frequency ramp, and therefore, the process described in Eqs. (7)-(9) can be used to demodulate a received signal, recovering the original symbol as a single tone. Using this as our foundation, we were able to develop a technical method to produce a CSS-like signal using an FM modulator and chirp baseband waveforms, map them to SX1276/SX1278 radio transceivers and an STM32F103 microcontroller-based host board, and conceptualize potential applications including borrowing an existing CTCSS/DCS "tune-in" functionality from traditional UHF radios like Motorola's GM300. We followed this with a symbolic distortion analysis resulting in equations (10)- (16), establishing the boundaries to practical implementation of these concepts.

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Тестировочный стенд для беспилотных летательных аппаратов: конструкция, модификации и образовательный потенциал

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Аннотация
В работе рассматривается разработка тестировочного стенда для беспилотных летательных аппаратов, предназначенного для проведения безопасных испытаний, настройки и диагностики БПЛА. Проведен анализ конструктивных решений и определены основные требования к создаваемому стенду, обеспечивающие возможность моделирования эксплуатационных условий и расширения функциональных возможностей оборудования. Описаны особенности конструкции разработанного прототипа, а также его модификационный потенциал, позволяющий интегрировать дополнительные датчики и элементы управления. Результаты экспериментальных испытаний подтвердили работоспособность стенда и эффективность его применения для инженерных исследований, образовательных задач и отработки алгоритмов стабилизации и управления беспилотными летательными аппаратами.
Ключевые слова: тестировочный стенд, дрон, БПЛА, гироскоп, акселерометр, модификация, телеметрия, испытания.

Abstract
A drone test bench provides safe and efficient testing of unmanned aerial vehicles (UAVs) across various fields. Modern test bench enable simulation of real operating conditions, detection of hardware and software errors, as well as calibration and debugging of UAVs before field deployment. The flexible and scalable design allows for hardware modifications, installation of additional sensors, and support for different UAV types. The test bench is used in engineering, scientific, and educational tasks, as well as for testing new control technologies and stabilization algorithms.
Keywords: test bench, drone, UAV, gyroscope, accelerometer, modification, telemetry, testing, research.

Основные цели использования тестировочного стенда

В образовании стенд служит для безопасной демонстрации работы БПЛА в помещении, снижая риски для оборудования и людей и повышая наглядность обучения.

Он позволяет исследовать статические и динамические характеристики дрона: моделировать полётные положения для оценки устойчивости, эффективности пропеллеров и работы стабилизации. На стенде тестируют двигатели, регуляторы, аккумуляторы (выявляя перегрев и сбои тяги), калибруют навигационные датчики и автопилот, безопасно проверяют ПО (алгоритмы стабилизации, автономного полёта, избегания столкновений), оценивают энергопотребление, а при необходимости создают экстремальные условия (вибрации, помехи, перепады температур) для проверки надёжности.

Мультироторные БПЛА просты в конструкции и доступны для сборки даже в учебных условиях, но при этом являются сложными киберфизическими системами: их устойчивость как статически неустойчивой платформы обеспечивается контурами обратной связи на основе данных датчиков. Программные симуляторы (SITL) упрощают физику и не учитывают вибрации, инерцию, погрешности датчиков и помехи, к тому же не поддерживают все типы контроллеров. Поэтому для выявления ошибок сборки и настройки нужны испытания на реальных аппаратах, но в безопасных условиях — особенно важно для учебного процесса.

Изолированные зоны для полётов защищают людей, но не сам аппарат при первых запусках, поэтому распространены испытательные стенды, ограничивающие перемещение БПЛА при сохранении возможности изучения динамики. Для учебных задач наиболее актуальны стенды для мультироторов, поскольку самолётные схемы требуют аэродинамических труб, труднодоступных в образовательной среде.

Функция стенда — обеспечить контролируемую подвижность аппарата при ограничении линейных перемещений. У БПЛА шесть степеней свободы (три поступательные, три вращательные), и конструкция стенда реализует часть из них в зависимости от целей и требований безопасности.

Среди конструктивных решений: карданов подвес (три степени свободы вращения, удобен для изучения стабилизации при смене ориентации), шаровые/универсальные шарниры, упругие подвесы и тросовые ограничители (частичная компенсация перемещений). Для линейных перемещений по нескольким осям нужны более сложные системы — направляющие каретки, шкивы, балансировочные грузы. Простые конструкции обычно дают одну степень свободы поступательного движения (вал в линейном подшипнике или подвес на шкивах), что позволяет изучать вертикальные режимы работы и устойчивость удержания высоты.

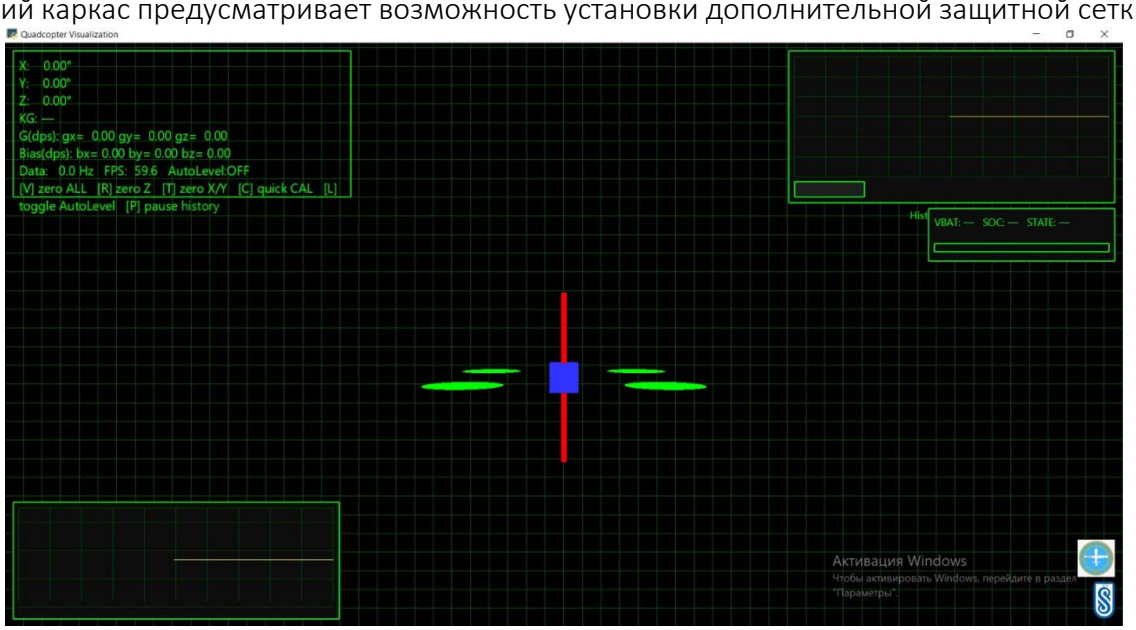
Результаты и обсуждение

Существующий набор конструктивных решений испытательных установок позволяет формировать стенды с заданными функциональными характеристиками в зависимости от целей тестирования беспилотных летательных аппаратов. В рамках данной работы основное назначение разрабатываемого стенда определялось его применением в учебном процессе, а также возможностью проведения первичной проверки корректности сборки и настройки беспилотных воздушных судов мультироторного типа. Это обусловило формирование требований к конструкции, включающих мобильность, компактность, безопасность эксплуатации, функциональную пригодность для отработки базовых режимов полета и возможность интеграции измерительного оборудования.

Требование мобильности связано с необходимостью перемещения установки между учебными аудиториями через стандартные дверные проемы, что накладывает ограничения на габаритные размеры и массу стенда. Компактность конструкции обеспечивает

возможность размещения установки на стандартной лабораторной мебели. Безопасность эксплуатации достигается за счет конструктивной возможности установки защитного экрана сеточного типа, ограничивающего разлет фрагментов в случае отказа силовой установки или разрушения пропеллеров. Существенным условием является также обеспечение старта с горизонтальной поверхности, поскольку большинство полетных контроллеров выполняют предстартовую калибровку с контролем ориентации аппарата в пространстве. Дополнительным требованием является возможность установки вспомогательных датчиков и модулей для регистрации полетных и силовых характеристик, что расширяет область применения стенда в научно-исследовательских задачах.

В соответствии с указанными требованиями были разработаны два варианта испытательного стенда, отличающиеся типом подвеса летательного аппарата и способом реализации угловых перемещений. Оба варианта имеют общую несущую платформу, выполненную на основе фанерного основания толщиной 18 мм, оснащенного опорными элементами для установки на поверхность лабораторного стола. Горизонтальные размеры конструкции выбраны с учетом типовых размеров дверных проемов и столешниц. Вертикальные стойки выполнены из резьбовых шпилек диаметром 8 мм и длиной около 1 м, что определяет рабочую высоту стенда. Верхний пояс конструкции сформирован из алюминиевых уголков шириной 20 мм и толщиной 2 мм, обеспечивающих необходимую жесткость при сохранении малой массы. Все соединения элементов конструкции выполнены разборными, что упрощает транспортировку, обслуживание и модернизацию установки. Внешний каркас предусматривает возможность установки дополнительной защитной сетки.



Для реализации угловой подвижности летательного аппарата в конструкции используется либо система скользящей петли, либо карданов подвес, обеспечивающие три степени свободы вращения. Компенсация массы системы подвеса и летательного аппарата осуществляется с применением балансировочного груза, что снижает статическую нагрузку на силовую установку и повышает стабильность режимов зависания при испытаниях.

Экспериментальная проверка работоспособности стенда проводилась с использованием серийного беспилотного аппарата DJI Mini/Mavic 3, а также самодельного FPV-дрона. Летательные аппараты фиксировались с использованием демпфирующей подложки, изготовленных методом 3D-печати.

В процессе испытаний осуществлялся контроль управляемости БПЛА при горизонтальных и вертикальных отклонениях, а также оценка устойчивости режима зависания. Проверка управляемости по каналам курса, крена и тангажа выполнялась сигналами с пульта и визуального контроля реакции летательного аппарата. Дополнительно

оценивалась стабильность удержания высоты при изменении режимов работы силовой установки.

После завершения программы испытаний выполнялось горизонтирование аппарата и постепенное снижение тяги до посадочного режима, после чего осуществлялся контроль корректности перехода летательного аппарата в состояние DISARM в ручном либо автоматическом режиме. Полученные результаты подтверждают пригодность разработанного стенда для проведения первичной диагностики, калибровки и настройки мультироторных беспилотных летательных аппаратов в безопасных лабораторных условиях, а также для использования в учебных и исследовательских целях.

Методология исследования

Методология разработки тестировочного стенда для беспилотных летательных аппаратов (БПЛА) основывалась на последовательном инженерно-экспериментальном подходе, включающем анализ существующих решений, проектирование конструкции, разработку аппаратно-программной части и проведение экспериментальных испытаний.

На первом этапе выполнялся анализ научных публикаций и технических решений в области испытательных стендов для мультироторных БПЛА. В результате были определены основные требования к разрабатываемой установке: мобильность, компактность, безопасность эксплуатации, универсальность применения и возможность модернизации измерительной системы.

На втором этапе осуществлялось проектирование конструкции стенда. Механическая часть разрабатывалась с учетом размеров типовых дронов. Конструкция выполнена по модульному принципу, что обеспечивает простоту сборки и модернизации. Для обеспечения угловой подвижности летательного аппарата использовались гироскопически подвес и скользящая петля, позволяющие реализовать вращение относительно осей. Для компенсации массы применялись балансировочные элементы.

Третьим этапом являлась разработка измерительной системы. Для пространственной ориентации БПЛА использовался модуль MPU-6050, объединяющий гироскоп и акселерометр. Измерение подъёмной силы выполнялось тензометрического датчика с ацп HX711. Контроль состояния акб реализован с использованием делителя напряжения. Обработка данных осуществлялась микроконтроллером Raspberry Pi Pico.

На четвертом этапе выполнялась сборка экспериментального образца стенда, установка датчиков и настройка программного обеспечения. Особое внимание уделялось точности размещения измерительных элементов и балансировке.

Заключительный этап включал проведение экспериментальных испытаний с использованием мультироторных БПЛА. В ходе экспериментов оценивались устойчивость режима зависания, управляемость аппарата и характеристики силовой установки. Полученные данные записывались и анализировались для оценки работоспособности стенда и подтверждения его пригодности для задач.

Конструктивные особенности тестировочного стенда
Сборка

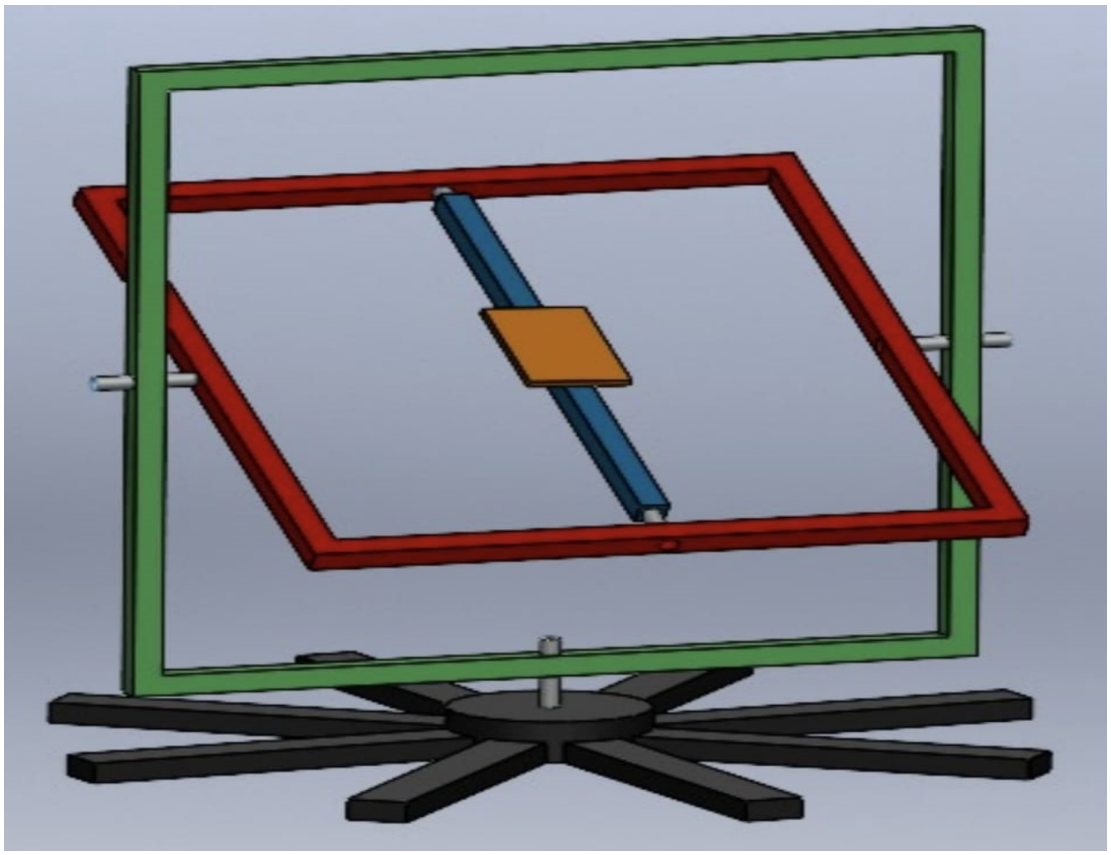


Рисунок 1 – полноценный каркас

Где, Обозначения по цветам:
оранжевый – подложка – держатель дрона с тензодатчиков
синий внутренняя ось
красный – вторая ось
зелёный – основная ось
черный – сошки

Рамка представляет собой 4 алюминиевые и 4 угловые вставки . Внутренняя перегородка представляет собой профиль с подготовленным держателем и двумя опорными подшипниками с сменной осью для саморегуляции положения дрона. В промежутке 1й и 2й рамки находятся 2 подшипника с алюминиевой трубой) встраиваемые в 1ю и 2ю рамку для подвижности .

