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ARMENIAN NATIONAL AGRARIAN UNIVERSITY

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АГРОНАУКА И ТЕХНОЛОГИЯ

НАЦИОНАЛЬНЫЙ АГРАРНЫЙ УНИВЕРСИТЕТ АРМЕНИИ

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Национальный аграрный униветситет Армении

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Research and Development of a Mechanism for Fixing the Hydraulic Cylinder for Controlling the External Working Element of a Garden Milling Machine and Determining its Optimal Parameters

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ABSTRACT

The article is devoted to improving the operation of the control system of the remote soil-cultivating working element of the garden milling machine (patent of the Republic of Armenia, No. 2993 A, 16.02.2016), as a result of which it becomes possible to bypass the working element of thick-trunked trees and trees deviated from the row line, as well as slippages and other obstacles, with simultaneous near-trunk processing. Based on the research of the Scientific Research Institute for Agricultural Mechanization and Automation of the Armenian National Agrarian University (ANAU), a control system for the remote working body of a tillage machine (patent of the Republic of Armenia, AM20230106Y, 01.07.2024.) has been developed and implemented. To fix the hydraulic cylinder piston in intermediate positions, depending on the total value t of the tree trunk diameter, the width of the protective zone and the amount of overlap of the treatment, a mechanism for adjusting the length of the slider was investigated and developed and its optimal parameters were determined. For the purpose of practical regulation of the slider length for specific values of t, a corresponding nomogram was constructed.

Introduction

It is known that technical means intended for processing inter-trunk and near-trunk spaces in orchards and vineyards are equipped with control systems for the remote working element of mechanical, hydraulic, hydromechanical and other types (patent of the Republic of Armenia, AM20230106Y, 01.07.2024, patent of the Republic of Armenia, No. 2993 A, 16.02.2016, Balasanyan, 1985, Grigoryan and Altunyan, 2018, Petrosyan, et al., 2017, Manaenkov, et al., 2017). Research conducted by the Scientific Research Institute for Agricultural Mechanization and Automation of the Armenian National Agrarian University (ANAU) showed that the main drawback of these systems is the inability of the working element to bypass thick-trunked trees and trees deviating from the line, as well as sleepers and other obstacles, while simultaneously performing near-trunk processing

(Weidong Jia, et al., 2024, Grigoryan and Altunyan, 2018, CN105766098A, 13.04.2016., EP 3 824 708 A1, 26.05.2021., Petrosyan, et al., 2018). It was also revealed that the main reason for this is that the control system of the remote working element does not provide for the possibility of fixing the piston of the hydraulic cylinder of the control of this element also in the middle positions, depending on the total value of the trunk diameter, the width of the protective zone and the amount of deviation from the row of trees (patent of the Republic of Armenia, AM20230106Y, 01.07.2024).

Taking into account the above, a control system for the working body of a tillage machine (patent of the Republic of Armenia, AM20230106Y, 01.07.2024) was developed, the design diagram of which is shown in Fig. 1.

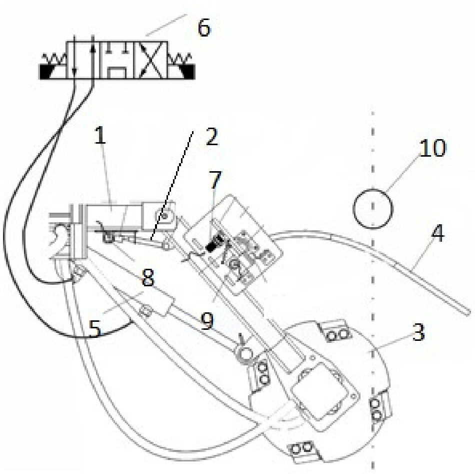

Figure 1. Structural diagram of the control system of the remote working element *1. machine frame, 2. device for fixing the hydraulic cylinder in intermediate positions, 3. working body, 4. sensor rod, 5. hydraulic cylinder, 6. hydraulic distributor, 7, 8, 9. sensors, (10. Tree) (composed by the authors).*

It should be noted that one of the main components of the proposed control system for the remote working body is the device for fixing the hydraulic cylinder in intermediate positions (*2* in Fig. 1). Field tests of the developed model for a garden milling machine (patent of the Republic of Armenia, No. 2993 A, 16.02.2016), with the account of the Control system for the working body of a tillage machine (patent of the Republic of Armenia, No. AM20230106Y, 01.07.2024), showed a number of shortcomings of this device; in particular, there is no precise method for adjusting the position of the slider relative to the sensor (8, Fig. 1) based on the rotation angle of the external working body's rack. Additionally, the device's parameters, such as the slider's size and adjustment limits, are not well-substantiated. In this regard, we have developed a mechanism for securing the hydraulic cylinder (5, Fig. 1) in intermediate positions, with the calculation scheme for determining its optimal parameters shown in Fig. 2.