Датчики

Главный датчик - 6ти осейвой гироскоп акселерометр (Mpu 6050) .

Измерение подъемной силы и веса дрона происходит с ипользованием тензометрического датчика и модуля (24-битный АЦП HX711)

Делитель напряжения для измерения свойст Акб , он нужен т.к аналоговый выход Piko (A26 -28) может принимать до 3 вольт а аккумуляторы для дронов выдают напряжение кратно 3.7 (3.0-4.2 вольт в пределах безопасных значений)

Он подключается к контактам АКБ (см. схема 1)

Микро контроллер для анализа и работы программы стенда представляет собой Raspberry pi piko

Сборка электронной части

После сборки корпуса идёт установка датчиков на нем . Установка Mpu 6050 должна вадный момент обеспечения точности показания программы тк. нахождение датчика не в центре осей вращения вызывает некорректное чтение данных

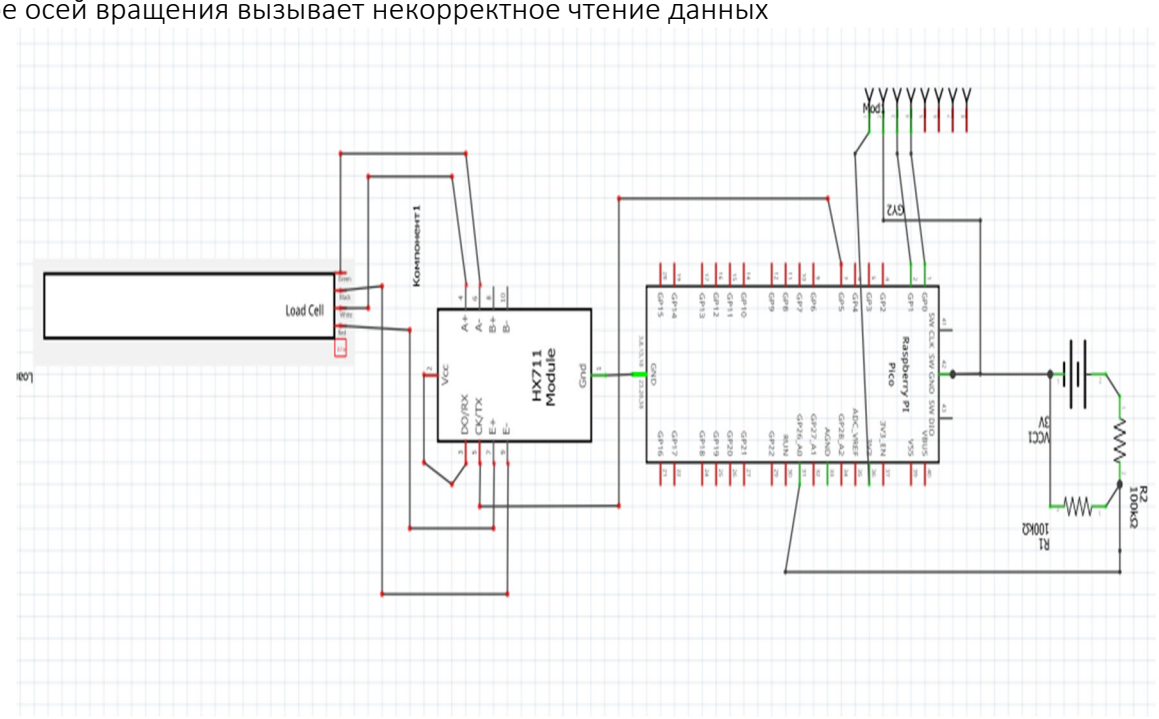


Рисунок 2. электронная схема

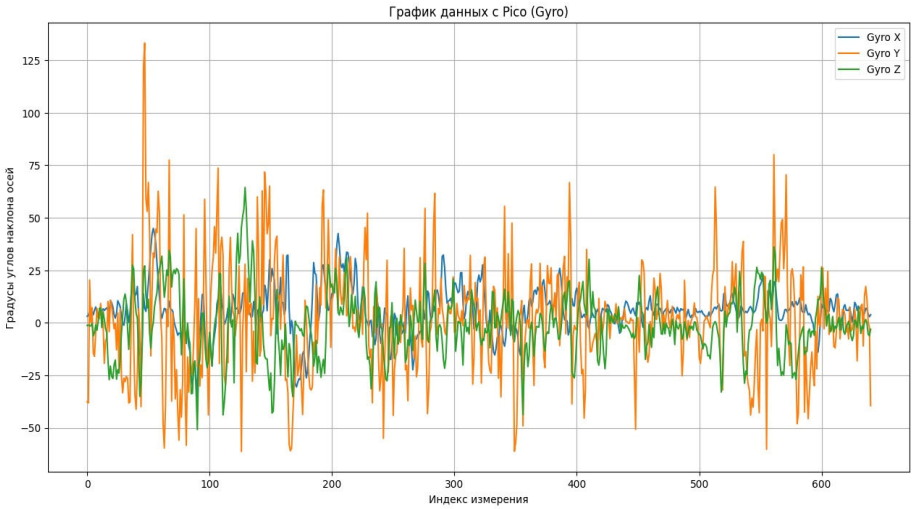
Результаты эксперимента №3

VBAT: 1.647 V [##--------] 24.44% [OK]
Accel: (9.78, 0.42, 1.79) | Gyro: (5.88, 20.37, -1.47) | KG: 0.353
Accel: (9.87, 0.45, 1.82) | Gyro: (6.51, 0.27, -1.48) | KG: 0.546
Accel: (9.96, 0.18, 2.06) | Gyro: (5.76, 7.21, -0.27) | KG: 0.753
Accel: (9.79, 0.36, 2.11) | Gyro: (3.76, -14.53, -6.33) | KG: 0.755
Accel: (9.83, 0.61, 1.72) | Gyro: (6.11, -15.98, -4.60) | KG: 0.783
Accel: (9.99, 0.28, 1.61) | Gyro: (7.52, -4.35, -0.97) | KG: 0.992
VBAT: 1.647 V [##--------] 24.42% [OK]

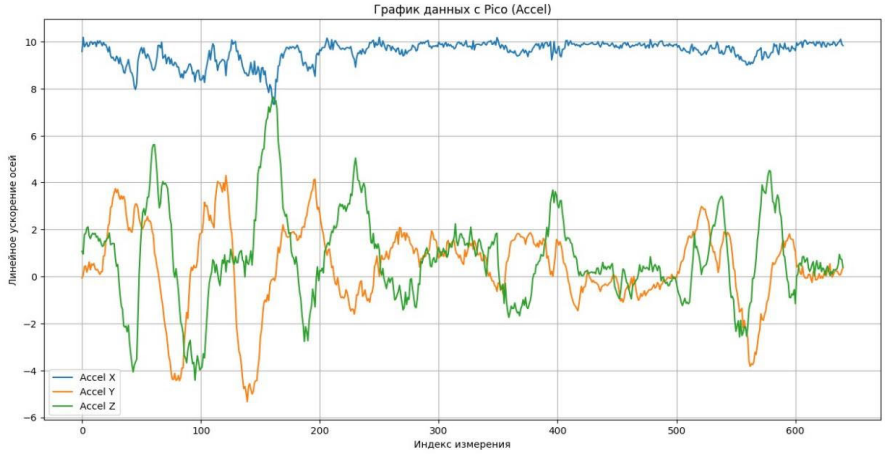
Эти данные использованы для сопоставления команд с пульта и положения дрона в стенде для проверки инерциальности системы.

t, c	Gx	Gy	Gz	Ax	Ay	Az	Left_X	Left_Y	Right_X	Right_Y
0	0.01	-0.02	0.00	0.01	-0.01	0.98	509	438	514	510
1	0.03	0.01	0.02	0.02	0.01	1.02	515	468	519	514
2	0.08	0.05	0.03	0.05	0.03	1.08	521	528	536	527
3	0.15	0.10	0.04	0.08	0.06	1.15	527	602	563	545
4	0.24	0.16	0.06	0.13	0.09	1.20	536	661	603	569
5	0.32	0.20	0.10	0.18	0.11	1.14	555	684	639	592
6	0.28	0.14	0.18	0.15	0.08	1.05	589	671	624	566

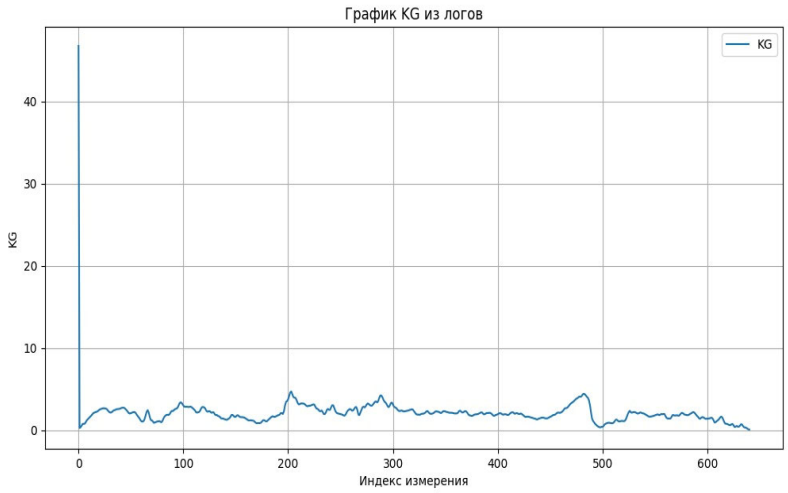
Незначительное расхождение между IMU-данными и сигналами пульта объясняется инерцией стенда, особенностями крепления дрона, задержкой ручного управления и естественным шумом аналоговых органов управления. люфтами и упругостью конструкции стенда и т.д.



Данные с гироскопа (индекс измерений – зависимоть от времени и скорости измерений)



Данные с акселерометра (индекс измерений – зависимоть от времени и скорости измерений)



Данные с тензодатчика (индекс измерений – зависимоть от времени и скорости измерений) изначальный пик был (t=0)был проверочным

ЗАКЛЮЧЕНИЕ

В рамках выполненного исследования реализован инженерный подход к разработке тестировочного стенда для беспилотных летательных аппаратов, ориентированного на решение задач первичной диагностики, настройки и экспериментальной отработки алгоритмов управления. В отличие от существующих решений, как правило обладающих узкой специализацией, предложенная конструкция сочетает в себе модульность, функциональную гибкость и адаптивность к различным сценариям испытаний.

Проведённый анализ показал, что программные методы моделирования не способны в полной мере учитывать влияние реальных физических факторов, таких как вибрации, инерционность конструкции и электромагнитные помехи. В связи с этим разработанный стенд выступает как промежуточное звено между симуляцией и натурными испытаниями, обеспечивая контролируемую и безопасную среду для верификации как аппаратной, так и программной части БПЛА.

В ходе проектирования была обоснована и реализована конструкция обеспечивающая адекватную имитацию динамики полета при сохранении механической устойчивости системы. Выбор измерительной базы, в частности использование инерциального модуля MPU-6050 и тензометрической системы на базе HX711, позволил достичь баланса между точностью измерений, стоимостью и сложностью интеграции.

Испытания подтвердили пригодность для решения ключевых задач: оценки устойчивости режима зависания, анализа управляемости по крену, тангажу и рысканию , а также измерения тяги. Наблюдаемая погрешность измерений носит предсказуемый характер и обусловлена конструктивными особенностями системы, что не снижает ценности получаемых данных.

Отдельно следует подчеркнуть высокий потенциал решения. Конструкция допускает дальнейшее развитие как в аппаратной части (интеграция дополнительных сенсоров, систем имитации внешних воздействий), так и в программной (поддержка телеметрических протоколов, интеграция с симуляторами). Это делает стенд универсальной платформой для научных исследований, образовательных задач и прототипирования решений в беспилотных системах .

Таким образом, разработанный стенд представляет собой эффективный инструмент инженерной практики, позволяющий существенно снизить риски при проведении испытаний, повысить воспроизводимость результатов и обеспечить качественную отработку как аппаратных, так и алгоритмических компонентов БПЛА. Дальнейшее развитие проекта целесообразно направить на повышение жесткости конструкции, снижение влияния паразитных факторов и расширение функционала системы за счёт внедрения интеллектуальных методов обработки данных и автоматизации испытательных процедур.

Physical and Mathematical Sciences

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МЕТОДЫ ЦИФРОВИЗАЦИИ СЕЛЬСКОГО ХОЗЯЙСТВА

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Аннотация:

В статье рассматриваются пути совершенствования цифровизации сельского хозяйства с помощью применения роботов и дронов для - прогнозирования урожайности, оптимизации использования ресурсов, выявления болезней и вредителей растений, рекомендации по принятию решений, управления цепочками поставок.

Ключевые слова: измерение, эксперимент, сбор, дроны, метод, оптимизация, технология.

ВВЕДЕНИЕ

Сегодня аграрный сектор, несмотря на свою многовековую историю, переживает период активного технологического обновления. Внедрение инновационных цифровых решений кардинально меняет подходы к ведению сельского хозяйства, открывая новые возможности для фермеров и специалистов отрасли. Использование современных технологий позволяет более рационально управлять производственными процессами, повышать продуктивность, оптимизировать расходы и обеспечивать экологическую устойчивость сельскохозяйственного производства.

Особое значение приобретают технологии точного земледелия, основанные на применении цифровых платформ, систем мониторинга, спутниковых данных и автоматизированных средств управления. Эти инструменты способствуют принятию более обоснованных решений и формируют перспективы дальнейшего развития агропромышленного комплекса [1].

В то же время сельское хозяйство сталкивается с рядом актуальных проблем. Рост численности населения мира приводит к увеличению потребности в продовольствии и требует наращивания объемов производства. Дополнительные трудности создают климатические изменения, проявляющиеся в виде засух, резких перепадов температуры, наводнений и других неблагоприятных природных явлений, которые снижают урожайность сельскохозяйственных культур. Кроме того, ограниченность земельных, водных и энергетических ресурсов диктует необходимость их более рационального и эффективного использования, что делает цифровизацию аграрной отрасли не просто актуальной тенденцией, а важным условием её устойчивого развития.

ОСНОВНАЯ ЧАСТЬ

Цифровые технологии предоставляют эффективные инструменты для решения современных проблем аграрной отрасли. Их внедрение позволяет совершенствовать производственные процессы и создавать наиболее благоприятные условия для выращивания сельскохозяйственных культур. Благодаря применению интеллектуальных систем управления становится возможным более рациональное использование земельных,

водных и энергетических ресурсов, а также сокращение затрат на минеральные удобрения, средства защиты растений и горюче-смазочные материалы.

Использование цифровых решений способствует повышению качества управления сельскохозяйственными предприятиями за счёт автоматизации многих операций, оперативного сбора информации и принятия решений на основе анализа данных. Кроме того, современные технологии помогают минимизировать негативное воздействие на окружающую среду, обеспечивая экологически безопасное и ресурсосберегающее производство. Не менее важным преимуществом является возможность осуществления контроля качества продукции на всех стадиях её производства — от подготовки почвы до хранения и реализации урожая.

Применение цифровых технологий в сельском хозяйстве охватывает широкий круг направлений, среди которых особое место занимает точное земледелие. Оно представляет собой совокупность методов и технических средств, основанных на использовании цифровых данных для повышения эффективности сельскохозяйственных операций. Одним из основных элементов данной технологии являются системы спутниковой навигации GPS и ГЛОНАСС, обеспечивающие высокоточную ориентацию сельскохозяйственной техники, построение электронных карт полей и выполнение агротехнических работ с минимальными отклонениями.

Важную роль играют различные датчики и сенсорные системы, предназначенные для контроля состояния почвы, растений и окружающей среды. Они позволяют получать сведения о влажности, температуре, кислотности почвы, содержании питательных веществ, а также оценивать состояние посевов, интенсивность их роста и потребность в воде. На основе собранных данных создаются цифровые карты урожайности, рельефа местности и агрохимических характеристик почвы.

Современные технологии также предусматривают дифференцированное внесение удобрений и средств защиты растений. Специальные автоматизированные системы определяют потребности каждого участка поля и обеспечивают внесение необходимых веществ в оптимальном количестве, что способствует повышению урожайности и снижению производственных затрат.

Значительное место в цифровизации аграрного сектора занимают беспилотные летательные аппараты и роботизированные комплексы. Дроны используются для проведения аэрофотосъёмки, мониторинга состояния посевов, выявления проблемных зон и прогнозирования урожайности. Роботизированные системы позволяют автоматизировать отдельные технологические операции и повысить точность выполнения сельскохозяйственных работ[2].

Неотъемлемой составляющей цифрового сельского хозяйства является специализированное программное обеспечение, предназначенное для сбора, обработки и визуализации информации, планирования производственных процессов, управления ресурсами и поддержки принятия управленческих решений. Комплексное использование этих технологий создаёт условия для формирования высокоэффективного, конкурентоспособного и устойчивого агропромышленного производства.

В современных условиях роботизированные системы становятся важной составляющей цифрового сельского хозяйства. Роботы способны выполнять широкий спектр агротехнических операций, включая посев и посадку культур, борьбу с сорной растительностью, уход за посевами и сбор урожая. Их применение способствует повышению производительности труда, снижению зависимости от ручного труда и повышению точности выполнения сельскохозяйственных работ.

Особую роль в развитии аграрного производства играют технологии анализа больших данных и искусственного интеллекта. Современные информационные системы позволяют

собирать, обрабатывать и анализировать значительные объёмы информации, поступающей из различных источников, таких как датчики и сенсоры, спутниковые снимки, метеорологические службы, данные о состоянии рынка и результаты производственной деятельности предприятий. На основе комплексного анализа этих данных формируются прогнозы и рекомендации, необходимые для эффективного управления сельскохозяйственным производством.

В настоящее время интеллектуальные системы и роботизированные комплексы используются для прогнозирования урожайности сельскохозяйственных культур, более рационального использования материальных и природных ресурсов, своевременного выявления заболеваний растений и распространения вредителей. Кроме того, технологии искусственного интеллекта помогают аграриям принимать обоснованные управленческие решения и совершенствовать процессы управления логистикой и цепочками поставок сельскохозяйственной продукции.

Центральное место в цифровой трансформации агропромышленного комплекса занимает точное земледелие, представляющее собой современную систему управления производством, основанную на учёте пространственной неоднородности сельскохозяйственных угодий и использовании цифровых технологий для повышения эффективности агротехнических мероприятий.

Одним из важнейших элементов точного земледелия является дифференцированное внесение удобрений. На основании результатов агрохимического анализа почвы и карт плодородия определяется потребность каждого участка поля в питательных веществах, что позволяет вносить удобрения в необходимых количествах. Такой подход способствует сокращению материальных затрат и одновременно повышает урожайность сельскохозяйственных культур.

Аналогичный принцип применяется при использовании средств защиты растений. Благодаря анализу данных о распространении болезней и вредителей пестициды вносятся только в те зоны, где действительно существует необходимость их применения. Это позволяет уменьшить расход химических препаратов и снизить негативное воздействие на окружающую среду.

Важным направлением цифровизации является внедрение интеллектуальных систем орошения. Автоматизированные системы регулируют объёмы и режимы полива с учётом состояния почвы, потребностей растений и текущих погодных условий. Такой подход обеспечивает более эффективное использование водных ресурсов и создаёт благоприятные условия для роста и развития сельскохозяйственных культур[3].

ВЫВОДЫ

Большое значение в современном земледелии приобретают беспилотные летательные аппараты. Использование дронов позволяет оперативно получать информацию о состоянии посевов, выявлять проблемные участки, контролировать развитие растений и прогнозировать будущую урожайность. Дополнительный анализ данных о погодных условиях, состоянии почвы и динамике роста культур даёт возможность выбирать наиболее благоприятные сроки проведения посевных и уборочных работ, что способствует повышению эффективности производства и снижению потерь сельскохозяйственной продукции.

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Philological Sciences

Ta'arof as Sociopragmatic Competence in Persian Language Learning: Beyond Politeness and Cultural Etiquette

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Abstract
Ta'arof is often described as a system of ritual politeness in Persian-speaking culture, especially in Iranian social interaction. However, reducing Ta'arof to "politeness," "etiquette," or "cultural ornament" weakens its linguistic and pedagogical importance. This theoretical article argues that Ta'arof should be understood as a form of sociopragmatic competence in Persian language learning. In Persian interaction, offers, refusals, thanks, invitations, compliments, and forms of self-lowering often do not operate through literal meaning alone. They are shaped by culturally organized expectations concerning respect, modesty, hierarchy, reciprocity, and relational harmony. For learners of Persian, this creates a major interpretive challenge: a grammatically correct understanding of an utterance may still lead to communicative misunderstanding. Drawing on studies of Persian politeness, face, communicative competence, and intercultural pragmatics, this article proposes that Ta'arof should be explicitly integrated into Persian language teaching. It suggests that Ta'arof can be taught through contextualized dialogues, role-play, pragmatic awareness tasks, and comparison of literal and sociocultural meanings. The article concludes that Ta'arof is not merely a cultural topic added to language instruction; rather, it is part of how meaning is negotiated in Persian.
Keywords: Ta'arof, Persian language teaching, sociopragmatics, politeness, intercultural competence, pragmatic competence

1. Introduction

Language learning is not limited to vocabulary, grammar, and pronunciation. A learner may know the grammatical structure of a sentence and still misunderstand what the speaker is doing with that sentence in a real social context. This is especially clear in Persian, where many everyday interactions are shaped by Ta'arof, a culturally embedded system of ritual courtesy, modesty, deference, and indirectness. Ta'arof appears in greetings, invitations, offers, refusals, thanks, compliments, commercial exchanges, family relations, academic interaction, and public encounters. It is therefore not a marginal cultural habit, but an important part of Persian communicative life.

In many introductory explanations, Ta'arof is presented as "Iranian politeness" or "excessive courtesy." Such definitions are useful at a very basic level, but they are insufficient for language teaching and intercultural communication. Ta'arof does not simply mean being polite. It involves a complex relation between what is said, what is meant, what is socially expected, and how participants interpret one another's intentions. For example, an offer may not be a simple offer, a refusal may not be a final refusal, and a phrase of self-lowering may actually function as a way of honoring the other person. These forms of communication cannot be explained only through direct translation.

The present article argues that Ta'arof should be treated as a form of sociopragmatic competence in Persian language learning. Sociopragmatic competence refers to the learner's ability to understand how social meanings are expressed in language according to context, relation, status, intention, and cultural expectation. From this perspective, Ta'arof is not merely a topic for cultural notes at the end of a textbook chapter. It is part of communicative meaning itself.

The article is theoretical in nature. It does not present new empirical data, but it draws on existing studies of Persian politeness, communicative competence, and intercultural language teaching. Its main aim is to offer a simple but pedagogically useful framework for understanding Ta'arof in Persian language education. The central claim is that Persian learners need not only grammatical competence, but also the ability to recognize when an utterance should be interpreted literally and when it should be understood as part of a Ta'arof sequence.

2. Communicative Competence and the Place of Ta'arof

The concept of communicative competence shifted language teaching away from a narrow focus on grammar. Hymes (1972) argued that knowing a language means knowing not only whether an utterance is grammatically possible, but also whether it is socially appropriate. Canale and Swain (1980) later developed this idea in language education by distinguishing different dimensions of communicative competence, including grammatical, sociolinguistic, discourse, and strategic competence. These frameworks are important for Persian teaching because Ta'arof belongs precisely to the social and pragmatic dimensions of language use.

If a Persian learner hears the expression "qābel nadārad" in a commercial or interpersonal exchange, a literal translation such as "it has no value" or "it is not worthy" does not explain the social function of the phrase. Depending on the situation, it may be a courteous formula, a ritual refusal of payment, an expression of generosity, or an opening move in a sequence where the other person is expected to insist. The learner's problem is therefore not lexical alone. The main difficulty is sociopragmatic: how should this expression be interpreted in this situation, between these speakers, with this relation of status and familiarity?

Ta'arof also demonstrates the limits of treating politeness as a universal system that functions in the same way across cultures. Brown and Levinson's (1987) influential theory of politeness is useful because it highlights face, indirectness, and the management of social relations. However, Persian politeness cannot be fully explained by a simple distinction between positive and negative face. Koutlaki (2002) argues that Persian offers and expressions of thanks may function not merely as face-saving acts, but as face-enhancing acts. In other words, the speaker may honor both self and other through the performance of ritual courtesy. This is highly relevant for Persian language teaching because learners may wrongly interpret such interactions as insincere, excessive, or confusing if they rely only on their own first-language norms.

Ta'arof therefore belongs to the broader field of pragmatic competence. Pragmatic competence requires understanding how speech acts such as requesting, refusing, thanking, inviting, apologizing, and complimenting are performed in socially appropriate ways. Ishihara and Cohen (2010) emphasize that pragmatics is where language and culture meet. This is exactly the point at which Ta'arof becomes pedagogically important. It is not enough to teach learners how to say "thank you," "please," or "come to my house." They must also learn how these expressions operate within sequences of expectation, insistence, modesty, and relational negotiation.

3. Ta'arof in Persian Social Interaction

Ta'arof can be understood as a culturally patterned system of verbal and non-verbal behavior through which speakers manage respect, modesty, and social distance. It is not a fixed rule applied in the same way everywhere. Its form changes according to age, gender, class, familiarity, region, context, and institutional setting. Nevertheless, several recurring features can be identified: deference to the other, lowering of the self, indirect expression of desire, ritualized offering, repeated refusal, and verbal exaggeration of respect.

Beeman's (1986) sociolinguistic analysis of Iranian interaction is especially important because it connects language, status, and power. In Iranian social life, speech is not merely a vehicle of information; it is a medium through which social relations are organized and displayed. Ta'arof participates in this organization. Through Ta'arof, speakers may avoid appearing selfish, direct, greedy, proud, or disrespectful. At the same time, they may protect the dignity of the other person by offering honor, choice, and symbolic superiority.

One of the most visible forms of Ta'arof occurs in invitations and offers. A host may repeatedly invite a guest to eat more, stay longer, or visit again. The guest may refuse at first, even if willing to accept. The host may insist, and the guest may eventually accept after a ritual sequence. The meaning of the exchange does not lie in one sentence alone. It emerges through the sequence. A direct acceptance at the first offer may sound too eager in some contexts, while a final refusal may require careful phrasing to avoid offense.

Babai Shishavan's (2016) study of refusals in Persian is useful here because it distinguishes between genuine refusals and ostensible or ritual refusals. In Persian, a refusal may not always mean that the speaker truly rejects the offer. It may be part of a ritualized pattern in which the speaker demonstrates modesty, restraint, or respect. For learners of Persian, this creates a serious interpretive challenge. If they treat every refusal as literal, they may fail to understand the interaction. If they treat every refusal as ritual, they may become socially intrusive. Competence therefore requires sensitivity to context, tone, repetition, relation, and the type of offer.

Ta'arof also appears in expressions of gratitude and humility. A speaker may lower the self through phrases that present the other person as generous, honorable, learned, or superior. These expressions should not always be interpreted as literal statements about inferiority. They are often relational moves. Their purpose is to build or maintain social harmony. Similarly, compliments may be answered with denial, minimization, or self-deprecation. A person praised for skill, beauty, knowledge, or hospitality may reject the compliment not because the compliment is false, but because modesty is socially expected.

At the same time, Ta'arof should not be romanticized. It can create pressure, ambiguity, and misunderstanding. It may force people to accept obligations they did not want. It may hide real intentions behind excessive courtesy. It may also be difficult for younger speakers, diaspora speakers, or second-language learners to navigate. Shiri's (2023) recent work on attitudes toward Ta'arof shows that Ta'arof is not simply a stable traditional code; it is also a social practice that people may evaluate differently. Some may see it as beautiful and respectful, while others may experience it as burdensome, indirect, or outdated. This internal diversity is important for teaching. Learners should not be told that "all Iranians always do Ta'arof in the same way." Instead, they should learn that Ta'arof is variable, context-dependent, and socially meaningful.

4. Ta'arof as Sociopragmatic Competence

The central argument of this article is that Ta'arof should be taught as sociopragmatic competence rather than as a cultural curiosity. Sociopragmatic competence concerns the learner's ability to judge what kind of language is appropriate in a given social situation. It includes understanding power relations, social distance, degree of imposition, politeness expectations, and culturally preferred forms of speech. Ta'arof is a clear example of this competence because it regulates how Persian speakers perform social actions indirectly and relationally.

A learner may know how to form polite imperatives, use pronouns, conjugate verbs, and understand common phrases. However, without sociopragmatic competence, the learner may still misread the interaction. For example, when a host says, "befarmāyid," the phrase may mean "please," "come in," "go ahead," "eat," "sit," or "after you," depending on the context. Its meaning cannot be reduced to one dictionary equivalent. It is a pragmatic signal that invites the other person into a socially appropriate action. Similarly, "lotf dārid" may be translated as "you are kind,"

but its function may be to modestly receive a compliment, soften social distance, or return respect.

Ta'arof therefore requires learners to move from sentence-level meaning to interactional meaning. In grammar-based teaching, the sentence is often treated as the basic unit of meaning. In Ta'arof, however, meaning is distributed across a sequence. The first offer, first refusal, second offer, second refusal, insistence, acceptance, thanks, and self-lowering all work together. The learner must understand not only what each sentence means, but what role it plays in the interaction.

This also means that Ta'arof is closely connected to intercultural competence. Kramsch (1993) argues that culture is not an additional fifth skill separate from language, but a central dimension of meaning. In the case of Persian, Ta'arof shows this clearly. A learner who lacks knowledge of Ta'arof may evaluate Persian interaction through the norms of another language. They may think Persian speakers are not sincere, or that they never say what they mean. Conversely, Persian speakers may perceive the learner as cold, rude, overly direct, or socially untrained. The problem is not only linguistic error, but pragmatic mismatch.

This point has become even more relevant in the digital age. Recent work on large language models and Ta'arof suggests that even advanced computational systems may fail to recognize culturally specific politeness norms. Gohari Sadr et al. (2025) show that general politeness does not automatically equal culturally appropriate Ta'arof. This supports the broader argument of the present article: Ta'arof cannot be reduced to generic politeness. It must be understood as a culturally situated pragmatic system.

5. Pedagogical Implications for Persian Language Teaching

If Ta'arof is part of sociopragmatic competence, then Persian language teaching should include it explicitly and systematically. Many Persian courses introduce Ta'arof only through short cultural notes. For example, a textbook may explain that Iranians use many polite expressions or that hosts insist when offering food. Such notes are helpful, but they are not enough. Learners need repeated exposure to Ta'arof in context, with attention to sequence, intention, relation, and interpretation.

First, Ta'arof should be taught through contextualized dialogues rather than isolated phrases. A list of expressions such as "qābel nadārad," "befarmāyid," "lotf dārid," and "sharmandeh-am" is useful only if learners also see when, why, and how these expressions are used. A classroom dialogue may show a shopkeeper and customer negotiating payment, a host and guest negotiating food, or a teacher and student exchanging compliments. The teacher can then ask learners to identify which expressions are literal and which are ritualized.

Second, learners should be trained to distinguish between literal refusal and ritual refusal. This can be done through scenario-based tasks. For example, students may read three short dialogues: one in which the guest truly cannot stay, one in which the guest refuses only at first, and one in which the host's invitation is merely polite. Students can discuss the signs that help them interpret the situation: repetition, tone, relationship, urgency, body language, and the type of invitation.

Third, role-play can be used to develop pragmatic awareness. Students can act out common Ta'arof situations: entering a room, offering tea, giving a compliment, receiving a gift, paying in a taxi, or inviting a colleague. The aim should not be to make learners imitate exaggerated Ta'arof mechanically. Rather, the aim is to help them feel how social meaning is negotiated in Persian. After each role-play, the teacher can ask what would happen if the learner accepted too quickly, refused too strongly, or translated directly from their first language.

Fourth, teachers should compare direct translation with pragmatic interpretation. This is especially important because Ta'arof often creates translation traps. For example, "qābel nadārad" should not simply be taught as "it is free" or "it has no value." Its interpretation depends on context. Similarly, "chashm" may be translated as "eye," but pragmatically it can mean

"certainly," "I will do it," or "with respect." By comparing literal meaning and social meaning, students learn that language is not only a system of words but also a system of relations.

Fifth, Ta'arof should be taught with internal diversity and critical awareness. Not all Persian speakers use Ta'arof in the same way. Some may use it frequently; others may avoid it. Some may consider it respectful; others may criticize it as artificial or socially tiring. Generational, regional, class-based, gendered, and diaspora differences may also affect Ta'arof practices. Therefore, learners should not receive rigid rules such as "always refuse three times" or "never accept the first offer." Such formulas may create new misunderstandings. A better approach is to teach Ta'arof as a flexible cultural-pragmatic system.

Sixth, teachers should connect Ta'arof to broader communicative competence. Ta'arof can be integrated into lessons on greetings, invitations, food, shopping, family visits, academic communication, and formal correspondence. It does not need to be taught as a separate cultural unit only once. Instead, it can appear gradually across levels. Beginners can learn basic formulas; intermediate learners can analyze dialogues; advanced learners can compare Ta'arof with politeness systems in other languages and discuss its social meanings critically.

Finally, assessment should also include pragmatic interpretation. A learner's success should not be measured only by grammatical accuracy. Teachers can ask students to explain what a speaker probably means in a dialogue, choose an appropriate response, or rewrite a direct sentence in a more culturally appropriate form. This kind of assessment encourages learners to think beyond grammar and toward communicative meaning.

6. Discussion

The theoretical importance of Ta'arof lies in its ability to show that politeness is not universal in form, even when all societies have ways of managing respect and social harmony. Ta'arof challenges simple models of communication in which speakers say what they mean directly and listeners decode the message literally. In Persian interaction, meaning often emerges through social choreography. Speakers may offer what they do not expect to be immediately accepted, refuse what they may later accept, and lower themselves in order to honor others.

This does not mean that Ta'arof is irrational or deceptive. Rather, it means that sincerity and indirectness are organized differently across cultural systems. In many Ta'arof situations, the point is not to hide meaning but to perform respect. The performance itself is meaningful. A direct offer without ritual courtesy may feel incomplete, while a direct refusal without softening may feel harsh. From this point of view, Ta'arof is not outside language; it is part of how Persian language creates social reality.

For Persian language pedagogy, the implication is clear. Teaching Persian without Ta'arof risks producing learners who are linguistically competent but pragmatically vulnerable. They may understand the dictionary meaning of words, but fail to understand the social meaning of interaction. This gap is especially important for learners who will travel to Iran, interact with Persian-speaking communities, read contemporary dialogues, translate literary or cinematic texts, or work in intercultural settings.

7. Conclusion

This article has argued that Ta'arof should be understood as a form of sociopragmatic competence in Persian language learning. Ta'arof is not merely politeness, etiquette, or cultural decoration. It is a system through which Persian speakers negotiate respect, modesty, status, generosity, refusal, gratitude, and social harmony. Because its meanings often go beyond literal translation, it creates important challenges for learners of Persian.

The article proposed that Ta'arof should be integrated into Persian language teaching through contextualized dialogues, role-play, pragmatic awareness tasks, comparison of literal and interactional meaning, and discussion of cultural variation. Such an approach helps learners understand not only what Persian expressions mean, but what they do in social interaction.

For a simple theoretical article, the main contribution is modest but important: Ta'arof should be moved from the margins of "culture notes" to the center of Persian communicative competence. A learner who understands Ta'arof does not merely learn a cultural habit; they gain access to one of the key ways in which Persian organizes social meaning.

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Chemical Sciences

Thermochemical gasification and activation of coal–biomass briquettes

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Today, the main method of thermal treatment of municipal solid waste is its direct incineration. At the same time, technologies based on processes such as gasification, pyrolysis, and combustion in slag melts are also known, including those utilizing plasma torches; however, they are used on a very limited scale and have virtually no impact on the overall volume of waste utilization [1–3]. During the gasification process, the feedstock is mainly converted into synthesis gas consisting of H_2, CO, and CO_2. Paper and cardboard constitute a significant portion of municipal solid waste (up to 40% in developed countries). The second largest category worldwide is organic

matter, including food waste and other household waste, while metals, glass, and plastics account for 7–9% of total waste [4]. Compared with the conventional combustion of solid fuels, another advantage of municipal solid waste gasification is the almost complete gasification of carbon, resulting in a significantly lower degree of incomplete fuel combustion; consequently, the producer gas and ash residues contain no unreacted carbon or soot [5].

During the briquette production process, biomass and coal were used (Table 1). Food waste was used as the biomass component. Subsequently, 100 g of food waste and 50 g of Sarykol coal were mixed at a ratio of 2:1, after which water, starch, and alkali were added according to the procedure, and a homogeneous mixture was prepared.

Table 1 – First steps in making briquettes

Step 1	Step 2	Step 3
First, 100 grams of food waste was taken.	The food waste was dried in a drying oven for 1-1.5 hours.	Removed from the oven, they were dried in the room for a few more days.
		

Dissolve 0.5 grams of lye in 17.3 grams of water. Add 5.2 grams of starch to it and mix well. A loose mixture is formed. It is mixed with a mixture of coal and food waste to make a homogeneous ready-made mixture. Then it is placed in a special hydraulic press, compacted and briquettes are made (Figure 1).

Figure 1 – Briquettes made from Sarykol coal and food waste

Gasification is a thermochemical conversion process of solid fuels, including coal and coal briquettes, at high temperatures (typically 800–1000°C) in a limited oxygen or steam environment. As a result of this process, synthesis gas is produced, consisting mainly of CO, H_2, and other combustible gases, which can subsequently be used for energy or technological purposes. To ensure the efficient gasification of coal briquettes, it is important to investigate their physicochemical properties, including moisture content, ash content, elemental composition, as well as ignition and self-ignition temperatures.

During the gasification process, the concentration of the gas obtained from the first sample

was analyzed using a gas chromatograph (GC) (Table 2 and Figure 2). The table demonstrates the effect of temperature on gas concentrations during the gasification process. An increase in temperature significantly changes the gas composition. For example, at 200°C, the hydrogen (H_2) concentration reaches 98.93%, indicating its predominance. However, as the temperature increases (up to 700°C), the proportion of other gases rises. At 700°C, the hydrogen concentration decreases to 26.44%, while the levels of gases such as carbon monoxide (CO) and methane (CH_4) increase.

Table 2 – Gas concentrations during the gasification process of briquettes made from Sarykol coal and food waste with the presence of water vapor

Temperature	Concentration of gases released during the gasification process (%)							
	H_2	O_2	N_2	CO_2	CO	H_2S	CH_4	C_3H_8
200°C	98.93	0.04	-	1.03	-	-	-	-
300°C	99.47	0.03	-	0.50				
400°C	52.31	20.0	27.31	0.18	-	-	-	-
500°C	50.30	19.37	30.33	-	-	-	-	-
600°C	45.87	16.59	16.04	17.91	3.37	-	0.22	-
700°C	26.44	6.61	16.87	28.88	8.78	1.50	10.28	0.64

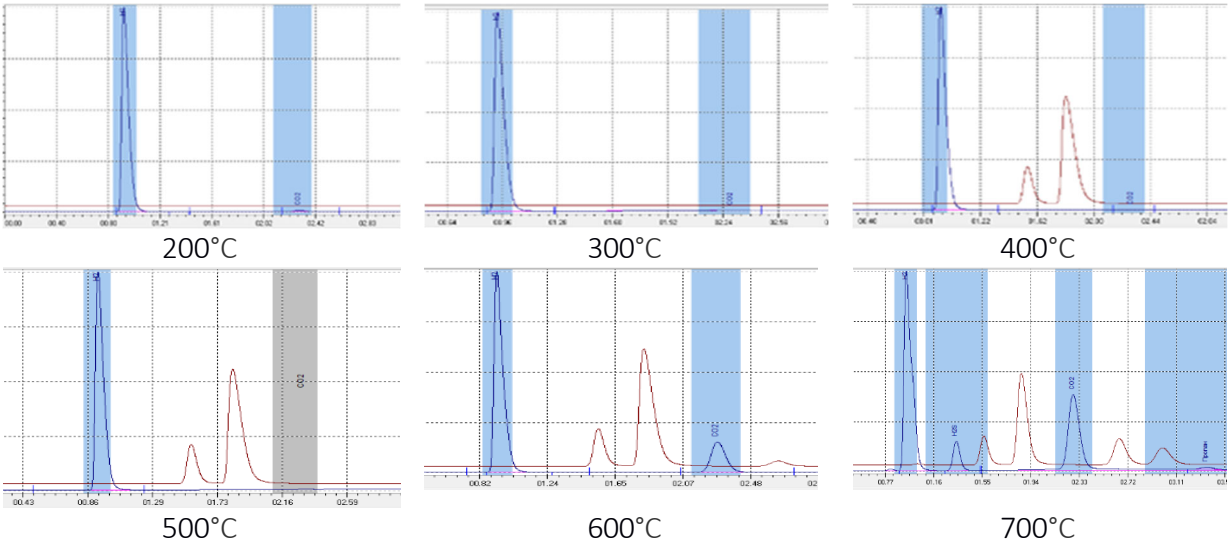

Figure 2 – Graphs of gasification of briquettes made from Sarykol coal and food waste with the presence of steam at different temperatures

Initially, at lower temperatures (200°C and 300°C), hydrogen is the dominant component of the gas mixture. However, as the temperature increases, the hydrogen concentration decreases, while the concentrations of other gases begin to rise. At 700°C, the hydrogen concentration decreases to 26.44%, indicating a reduction in its amount due to decomposition and other chemical reactions occurring during the process. At a temperature of 700°C, the concentration of carbon monoxide (CO) reaches 8.78%, while methane (CH_4) is present at a level of 10.28%. This demonstrates that higher temperatures promote the formation of carbon monoxide and methane. From 200°C to 700°C, the proportion of these gases increases steadily. Hydrogen sulfide (H_2S) reaches a noticeable concentration only at 700°C (1.50%). Although its content is relatively low compared to other gases, its formation becomes evident at elevated temperatures. At temperatures of 200°C and 300°C, the gas composition consists mainly of

hydrogen (H_2) and a small amount of oxygen (O_2). At 700°C, however, the gas mixture becomes more complex, containing nitrogen (N_2), carbon monoxide (CO), methane (CH_4), propane (C_3H_8), and hydrogen sulfide (H_2S). This indicates that temperature has a significant influence on both the composition and concentration of the gases produced.

During the steam gasification of briquettes produced from Sarykol coal and food waste, an increase in temperature significantly changes both the types and concentrations of the gases formed. As the temperature rises, the levels of gases such as carbon monoxide (CO) and methane (CH_4) increase, while the hydrogen (H_2) concentration decreases. This behavior can be regulated in industrial processes depending on the required concentration of specific gases.

In the gasification process, the amounts of carbon and steam present in the initial briquette play an important role. If the amount of steam is insufficient for the complete gasification of carbon, only part of the carbon is converted into gas, while the remaining portion stays unreacted in the form of solid residue. In addition, the ash contained in the briquette does not participate in the reaction and remains as a solid residue after the process.

Table 3 – Material balance of briquettes made from Sarykol coal and food waste as a result of the gasification process with the participation of water vapor

Incoming products				Output products			
№	Name	Composition		№	Name	Composition	
		г	%			г	%
1	"Sarykol" coal	50.2	9.3	1	Coal	12.65	2.3
2	Water	490	90.7	2	Gases	87.55	16.2
3	-	-	-	3	Water and resin	440	81.5
4	Total	540.2	100		Total	540.2	100

The highest percentage in the composition of the output products is represented by water and tar (81.5%), indicating the predominance of liquid-phase products during the gasification process. The coal content accounts for only 2.3%, which means that only a small portion of the solid coal remains after gasification, while most of it is converted into gaseous and liquid products. Gas products constitute 16.2%, formed as a result of the release of steam and tar during the gasification process. As a result of the gasification process, only a small amount of coal (2.3%) remains in the output products, whereas the majority is converted into water and tar (81.5%). These results characterize the efficiency of the gasification process and the nature of the obtained products. The participation of steam in the process changes the composition of the products formed during gasification, increasing the tendency toward the formation of liquid-phase products as the main output.

In the second gasification experiment, performed using air and steam, the combustion process was completed successfully. The concentration of the obtained gas was analyzed using a gas chromatograph (GC) (Table 4, Figure 3).

Table 4 – Temperature-dependent gas concentrations during the gasification process of briquettes made from Sarykol coal and food waste with air and water vapor

Temperature	Concentration of gases released during the gasification process (%)							
	H_2	O_2	N_2	CO_2	CO	H_2S	CH_4	C_3H_8
200°C	65	9.83	25.14	-	-	-	-	-
300°C	61.67	23.88	14.36	0.09				
400°C	48.72	18.90	32.13	0.25	-	-	-	-
500°C	50.36	19.01	30.50	0.13	-	-	-	-
600°C	47.83	17.45	30.00	4.72	-	-	-	-
700°C	50.91	18.62	29.01	1.47	-	-	-	-

After gasification, the mass of the remaining product obtained from 54.46 g of briquette was 7.90 g. The table shows how temperature affects the concentration of gases during the gasification process. At the initial stage of the gasification process, namely at a temperature of 200°C, the hydrogen concentration is 65%, indicating that hydrogen is the dominant component of the gas mixture. As the temperature increases, the hydrogen concentration gradually decreases. At 300°C, its level is 61.67%, while at 700°C it decreases further to 50.91%.

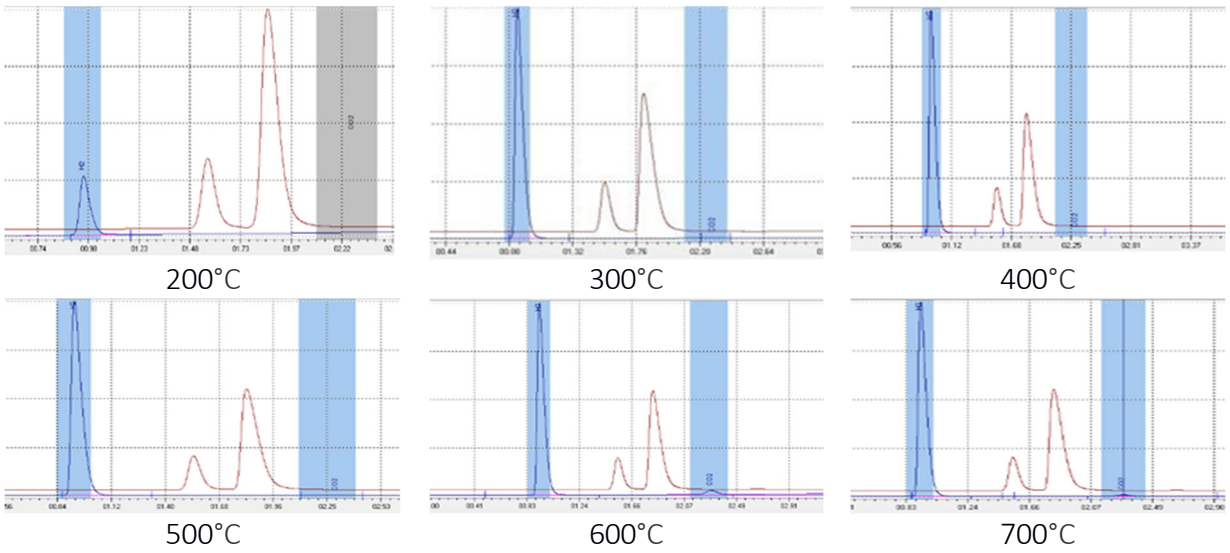

Figure 3 – Graphs of gasification of briquettes made from Sarykol coal and food waste in the presence of water vapor and air at different temperatures

At a temperature of 200°C, the oxygen concentration is 9.83%, which is relatively low. However, as the temperature increases, the oxygen concentration rises significantly. At 300°C and 400°C, the oxygen concentrations are 23.88% and 18.90%, respectively, while at 600°C and 700°C they reach 17.45% and 18.62%, respectively.

The nitrogen concentration remains relatively stable at all temperatures, although it reaches its highest value at 200°C (25.14%). At temperatures of 300°C, 400°C, and 500°C, the nitrogen content decreases to approximately 14–18%.

Carbon dioxide (CO_2) begins to appear starting from 300°C. At 300°C, its concentration is 0.09%, while at 600°C it increases to 4.72%.

The increase in carbon dioxide concentration may be associated with the intensification of complete combustion and oxidation reactions at higher gasification temperatures. At a temperature of 700°C and a heating rate of 20°C/min, the material balance for the activation of

Sarykol coal was determined (Table 5).

Table 5 – Material balance of activated carbon "Sarykol" at a temperature of 700°C with a heating rate of 20°C/min

Incoming products				Output products			
№	Name	Composition		№	Name	Composition	
		г	%			г	%
1	"Sarykol" coal	54.46	13.82	1	Coal	7.9	2
2	Water	340	86.18	2	Gases	176.56	44.8
3	-	-	-	-	Water and resin	210	53.2
4	Total	394.46	100	3	Total	394.46	100

During the coal activation process, the ash content is very low (2%), which indicates the efficiency of the gasification or pyrolysis process. The majority of the coal is converted into gas or liquid phases. The gas fraction in the resulting products is 44.8%, indicating that a significant portion of water is condensed during the gasification process and remains in the final products. This also confirms that the process proceeds in the presence of steam.

The combined fraction of water and tar is 53.2%, demonstrating that liquid products, including organic compounds, are predominantly formed during the activation process.

During the activation of Sarykol coal, a large amount of water and tar is produced, indicating the important role of steam and organic compounds in the process. The low ash content (2%) confirms the efficiency of the activation process and shows that only a small amount of solid residue remains after gasification. Overall, the process is dominated by the formation of liquid-phase products, with a significant yield of water and tar.

The results of the study showed that briquettes made from Sarykol coal and food waste show high efficiency in the processes of thermochemical gasification and activation in the presence of water vapor and air. An increase in temperature significantly affects the composition and concentration of gases: the amount of hydrogen decreases, and the formation of carbon monoxide and methane increases. In addition, it was found that the main part of the products is converted into a liquid phase (water and tar). The small amount of solid waste (ash) during gasification indicates the efficiency of the process. The results obtained allow us to consider coal-biomass briquettes as a promising raw material for energy production and gas production.

Acknowledgement

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Biological Sciences

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New Results of the Study of Neogene Paleontological Sites in the Tekes and Jalangash Canyons

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Abstract

The article “Interdisciplinary Study and Enrichment with New Materials of the Collections of the Institute of Paleontology, Zoology, Archaeology, and Archaeography (Based on the ‘Ghylym Ordasy’ Museums)” The results of the comprehensive paleontological research conducted in May 2026 in the Tekes and Zhalanash basins of Almaty Province are considered within the framework of the scientific program “Interdisciplinary Study and Supplementation of Collections of Paleontology, Zoology, Archaeology, and Archaeography with New Materials (Based on the ‘Science Palace’ Museums)”. During the research, systematic reconnaissance, geological observation, and the collection of fossil materials were carried out at the Esesartqan, Adyrgan, Aigyrzhal, At the Zhabyrtau and Botamoynak paleontological localities, route reconnaissance, geological observation, and fossil collection were conducted. As a result of the fieldwork, new fossil remains of vertebrates were discovered, and the collection materials were supplemented. The obtained data allow for the clarification of the Neogene stratigraphy, faunal composition, and paleogeographic development features of the Tekes–Kegen region.

Keywords: Neogene, paleontology, Tekes Depression, Zhalanash Basin, Esesartkhan, Adyrgan, Botamoynak, fossil vertebrates.

Introduction

The Tekes and Zhalanash basins in southeastern Kazakhstan are one of the important palaeontological areas, where Cenozoic sediments are widespread and characterized by a rich fossil record of vertebrate animals. Systematic geological and paleontological studies have been conducted in these regions since the mid-20th century [1–4].

Comprehensive field studies were organized in this area from May 6 to 25, 2026, under the scientific program “Ghylym Ordasy” of the National Academy of Sciences of the Republic of Kazakhstan. The main objective of the work was to clarify the distribution of Neogene sediments, assess the current condition of paleontological sites, and collect new scientific material.

Geological Description of the Study Area

The Tekes and Zhalanash basins are part of the intermountain tectonic structures of the Northern Tianshan. The Tekes basin is bounded to the north by the Basulytau Ridge and to the south by the Teriskey Alatau. The Zhalanash Basin was formed in genetic association with the Kegen and Tekes basins [14].

Conglomerates, sandstones, siltstones, clays, marls, and limestones are widespread in the geological cross-section of the basins. These rocks represent sediments deposited in ancient lacustrine, fluvial, and alluvial environments [2, 12].
Stratigraphically, the deposits consist of lower conglomerate beds, middle sandstone-mudstone complexes, and upper lacustrine marls and limestones [2, 3].

Research Methods

A combination of geological, stratigraphic, and paleontological methods was used during the research.

Geological work included: field surveys; geological mapping; and lithological description.
During the paleontological investigations, the following activities were conducted: prospecting for fossil localities; stratigraphic observation; collection of fossil remains; conservation of bone material; and field documentation.

The collected materials were prepared for subsequent laboratory processing and taxonomic identification.

Results and Discussion

The Esecartqan Paleontological Site

The Esecart site is one of the most well-known Neogene fossil localities in the Tekes Depression. Remains of turtles, ostriches, hipparions, rhinoceroses, camels, deer, and mastodons have been identified from this site [1].

The previously studied fauna includes taxa characteristic of the late Miocene and early Pliocene, as well as late Pliocene forms. Therefore, the question of determining the exact age of this assemblage remains a current issue [1, 4].

View of the fossil-rich archaeological site

Адурган Paleontological Site

The Adyrgan site is located in the southeastern part of the Karaoй River valley. From this location, remains of animals such as Agama sp., Struthio sp., Orientalomys adyrganus, *Mimomys

ex gr. newtoni-intermedius*, *Equus stenonis*, Remains of animals such as Gigantocamelus longipes and Gazella sinensis have been identified [4].

The lithology of the section consists of deposits formed in lacustrine and alluvial environments. The faunal assemblage indicates a late Pliocene age [4, 5].

Aygyrzhal and Zhabyrtau localities

Upper Pliocene-aged sediments are widespread in the Aygyrzhal and Zhabyrtau areas. Research at these sites has yielded vertebrate bone remains and faunal material [2, 3].

These sites play an important role in clarifying the stratigraphic structure of the Tekes Depression.

Zhabertau Paleontological Site

Botamoynak Paleontological Site

The Botamoynak locality is one of the most important vertebrate fauna sites of the Neogene period in Kazakhstan. Botaomynak bone remains were first identified in 1975 by GIN RAN geologist S. A. Nesmeyanov. Excavations conducted from 1977 to 1980 uncovered a rich early hippariodont fauna. The identified fauna included Dicerorhinus kurmetiensis, Chilotherium anderssoni, Hipparion sp., Tragoceros frolovi, Lagomeryx satensis, Miotragoceros sp., Plesiogulo crassa, Ictitherium wongii, Percrocuta sp., Pseudaelurus turnauensis, Chalicotherium botamojnacum, and other vertebrates [6, 7].

In 2012, a new species of chalicotherian, Chalicotherium botamojnacum, was described from this locality for the first time in Kazakhstan [9].

To this day, the Botamoynak paleontological site retains its high scientific significance. Materials collected during previous excavations are one of the main sources for studying the Pliocene–Miocene vertebrate fauna of Kazakhstan. In particular, the remains of Hipparion, Chilotherium, Dicerorhinus, Gigantocamelus, and predatory mammals play an important role in reconstructing the region's paleoecological conditions.

The current condition of the Botamoynak paleontological site indicates that the work of technicians at the excavation site is necessary to make it suitable for further comprehensive stratigraphic, taphonomic, and paleoecological research. Furthermore, this site holds exceptional scientific value in terms of preserving Kazakhstan's geological and paleontological heritage.

Although the site's geological outcrops are well-exposed along the banks of the Shilik River, individual sections show weathering, scouring, and slope failures due to natural erosional processes. In particular, the loose layers of alluvial-proluvial deposits are being altered by seasonal precipitation and temporary water flows. Currently, a certain level of anthropogenic impact is observed at the site. Natural erosion is causing the disruption of certain stratigraphic levels. Therefore, it is necessary to protect the paleontological site, conduct monitoring, and organize scientific conservation measures.

The Botamoynak paleontological site is marked in blue.

Results of the 2026 Field Studies

During the exploration work, new paleontological materials were collected. At the Botamoynak site, friable sediments were identified covering the bone-bearing layers, indicating the need for additional excavation work there.

Prospective sites for future systematic excavations were identified at the Adyrgan, Aygyrzhal, and Zhabyrtau localities. These areas were noted for their high level of faunal remains preservation.

Conclusion

As a result of the comprehensive studies conducted, new data was obtained on the Neogene deposits and paleontological sites of the Tekes and Zhalanash basins.

Bone remains of the following animals were found at the Esekart fossil locality: *Palaeotragus, Samotherium, Sivatherium, Gazella, Hipparion, Gigantocamelus*, and *Anancus kazachstanensis*. The collected materials are of significant scientific importance for studying the evolution of the Cenozoic vertebrate fauna of Kazakhstan, its stratigraphic structure, and its paleogeographic development history.

In the future, it is recommended to continue large-scale excavations at the Botamoynak, Adyrgan, Aygirzhal, and Zhabyrtau sites.

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Rare but Reproducible: Bioinformatic Analysis of Unusual Correlations Across Multi-Omic Systems and a Latent State Boundary Hypothesis

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Abstract

Rare correlations in biomedical data are usually treated as nuisances. When they are weak, unstable, or inconsistent with prevailing models, they are often attributed to noise, batch effects, hidden confounding, or statistical overfitting. This caution is necessary, but it has also created a systematic blind spot. Across genomics, transcriptomics, proteomics, metabolomics, microbiome research, and complex trait genetics, a recurring class of observations persists: correlations that are statistically uncommon, directionally paradoxical, or mechanistically difficult to reconcile, yet repeatedly reappear across independent datasets. These include inverse genotype-phenotype relationships, stable transcript-protein discordance, trait-sharing loci with opposite phenotypic effects, context-dependent host-microbiome associations, and tissue-specific reversals that cannot be reduced to simple artifact. The present article develops a bioinformatic framework for studying such unusual but likely real associations and advances a unifying hypothesis to explain them.

We argue that rare correlations should not be defined merely by low frequency, but by a joint profile of reproducibility, biological implausibility under dominant models, conditional stability, and cross-layer asymmetry. Using evidence from disease-omics, systems genetics, proteogenomics, microbiome research, and pleiotropic genetic studies, we show that many paradoxical associations emerge at the intersection of asynchronous regulation, latent cellular heterogeneity, ecological compositionality, nonlinear response surfaces, and time-lagged adaptation. Rather than representing statistical debris, some rare correlations may be signatures of hidden biological phase boundaries: transitions between regulatory states in which the apparent relationship between two variables is determined by unmeasured state occupancy rather than direct linear coupling.

On this basis, we propose the Latent State Boundary Hypothesis, which posits that rare but reproducible paradoxical correlations arise when biological systems are sampled across mixed, partially synchronized states distributed over multiple regulatory layers. In such settings, observed variables may remain stably associated, but the sign, magnitude, or interpretability of the association becomes counterintuitive because the correlation is generated indirectly by state transitions, buffering loops, or ecological replacement processes. This hypothesis yields concrete predictions. Rare correlations should strengthen after stratification by inferred state, show nonlinearity or sign reversal across pseudotime or disease stage, replicate more robustly in multimodal than in single-omic datasets, and map preferentially to nodes with regulatory buffering, antagonistic pleiotropy, or high contextual plasticity.

We outline computational strategies to detect, prioritize, and validate these patterns using public datasets. These include compositional transformations, conditional dependence models, mixed-effects correlation screens, latent variable inference, time-shifted correlation analysis, causal triangulation with genetics, and network-based discordance scoring. We further discuss the implications of rare correlations for biomarker discovery, causal inference, precision medicine, and systems biology. The central conclusion is that unusual correlations should not be discarded solely because they resist immediate explanation. In the era of multi-omics, some of the most informative signals may be the least intuitive ones.
Keywords: bioinformatics; multi-omics; rare correlations; paradoxical associations; transcript-protein discordance; compositionality; latent states; systems biology; causal inference; hypothesis generation

Introduction

Biomedical data science has been built on a productive simplification: if an association is strong, reproducible, and biologically plausible, it deserves attention; if it is weak, unstable, or paradoxical, it probably reflects error. This rule has protected the field from innumerable false leads. However, it also reflects the structure of earlier datasets, which were smaller, shallower, and often confined to one molecular layer at a time. Contemporary bioinformatics operates in a different regime. Public repositories now contain millions of measurements spanning DNA variation, chromatin marks, RNA expression, protein abundance, metabolites, cellular neighborhoods, microbiome composition, and clinical phenotypes. In this regime, the relationship between signal and explanation has become less straightforward. Associations that once seemed implausible now recur across studies, while many intuitively “clean” linear relationships collapse under multi-layer validation (Birney et al., 2016; Civelek & Lusis, 2014).

One reason is that biological systems are not organized as synchronous pipelines in which DNA determines RNA, RNA determines protein, and protein determines phenotype in a near-linear manner. Regulation is distributed across timescales, compartments, and feedback loops. Messenger RNA can rise while protein remains unchanged because of translational buffering or altered protein turnover. A microbial taxon can correlate with disease in one cohort and invert in another because the observed variable is compositional and ecologically constrained. A genetic variant can appear simultaneously harmful for one trait and protective for another because selection has preserved trade-offs over evolutionary time. A transcriptomic biomarker can track disease severity but reflect consequences rather than causes. The closer one looks, the more often biological correlation departs from naive expectation (Vogel & Marcotte, 2012; Liu et al., 2016; Holmes et al., 2017).

These departures are not all meaningful. Many arise from well-known technical and statistical distortions, including batch structure, collider bias, sparse matrices, over-normalization, and hidden covariates. Yet the existence of artifact does not eliminate the possibility of genuine exception. Indeed, some of the most durable findings in modern biology initially looked paradoxical. Disease-omics studies repeatedly confronted associations that could not be interpreted without accounting for cell composition and reverse causation (Birney et al., 2016). Microbiome studies found that host genotype effects seemed weak or inconsistent at the global level despite strong gene-specific microbial consequences in model systems (Spor et al., 2011). Proteogenomic studies showed that transcript abundance frequently fails to predict protein abundance in a manner that is too systematic to dismiss as noise (Buccitelli & Selbach, 2020; Eraslan et al., 2019). Cross-trait genetic studies revealed loci whose shared architecture produces mixtures of concordant and discordant trait effects, complicating any simple model of pleiotropy (Lam et al., 2019).

The present article addresses a neglected question: how should bioinformatics treat rare correlations that are unusual, reproducible, and not yet mechanistically explained? The goal is not to defend every anomaly. Rather, it is to establish a principled framework for separating biologically generative exceptions from disposable artifacts. I use the term rare correlations to describe associations that are uncommon relative to background expectations within a dataset class, especially when they display one or more of the following features: sign inversion, cross-layer discordance, context dependence, nonlinear emergence, or contradiction with prevailing mechanistic models. Such correlations are not important because they are rare per se. They are important because they frequently mark the limits of the current explanatory model.

This manuscript makes four arguments. First, rare correlations can be classified into recurring bioinformatic types, each with distinct failure modes and interpretive opportunities. Second, the same methodological features that create false paradoxes can also conceal true biological exceptions; therefore, rigorous filtering should be coupled to hypothesis generation rather than used only as a deletion step. Third, published evidence across multi-omic domains suggests that a subset of unusual correlations is structurally real and can reveal hidden regulatory organization. Fourth, these observations can be unified by a novel explanatory model, the Latent State Boundary Hypothesis, in which paradoxical correlations arise when measurements are taken across asynchronous, mixed, or transitioning biological states. Under this view, the anomaly is not the correlation itself, but our assumption that the sampled system occupies one coherent state at one level of description.

Why Rare Correlations Matter in Bioinformatics

Bioinformatics has traditionally prioritized central tendency. Differentially expressed genes, major quantitative trait loci, pathway enrichments, and consensus co-expression modules are designed to capture recurrent structure. This emphasis is statistically sensible because common patterns are easier to estimate and more likely to replicate. However, in complex systems, rare structure can be disproportionately informative. A rare regulatory inversion may identify a stress-adaptive switch. A small subset of loci with discordant pleiotropic effects may distinguish developmental from adult disease mechanisms. A low-prevalence but repeated transcript-protein mismatch may point to translational control that defines a clinically important phenotype. Ignoring uncommon but consistent patterns therefore creates a selection bias toward explanatory comfort.

The conceptual mistake is to equate rarity with irrelevance. In many biological systems, critical state transitions are sparse by design. Stem-cell commitment, immune activation, metastatic escape, ecological collapse, and acute compensation to injury often occupy narrow temporal windows or specific microenvironmental niches. Signals associated with these windows will appear infrequently in bulk data, and when observed, they may contradict expectations derived from steady-state biology. A paradoxical correlation may thus reflect low occupancy of an important state rather than unreliability of measurement.

A second reason rare correlations matter is that they can expose missing variables. When two variables remain associated after repeated adjustment but the sign is counterintuitive, one of several things is usually true: the measurement scale is inappropriate; the model omits a latent state; the relationship is nonlinear; the sampling window misses the causal interval; or the variables are coupled through ecological or feedback structure rather than direct regulation. In each case, the unusual correlation is diagnostically useful because it identifies where the current representation of the system is insufficient.

Third, rare correlations are increasingly relevant to translational biology. Precision medicine depends on subgroup structure. If unusual correlations cluster in particular ancestries, tissues, ages, disease stages, or treatment contexts, then averaging them away may erase clinically actionable heterogeneity. The practical future of systems medicine lies not only in recognizing dominant biomarkers but in mapping the circumstances under which dominant biomarkers fail.

A Taxonomy of Rare and Unusual Correlations

A rigorous treatment requires a taxonomy. Not all anomalies are alike, and different classes imply different analytic strategies.

The first class is the cross-layer discordance correlation. This occurs when a variable at one molecular layer correlates weakly, inversely, or non-monotonically with its expected downstream counterpart. The classic example is transcript-protein discordance, in which mRNA abundance explains only part of protein variability because translation, localization, and degradation introduce buffering and delay (Vogel & Marcotte, 2012; Liu et al., 2016; Buccitelli & Selbach, 2020). Similar discordance occurs between protein activity and abundance, or between metabolite pools and upstream enzyme expression (Fernie & Stitt, 2012) (Fig.1).

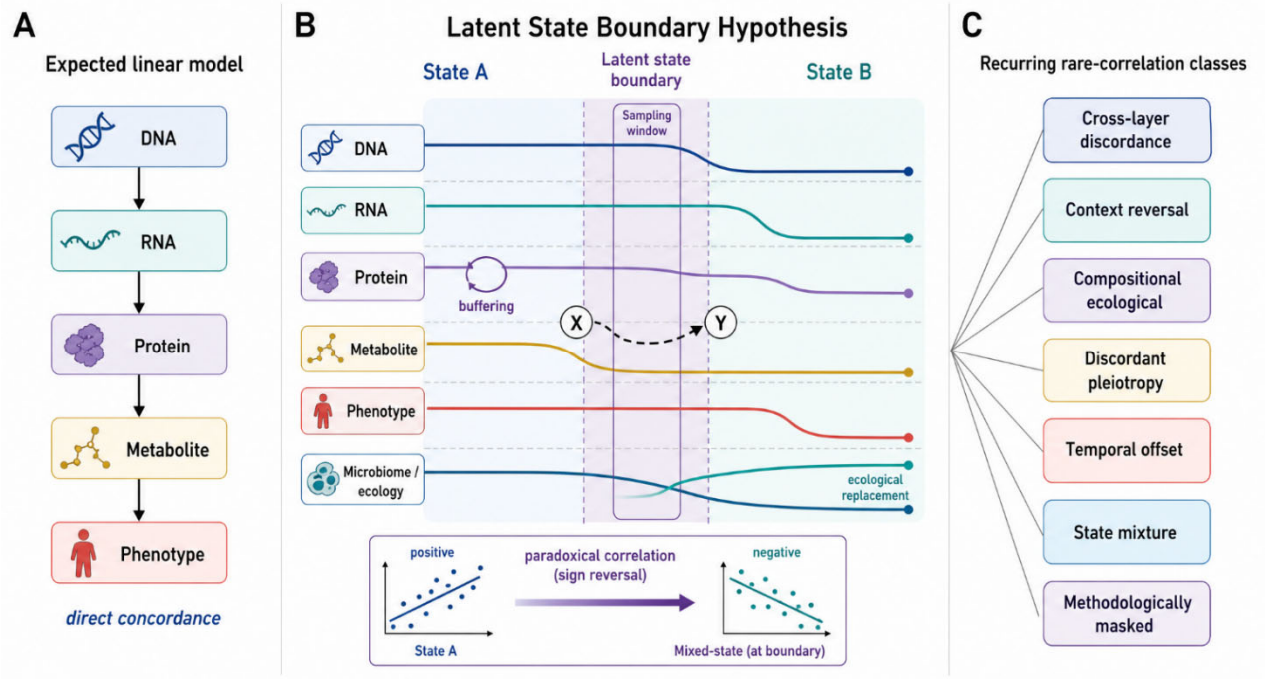

Figure 1. Conceptual overview of rare but reproducible correlations in multi-omic systems under the Latent State Boundary Hypothesis. Panel A shows the conventional linear expectation of concordance across molecular layers. Panel B illustrates the Latent State Boundary Hypothesis, in which paradoxical correlations arise when biological systems are sampled across mixed or transitioning states distributed asynchronously across regulatory layers, producing apparent sign reversal, indirect association, buffering, and ecological replacement effects. Panel C summarizes recurring classes of unusual correlations observed in bioinformatic data, including cross-layer discordance, context reversal, compositional ecological effects, discordant pleiotropy, temporal offset, state mixture, and methodologically masked signals.

The second class is the context-reversal correlation. Here, the sign of the association changes across tissues, cell types, environments, or disease stages. A marker that appears protective in one tissue may be harmful in another, not because one dataset is wrong, but because the biological role is state contingent. Context reversal also includes Simpson-like effects, where aggregated data obscure or invert within-stratum relationships. In disease-omics, such reversals are frequently driven by changes in cell composition, ancestry structure, or disease stage (Birney et al., 2016).

The third class is the compositional ecological correlation, common in microbiome and other relative-abundance datasets. Because the total is constrained, an increase in one component forces apparent decreases elsewhere, creating correlations that are algebraically induced or ecologically mediated rather than directly causal. Yet these are not always artifacts. In ecological systems, replacement processes are real biology. The challenge is distinguishing measurement-

induced interdependence from true competitive, trophic, or host-mediated coupling (Gloor et al., 2017; de Vos & de Vos, 2012).

The fourth class is the discordant pleiotropic correlation. A locus, pathway, or polygenic component may be associated with multiple traits in opposite directions. Such patterns often seem contradictory under one-trait models but become informative when traits occupy different developmental, metabolic, or evolutionary landscapes. Antagonistic pleiotropy is the evolutionary archetype: the same genetic architecture may enhance fitness or function under one condition while increasing disease risk under another (Byars & Voskarides, 2020).

The fifth class is the temporal offset correlation. Variables can be causally related yet poorly synchronized in measurement space. An acute transcriptomic response may precede a delayed proteomic adaptation; a metabolite signature may lag behind pathway activation; a microbial shift may follow, rather than initiate, inflammation. If samples are collected cross-sectionally, these offset relationships can appear weak, inverse, or inexplicable. In dynamic systems, correlation measured without time is often an alias of causation measured at the wrong phase.

The sixth class is the state-mixture correlation. Bulk measurements often average across subpopulations occupying distinct molecular states. If a gene is highly expressed in one expanding cell state but translated only in another, the aggregate relationship between RNA and protein may become paradoxical. Similarly, a microbe may associate with disease only through expansion of a host niche. The observed correlation then reflects changing state occupancy rather than pairwise regulation.

The seventh class is the methodologically masked real correlation. Some true correlations look anomalous because standard preprocessing distorts them. Over-correction for batch, rank-based normalization, aggressive imputation, or unmodeled sparsity can flatten relationships that exist only in tails, only above thresholds, or only in rare subgroups. In this situation, rarity arises not solely from biology but from method-biological mismatch.

These classes overlap. Indeed, the most interesting rare correlations often combine several features: they are cross-layer, context-reversed, temporally offset, and state-mixed simultaneously. This complexity helps explain why they resist immediate interpretation.

Methodological Sources of False and True Paradox

Before assigning biological meaning, one must take seriously the many ways rare correlations can be fabricated. Disease-omics studies are particularly vulnerable to confounding by cell composition, medication, ancestry, age, and reverse causation. Birney et al. (2016) argued persuasively that many epigenomic and other disease-omics findings fail because the measured molecular mark may reflect disease consequences or changing cell populations rather than causal biology. Rare paradoxical associations are enriched for such distortions because unusual signals often arise where sample composition is unstable.

Compositionality is another major source of false paradox, especially in microbiome datasets. Relative abundance induces interdependence among components even when absolute loads are unchanged. Standard correlation on closed data can therefore produce artifactual negative relationships or misleading network structure. Gloor et al. (2017) showed that this problem is not optional; it is intrinsic to the data geometry. Yet the solution is not to dismiss all unusual microbiome correlations. Rather, one must analyze them in the appropriate log-ratio space and, where possible, compare against absolute abundance or ecological covariates.

Collider bias and over-adjustment can also generate biologically seductive but false associations. Conditioning on a downstream consequence of two independent variables can induce a spurious correlation between them. This is especially dangerous in clinical cohorts where inclusion criteria are disease dependent. Likewise, selecting only survivors, responders, or treated individuals can create protective-looking signals for harmful variables. The more selective the cohort, the more plausible the paradox.

Measurement discordance between platforms is equally important. Proteomics and transcriptomics differ in depth, dynamic range, missingness, and molecular target. A gene absent from proteomics may not be unexpressed; it may simply be hard to detect. Dumitriu et al. (2016) showed that many differentially expressed transcripts in Parkinson disease were not represented in the proteomic layer, complicating direct comparison. Such gaps can create apparent inconsistencies that are partly technical. However, when discordance persists across well-measured features and replicate cohorts, the explanation must expand beyond platform failure.

Finally, rarity can emerge from statistical summarization itself. Correlation assumes a symmetric linear relationship across all observations. Biological systems often violate every part of that assumption. Threshold effects, hysteresis, bifurcation, and saturation can yield low global correlation despite strong local coupling. Conversely, mixture distributions can yield high correlation without direct regulation. Rare correlations therefore demand models that separate geometry from mechanism.

Bioinformatic Framework for Detecting Rare but Reproducible Correlations

A practical framework begins with a simple rule: unusual correlations should be screened under multiple representations of the data before they are interpreted. This means that a candidate association must survive not one correlation coefficient but a sequence of stress tests designed to distinguish fragility from structured exception.

The first step is multi-scale preprocessing. For RNA and protein data, raw counts, variance-stabilized values, and within-sample standardized abundances should all be examined. For microbiome data, centered log-ratio or isometric log-ratio transforms should replace naive relative abundance analysis where possible (Gloor et al., 2017). For multi-cohort studies, harmonization should preserve biological tails rather than overcompress them.

The second step is replication under conditional models. A rare correlation is more credible if it replicates after adjustment for major covariates, but it should also be tested for interaction rather than only persistence. If the association disappears globally yet reappears strongly within age strata, cell fractions, ancestry groups, or disease stages, this is not failure; it is evidence of context structure. Mixed-effects models, partial correlation, and hierarchical Bayesian frameworks are particularly useful here.

The third step is cross-layer concordance profiling. Rather than asking whether RNA predicts protein in a generic sense, one should score each feature for its pattern across layers: concordant, buffered, delayed, inverted, thresholded, or absent. This creates a “discordance phenotype” for each gene or pathway. Genes in the buffered or inverted classes are likely enriched for translational control, proteostasis, compartmentalization, or cell-state restriction (Buccitelli & Selbach, 2020; Liu et al., 2016).

The fourth step is latent variable inference. Matrix factorization, topic models, variational autoencoders, and graph-based single-cell decomposition can reveal hidden states that mediate paradoxical relationships. The key question is not whether a latent factor exists, but whether conditioning on it makes the unusual correlation more coherent. If an inverse association becomes monotonic within inferred states, the anomaly likely reflected state mixture.

The fifth step is temporal or pseudotemporal realignment. When longitudinal sampling is unavailable, trajectory inference, disease staging, or molecular clocks can approximate progression. Correlations should then be reevaluated with lags or along pseudotime. Temporal offset signals often emerge only after realignment of molecular layers.

The sixth step is causal triangulation. Genetic instruments, QTL colocalization, Mendelian randomization, and network-based causal scoring can help decide whether an observed association is upstream, downstream, or merely parallel to the phenotype of interest (Holmes et al., 2017; Porcu et al., 2021; Krämer et al., 2014). Rare correlations that are unsupported by causal

triangulation may still be useful biomarkers, but they should not be interpreted as mechanisms without additional evidence.

The seventh step is failure analysis, which is as important as success analysis. A genuine rare correlation often fails in patterned ways. It may vanish in one tissue but strengthen in another, fail in steady state yet appear under stress, or depend on a narrow abundance window. Mapping the topology of failure is often the fastest route to mechanistic insight.

Evidence from Disease-Omics: Association Without Easy Interpretation

Epigenome-wide and broader disease-omics studies illustrate the core problem. Molecular marks associated with disease are frequently interpreted as mechanisms, yet many may reflect altered cell composition, inflammatory consequences, or adaptive compensation rather than causal origin. Birney et al. (2016) emphasized that disease-omics can mislead when the cellular hypothesis is undefined. This critique is often taken as a warning against overinterpretation, but it also reveals why rare correlations emerge. If a molecular feature tracks disease in only a subset of contexts, or inversely relative to expectation, the explanation may lie in the mismatch between the sampled biospecimen and the true disease process.

For example, a methylation mark associated with disease severity may appear paradoxically protective when analyzed in whole blood because severe disease shifts leukocyte composition. After deconvolution, the signal may localize to a rare immune state with a plausible role in compensation or chronicity. Such findings are not “wrong” at the blood level; they are composite. The rare correlation is the visible trace of an unmeasured cellular redistribution.

Systems genetics provides a broader framework for this phenomenon. Civelek and Lusis (2014) described complex traits as flows of information across intermediate phenotypes rather than direct gene-to-disease mappings. In such systems, unusual associations can arise when a locus influences an intermediate network whose downstream phenotypic effect depends on tissue, environment, or network state. A locus may correlate weakly with disease overall while exerting strong, state-specific influence through one module. The signal therefore appears rare in the phenotype space but structured in the network space.

This logic matters for biomarker development. If disease-associated molecular marks are interpreted only by their average effect, rare but important subgroup-specific directions may be missed. The field has spent considerable energy eliminating heterogeneity to produce cleaner signatures. A complementary strategy is to model heterogeneity as signal-bearing structure.

Evidence from Transcript-Protein and Multi-Omic Discordance

Few areas demonstrate the reality of unusual correlations more clearly than the transcript-protein relationship. For years, the limited correlation between mRNA and protein abundance was treated either as a technical embarrassment or a vaguely acknowledged complexity. It is now clear that the discordance is systematic, biologically informative, and central to gene regulation (Vogel & Marcotte, 2012; Liu et al., 2016; Buccitelli & Selbach, 2020).

Liu et al. (2016) argued that transcript levels alone are often insufficient to explain phenotype because protein levels depend on translation, localization, and degradation, all of which vary across states and timescales. Buccitelli and Selbach (2020) extended this view by showing that mRNA-protein correlation is shaped by contextual confounders and buffering mechanisms, making transcriptomics and proteomics nonredundant rather than hierarchically redundant. The significance for rare correlations is profound. Genes that deviate most strongly from expected RNA-protein concordance may mark regulatory bottlenecks, proteostatic compensation, or stress adaptation.

Large atlas-scale work reinforces this interpretation. Eraslan et al. (2019) generated a paired proteome-transcriptome map across 29 healthy human tissues and observed strong differences between RNA and protein quantities both within and across tissues. Protein abundance was often more stable than transcript abundance, and many highly expressed transcripts lacked

corresponding protein detection. This is not a random failure of technology alone. It suggests that tissues distribute regulatory variance differently across layers. In practical terms, genes with unusually stable protein despite volatile RNA may define buffered physiological functions, whereas genes with high RNA but low protein may indicate poised or compartmentalized programs.

Disease studies show similar patterns. Dumitriu et al. (2016), analyzing Parkinson disease cortex, found limited overlap between differentially expressed RNAs and proteins, yet the discordant layers implicated complementary pathological pathways. Mitochondrial processes emerged more strongly in proteomics, while protein folding pathways appeared prominently in RNA-seq. The implication is that one layer may capture executed dysfunction while another captures attempted adaptation. A paradoxical cross-layer relationship can therefore be real precisely because disease biology is not synchronized.

The platelet study by Londin et al. (2014) adds another variant. Individuals showed strong transcriptome correlations, but these associated only weakly with the platelet proteome. This finding undermines the expectation that inter-individual RNA similarity should map straightforwardly to protein similarity. Instead, it suggests that the platelet proteome may be regulated by post-transcriptional inheritance, translational reserve, or activation history not adequately reflected in measured RNA. Again, the unusual correlation is not empty; it points toward hidden regulatory storage and delayed execution.

Metabolomics adds another layer of interpretive tension. Fernie and Stitt (2012) argued that discordance between metabolites, proteins, and transcripts is not surprising given pathway topology, chemistry, and network interactions. Metabolites integrate flux, compartmentalization, substrate availability, and enzyme regulation, so they need not align with upstream abundance. Rare metabolite-transcript correlations may therefore reveal branch-point control or rapid homeostatic correction. Systems that are best buffered often look least intuitive in static data.

Evidence from Host-Microbiome Associations

Microbiome research is exceptionally rich in unusual correlations because both the host and the microbial community are multistable, context-sensitive, and compositionally constrained. At first glance, the literature seems contradictory. Twin studies and population studies often report modest or inconsistent host genetic effects on overall gut community structure, whereas targeted manipulations in model systems show that individual host genes can strongly reshape microbial ecology. Spor et al. (2011) framed this tension explicitly: host genetics matters, yet global heritability appears limited and variable.

This is precisely the kind of unusual but real correlation structure that deserves closer analysis. The weak average host-genotype effect may not indicate biological insignificance. Instead, it may mean that host control is sparse, localized, and contingent. A small number of host pathways may regulate specific microbial hubs, but the overall community is simultaneously shaped by diet, exposure, medication, stochastic colonization, and ecological succession. The result is a signal that looks weak in aggregate but strong in selected subnetworks. Rare host-microbe correlations can thus be genuine signatures of niche-specific control.

The problem is compounded by compositionality. Gloor et al. (2017) showed that microbiome datasets are mathematically closed and therefore prone to misleading correlation structure under standard analysis. Negative correlations in particular are easily overinterpreted. Yet a strict artifact view is equally inadequate. Ecological replacement, resource competition, and host filtering produce true negative associations. The analytic task is to determine whether the observed pattern is invariant across log-ratio bases, robust to total load adjustment, and supported by ecological or host covariates.

De Vos and de Vos (2012) made another important point: much of microbiome medicine remains at the level of correlation rather than causation. But correlation is not therefore trivial. In systems where reciprocal causation and ecological feedback dominate, causal direction may be distributed

rather than linear. A disease-associated taxon may both reflect and reinforce host inflammation. Such circular structure naturally yields paradoxical associations across cohorts, stages, and interventions.

In bioinformatic practice, rare host-microbe correlations are particularly likely to identify hidden ecological transitions. A taxon that appears protective only in early disease may in fact mark an unstable intermediate state before community collapse. Another taxon may correlate inversely with inflammation in one ancestry because it substitutes for a different functionally equivalent organism absent in another ancestry. These are not contradictions of biology; they are reminders that microbial communities are functional collectives, not fixed species lists.

Evidence from Cross-Trait Genetics and Evolutionary Trade-Offs

Cross-trait genetics provides some of the clearest examples of real but counterintuitive association. Lam et al. (2019) analyzed cognition, educational attainment, and schizophrenia and showed that shared genetic architecture could be partitioned into pathways with discordant effects. Some components linked education and schizophrenia positively, while others tracked the expected inverse relationship between cognition and schizophrenia risk. The overall pattern is not a failure of association testing. It reveals that trait-sharing is mechanistically heterogeneous. A single summary genetic correlation compresses multiple biological directions into one estimate.

This has broad implications. Many disease relationships that appear contradictory at the epidemiologic level may reflect mixtures of developmental, synaptic, metabolic, or behavioral pathways with different directions of effect. Rare discordant loci are therefore disproportionately valuable because they identify the boundaries between mechanistic classes.

Evolutionary theory offers a related explanatory frame. Antagonistic pleiotropy predicts that variants or pathways can confer benefit in one context while imposing cost in another. Byars and Voskarides (2020) reviewed evidence for this pattern in human disease, arguing that trade-offs may explain the persistence of some risk alleles. Under this view, a paradoxical association is not anomalous but expected when selection acts across competing fitness landscapes. A gene that promotes immune vigor early in life may increase late inflammatory disease. A pathway that enhances neuronal plasticity may also elevate vulnerability to psychiatric instability. Bioinformatics often rediscovers these trade-offs as discordant correlation rather than as explicit evolutionary design.

The important insight is that discordant pleiotropy and antagonistic trade-off are not rare only because the underlying biology is rare. They are rare because our analysis typically aggregates across age, environment, phenotype definition, and developmental stage. Once stratified appropriately, the “paradox” may resolve into structured trade-off geometry.

Toward a Novel Explanation: The Latent State Boundary Hypothesis

The evidence surveyed above suggests a unifying interpretation. Rare but reproducible unusual correlations often arise where systems are observed across boundaries between latent biological states. I therefore propose the Latent State Boundary Hypothesis.

The hypothesis has five core claims.

First, biological systems are organized into partially discrete but dynamically traversed states distributed across multiple regulatory layers: transcriptional, translational, metabolic, cellular, ecological, and phenotypic. These states need not be sharply separated in molecular space, but they occupy distinguishable attractor-like regions.

Second, different molecular layers traverse these states asynchronously. Transcriptomes can respond within minutes, proteomes more slowly, metabolite pools still differently, and phenotypes only after integration. Microbial communities may lag host signals, and cell composition may shift after molecular initiation.

Third, bulk observational datasets often sample mixtures of these states without directly measuring state occupancy. The observed association between two variables therefore becomes

a weighted function of hidden state distribution rather than a direct summary of pairwise regulation.

Fourth, near state boundaries, the sign and magnitude of correlations become especially unstable to intuition but not necessarily to replication. If one variable changes early and another late, or if one is buffered while another is permissive, cross-sectional data can produce stable inverse or nonlinear relationships even when both variables participate in the same biological program.

Fifth, such paradoxical correlations are most likely to occur in modules characterized by buffering, feedback, ecological replacement, or evolutionary trade-off. In other words, rare correlations are enriched where biological systems preserve function by redistributing control.

This hypothesis differs from a generic "hidden confounding" explanation in an important way. Hidden confounding treats the anomaly as nuisance. The Latent State Boundary Hypothesis treats the anomaly as a signature of regulated transition. Under this model, the paradox is informative because it marks where biological coordination is changing state.

Predictions Derived from the Hypothesis

A useful hypothesis must yield predictions.

Prediction one: rare paradoxical correlations will become stronger and more interpretable after latent-state inference. If the anomaly is driven by state mixture, clustering, deconvolution, pseudotime alignment, or multimodal factorization should sharpen within-state relationships and reveal distinct directionality across states.

Prediction two: these correlations will be enriched in genes and pathways known for post-transcriptional regulation, protein turnover control, proteostasis, immune activation thresholds, developmental switching, or ecological niche competition. This follows from the expectation that buffering and replacement processes create asynchronous or indirect coupling.

Prediction three: paradoxical correlations will often show stage specificity. A disease-associated inverse RNA-protein relationship should be strongest at transition points such as early inflammation, compensation, metastable remission, or preclinical degeneration rather than across the entire disease course.

Prediction four: cross-omic replication will outperform same-omic replication for unusual signals. If a paradoxical relationship reflects hidden transition, one should often find complementary evidence in another layer even when the same-layer effect is modest. For example, a weak inverse RNA-protein signal may co-occur with strong pathway-level metabolomic or phenotypic coherence.

Prediction five: genetic causal triangulation will divide rare correlations into at least three groups: upstream drivers, downstream consequences, and transition markers. Transition markers may fail classic causal tests yet remain highly predictive of boundary crossing.

Prediction six: network localization of rare correlations will be nonrandom. They should cluster at interfaces between modules rather than in core housekeeping hubs. Boundary nodes transmit or absorb state change; core nodes maintain continuity.

Prediction seven: in microbiome and ecological data, unusual negative associations that are real will persist under compositional correction and map to functional replacement or resource competition, whereas algebraically induced associations will not.

A Computational Pipeline for Public-Dataset Discovery

The Latent State Boundary Hypothesis is testable using existing data. A practical discovery pipeline can be built entirely from public cohorts.

The first module would collect matched or linkable datasets across omic layers and phenotypes, prioritizing cohorts with tissue annotation, disease stage, ancestry, age, and treatment metadata. Where direct pairing is unavailable, pathway-level integration can substitute for feature-level overlap.

The second module would identify candidate rare correlations using a wide panel of association forms: Pearson, Spearman, distance correlation, mutual information, segmented regression, and threshold-dependent models. The aim is not to privilege one metric but to detect features whose relationship is unusual relative to the dataset background.

The third module would compute a paradox score integrating replication, biological implausibility under baseline expectation, context specificity, and cross-layer asymmetry. A strong positive RNA-protein correlation is not paradoxical; a replicated inverse correlation confined to one disease stage and supported by a protein-stability signature is.

The fourth module would infer latent states through deconvolution, topic modeling, nonnegative matrix factorization, or single-cell reference mapping. Candidate correlations would then be reevaluated within inferred states and along trajectories.

The fifth module would perform causal triangulation using QTL overlap, Mendelian randomization where appropriate, and curated network directionality tools such as pathway causal analysis frameworks (Krämer et al., 2014; Porcu et al., 2021). The goal is not necessarily to prove causality, but to classify the anomaly's likely regulatory position.

The sixth module would test portability across cohorts, tissues, and ancestries. A paradoxical signal that survives only in one highly processed dataset is likely expendable. One that recurs in distinct populations but under different state occupancies is especially interesting.

The seventh module would rank anomalies for experimental follow-up. Highest priority should go to those that are reproducible, mechanistically unresolved, state-structured, and clinically linked (Fig 2).

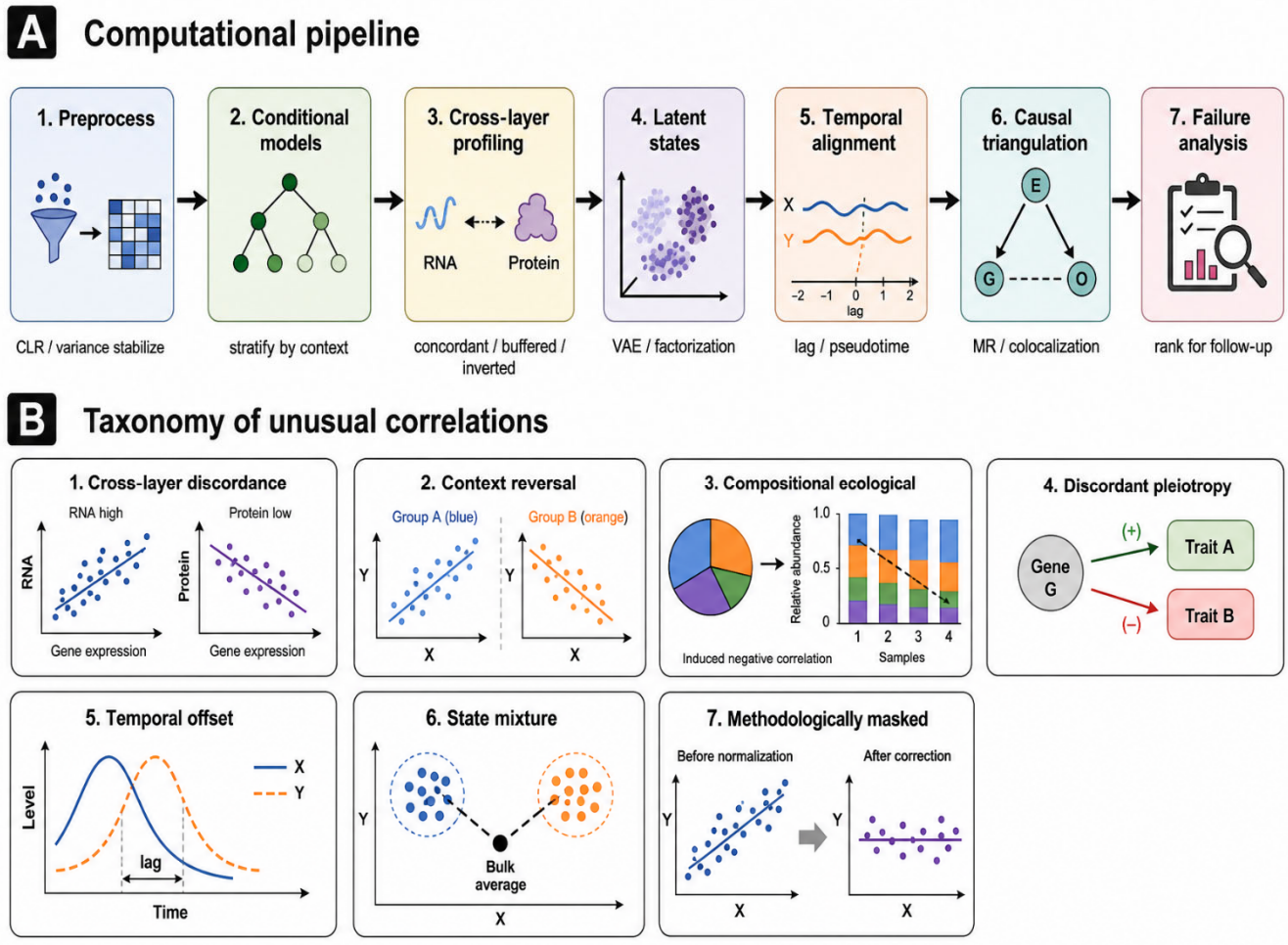

Figure 2. Computational framework for detection and interpretation of rare but reproducible correlations across multi-omic systems.

(A) Schematic overview of a seven-step bioinformatic pipeline for identifying biologically

meaningful outlier associations. The workflow includes preprocessing and variance stabilization, conditional modeling across relevant contexts, cross-layer concordance profiling, latent state inference, temporal or pseudotemporal alignment, causal triangulation, and failure analysis for prioritization of candidates for experimental follow-up. (B) Visual taxonomy of recurrent classes of unusual correlations discussed in the manuscript, including cross-layer discordance, context reversal, compositional ecological effects, discordant pleiotropy, temporal offset, state-mixture effects, and methodologically masked signals. Together, these modules operationalize the latent state boundary hypothesis by distinguishing regulated exceptions from technical noise and by mapping paradoxical associations to hidden biological structure.

Translational and Conceptual Implications

If the Latent State Boundary Hypothesis is broadly correct, several implications follow. First, biomarker pipelines should stop treating discordant signals as automatic failures. A biomarker that changes direction across disease stage may be more informative than a stable average marker because it reports transition risk. Second, multi-omic study design should be optimized not only for concordance discovery but for discordance interpretation. Matching timepoints, tissues, and cell states becomes essential when the biology is asynchronous. Third, precision medicine should incorporate anomaly-aware stratification. Patients whose molecular data display paradoxical signatures may occupy unstable or compensatory states not captured by standard classifications. Conceptually, the hypothesis reframes unusual correlation as a resource for model building. Modern bioinformatics has become extremely effective at ranking associations, but less systematic about explaining why some reproducible associations remain unintuitive. By foregrounding these cases, the field may discover new state variables, hidden compartments, and regulatory delays that are invisible to average-effect analysis.

Limitations

This argument has limitations. Some rare correlations will always be artifacts, and the danger of narrative overfitting is real. A paradox can be seductive precisely because it invites explanation. The proposed framework therefore depends on unusually strict replication, preprocessing sensitivity analysis, and negative controls. In addition, latent-state inference itself can be unstable; one can manufacture explanatory clusters as easily as one can miss real ones. The hypothesis is also easier to test in datasets with rich metadata and matched multi-omics than in sparse clinical cohorts. Finally, not every genuine rare correlation will reflect a state boundary. Some will arise from measurement nonlinearities, stochastic expression, or structural genomic peculiarities that do not fit the proposed model.

Even with these limitations, the key point remains: the correct response to a reproducible unusual correlation is not immediate belief or immediate deletion, but structured interrogation.

Conclusion

Bioinformatics is entering a phase in which explanation, not detection alone, is the central challenge. Rare, paradoxical, or mechanistically awkward correlations are often treated as leftovers of imperfect data. Yet across disease-omics, proteogenomic, microbiome ecology, and complex trait genetics, a recurring subset of these signals appears too structured, too reproducible, and too biologically situated to dismiss. They frequently emerge where biological systems cross hidden boundaries between states, where regulation is buffered across layers, or where ecological and evolutionary trade-offs reshape observable relationships.

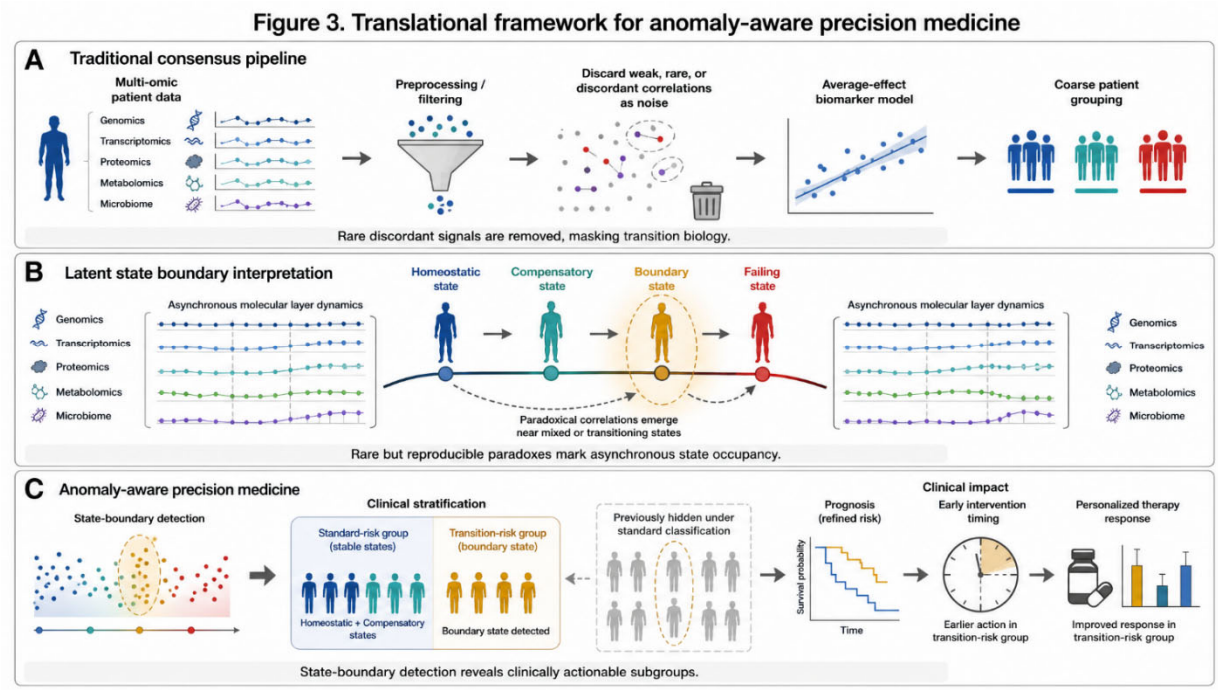

Figure 3. Translational framework for anomaly-aware precision medicine. (A) In conventional multi-omic analysis pipelines, weak, rare, or discordant correlations are frequently filtered out as noise, leading to average-effect biomarker models that can obscure biologically meaningful transition signals. (B) Under the latent state boundary hypothesis, rare but reproducible paradoxical correlations arise when biological systems are sampled across asynchronous or mixed state transitions distributed across molecular layers, including genomics, transcriptomics, proteomics, metabolomics, and the microbiome. (C) Incorporation of state-boundary detection into clinical stratification enables identification of transition-risk subgroups that may remain hidden under standard classifications, thereby improving prognosis, therapeutic timing, and precision intervention.

The proposed Latent State Boundary Hypothesis offers one way to organize these observations. It suggests that unusual but real correlations are often signatures of asynchronous state occupancy rather than contradictions of biology. If so, the anomalies that resist current models may become guides to the next generation of models. The future of high-resolution biomedical inference will depend not only on finding stronger signals, but on learning how to read the weak, rare, and paradoxical ones without mistaking mystery for error or noise for insight.

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Economic Sciences

THE IMPACT OF TRADE GAP ON INCOME INEQUALITY IN AZERBAIJAN: AN EMPIRICAL ANALYSIS

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SUMMARY

In this study, the impact of trade openness on income inequality in Azerbaijan was investigated from theoretical and empirical aspects. Acceleration of globalization processes and expansion of foreign trade relations have strengthened the integration of the country's economy into international markets and become one of the main sources of economic growth. At the same time, how the economic benefits created by trade openness are distributed among population groups remains one of the important socio-economic issues.

The study examined the relationship between trade openness and income inequality based on Heckscher–Ohlin and Stolper–Samuelson models, as well as modern empirical approaches. Taking into account the high dependence of Azerbaijan on the oil and gas sector, the characteristics of the export structure and the level of development of the non-oil sector, the mechanisms of influencing the distribution of trade openness on income distribution were analyzed.

The results of the study are expected to show that the impact of trade openness on income inequality depends on the structural characteristics of the economy. Especially in the context of the predominance of the oil sector, there is a possibility that the trade openness will increase the income gap. At the same time, the development of the non-oil sector and the diversification of exports can enhance the positive impact of trade on social welfare and reduce income inequality. The results of the study are important in terms of ensuring inclusive economic development in Azerbaijan, improving export policy and developing economic policy measures aimed at more equitable distribution of incomes.

Keywords: Trade openness, income inequality, Gini coefficient, ARDL model, foreign trade, globalization, Azerbaijani economy, non-oil sector.

In today's globalized world, international trade is considered to be one of the main drivers of economic development of countries. Liberalization of foreign trade creates conditions for accelerating economic growth, attracting investments, expanding production, and increasing international competitiveness. After gaining independence, Azerbaijan has identified integration into the world economy as one of the priority directions and has taken important steps in the field of expanding foreign economic relations. In particular, the development of the oil and gas sector, the implementation of international energy projects, the increase of the export potential of the non-oil sector, the negotiations on membership in the World Trade Organization (WTO) and participation in regional economic cooperation mechanisms have led to a significant increase in Azerbaijan's foreign trade turnover.

However, how the economic benefits obtained as a result of the expansion of foreign trade are distributed among different social groups of society is one of the important scientific and practical issues. The occurrence of economic growth does not always mean equal distribution of incomes. In some cases, trade openness can increase income inequality, leading to faster

enrichment of high-income strata, while in other cases, it can increase the well-being of low-income groups through increased employment and increased productive opportunities. In this regard, the study of the impact of trade openness on income distribution in Azerbaijan is of particular relevance.The relationship between trade openness and income inequality is one of the long-studied topics in economic theory. One of the most important theoretical approaches in this field is the Heckscher–Ohlin model of trade. According to this theory, countries specialize in the production of products that make more intensive use of the factors of production they have, and export those products. According to the model, international trade allows for a more efficient allocation of resources and increases the level of well-being of countries.

The Stolper–Samuelson theorem, a continuation of the Heckscher–Ohlin model, explains the effect of international trade on the distribution of income. According to this theory, when trade is liberalized, the income of the abundant factor of production in the country increases, while the income of the scarce factor decreases. Since it is accepted that the labor factor is relatively abundant in developing countries, trade openness is theoretically expected to reduce income inequality by increasing labor incomes. This approach suggests that international trade can improve social welfare and produce more balanced outcomes in income distribution. However, recent empirical studies have shown that these theoretical findings do not apply equally to all countries. It has been observed that trade openness can increase income inequality, especially in the context of technological development, capital mobility, and deepening globalization. According to modern approaches, new technologies entering the country as a result of foreign trade mainly increase the demand for highly skilled labor. This has led to a widening wage gap between skilled and unskilled workers. In addition, in countries dominated by capital-intensive sectors, the concentration of trade revenues among certain economic groups can lead to increased income inequality. In this regard, the impact of trade openness on income distribution in countries rich in natural resources, such as Azerbaijan, is of particular interest. Although the high level of profitability of the oil sector accelerates economic growth, the low share of this sector in employment may limit the equal distribution of income among the population.

Azerbaijan's economy has the characteristics of a small and open economy. Foreign trade plays an important role in the economic development of the country, and export revenues play an important role in the formation of the state budget. However, there are a number of specific features in the trade structure of Azerbaijan that are important to take into account in empirical analysis.

The most important of these features is that the economy is highly dependent on natural resources, especially the oil and gas sector. For many years, most of Azerbaijan's total exports fell on the share of oil and petroleum products. Since the oil sector is a high-capital-intensive sector, the added value created here is high, but its share in employment is limited. As a result, it is difficult to distribute the revenues from oil exports to other sectors of the economy and to all segments of the population at the same level. This can have an impact on income inequality.

Another important factor is the level of development of the non-oil sector. As a result of the economic diversification policy implemented in recent years, special attention has been paid to the development of agriculture, tourism, transport and logistics, information and communication technologies and service sectors. The expansion of foreign trade in the non-oil sector can create new jobs, increase employment and increase the income level of the population in the regions. Therefore, it is also important to assess the impact of trade openness in the non-oil sector on income inequality.

The relationship between trade openness and income inequality in Azerbaijan is assessed using econometric methods. Annual or quarterly time series data covering the years 2000–2025 can be used for analysis. The main sources of data will be the statistical databases of the State

Statistical Committee of the Republic of Azerbaijan, the Central Bank of the Republic of Azerbaijan, the World Bank and other international organizations.

It is considered appropriate to use the ARDL (Autoregressive Distributed Lag) model to determine the long-term and short-term relationships between variables. The advantage of the ARDL approach is that it allows for the evaluation of long-term relationships even when the degree of integration of variables is different.

$$Gini_t = \beta_0 + \beta_1 TO_t + \beta_2 GDPPC_t + \beta_3 FDI_t + \beta_4 INF_t + \varepsilon_t$$

Burada $Gini_t$ An expression of income inequality Gini Coefficient of Excellence, TO_t The Importance of Openness to Trade, $GDPPC_t$ The True Story of a Man Who Fell Into the Hands of a Man, FDI_t Individual External Investments, INF_t It shows the level of inflation. The Trading Transparency Index is calculated based on the following formula:

$$TO = \frac{\text{İ}xrac + \text{İ}dxal}{\text{Ü}DM} \times 100$$

Within the framework of the model, the stationary variables will first be checked by ADF and PP single root tests, and then the presence of a long-term cointegration relationship will be determined through the ARDL boundary test. Based on the results obtained, the direction and intensity of the impact of trade openness on income inequality in Azerbaijan will be assessed. This approach will provide a scientific basis for determining the effectiveness of trade and social policy measures implemented in the country and forming future policy directions.

The acceleration of globalization processes and the deepening of international economic integration have led to the expansion of foreign trade relations between the countries of the world. Liberalization of foreign trade is considered one of the most important factors of economic growth and ensures more active participation of countries in the international division of labor. Trade openness creates conditions for increasing economic efficiency, increasing investments, transferring technologies and expanding production opportunities. However, how trade openness affects the distribution of income between different segments of society is one of the long-debated issues among economists.

After gaining independence, Azerbaijan has identified the expansion of foreign economic relations as one of the priority directions in the process of transition to a market economy. In recent years, economic reforms implemented in the country, state programs aimed at the development of the non-oil sector, regional and international economic cooperation initiatives have created conditions for a significant increase in foreign trade turnover. In particular, the export of energy resources to world markets has accelerated Azerbaijan's integration into the international trade system. However, how income from foreign trade is distributed among population groups and its impact on income inequality remains a topical research topic.

Theoretical approaches to the impact of trade openness on income inequality yield different results. On the one hand, international trade can create conditions for a more efficient use of the country's factors of production, leading to an increase in employment and incomes. On the other hand, trade liberalization can lead to some sectors and social groups benefiting more than others, leading to a deepening of income disparities. Income inequality is more likely to increase when foreign trade concentrates revenues in certain areas, especially in economies based on natural resources.

One of the main features of Azerbaijan's economy is that most of the exports fall on the share of the oil and gas sector. Although revenues from the export of energy products make an important contribution to economic growth, it is not always possible to distribute these revenues equally to all sectors of the economy and to different segments of the population. Therefore, the study of the impact of trade openness on revenue distribution is important, both theoretically and practically.

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