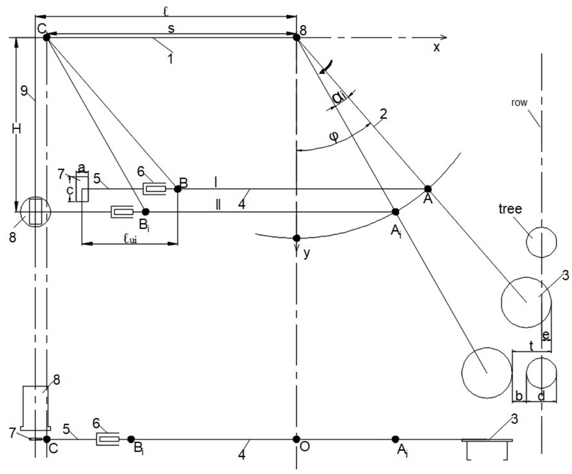

Figure 2. Calculation scheme for determining the parameters of the hydraulic cylinder fixation mechanism in intermediate positions *1. machine beam, 2. leading link of the four-link mechanism, 3. working element, 4. driven link of the four-link mechanism, 5. slider, 6. slider length adjustment mechanism, 7. slider contact, 8. sensor, 9. sensor stand. I - the working body processing the space between tree trunks, II - the working body bypassing the tree trunk (composed by the authors).*

During the processing of the inter-trunk space (Fig. 1, position I), the hydraulic cylinder (5) remains in the open position (with the rod at its farthest extreme) based on a signal from sensor 7 (Fig. 1). In this state, the contact (7) of the slider (5) is positioned at a certain distance from sensor 8 (Fig. 1, 2). When the working element (3) encounters a tree trunk (as detected by the probe making contact with the tree), it rotates by an angle α_i (Fig. 1, position II). As the slider's contact reaches the sensor's (8) action zone, the sensor transmits a signal, causing the distributor (6, Fig. 1) to halt the flow of liquid to the hydraulic cylinder (5, Fig. 1). This action fixes the piston's position at an intermediate stage. For thick tree trunks or trees deviating from the row, the probe rotates at a larger angle, activating sensor 9 (Fig. 2). In this case, sensors 7 and 8 disengage, and the hydraulic cylinder moves into the closed position.

Materials and methods

The main parameters of the mechanism for fixing the rod of the control cylinder of the working element in intermediate positions are the lengths of the links of the four-link mechanism (m, s, are set based on design considerations, respectively 80 and 100 mm), the length of the slider ℓ_s, the width and length of the contact of the slider (a and c), the distance of the rack of the sensor for fixing the cylinder in intermediate positions from the center of rotation of the rack of the working element ℓ, the length of the sensor rack H, the adjustment range of the slider length $\Delta\ell_s$ (Fig. 2).

It is obvious that with a change in the total value $t = e+0.5d+b$ (e is the overlap value during inter-trunk processing, d is the tree diameter, b is the width of the protective zone), the position of the working body stand will also change (it turns in the opposite direction by an angle of α_i, i.e. $\alpha_i= f(t)$), and the length of the slider ℓ_s will change accordingly. In this case, it will be necessary to increase this length for small values of t, and decrease it for large values of t. Therefore, it is necessary to clarify the pattern and changing range of ℓ_s depending on the angle of rotation of the working body rack α_i ($0 \leq \alpha_i \leq \varphi$), where zero corresponds to the open position of the hydraulic cylinder when processing the inter-trunk strip, and φ corresponds to the closed position (set value, $\varphi=41°$). To determine the above-mentioned parameters, we use the calculation scheme (Fig. 2).

Taking into account the fact that when the working body rack rotates, the slider contact moves in the directions of the x and y axes, we determine the values of these movements (Danielyan, 2016, Weidong Jia, et al., 2024):

$$\Delta x_i = x_A - x_{Ai}\ ,\ \Delta y_i = y_{Ai} - y_A\ , \tag{1}$$

where

$$x_A = m\sin\varphi,\ x_{Ai} = m\sin(\varphi - \alpha_i),$$

$$y_A = m\cos\varphi,\ y_{Ai} = m\cos(\varphi - \alpha_i).$$

Inserting the values x_A, x_i, y_A, y_i into expression (1) we obtain:

$$\Delta x_i = m[\sin\varphi - \sin(\varphi - \alpha_i)],$$
$$\Delta y_i = m[\cos(\varphi - \alpha_i) - \cos\varphi]. \tag{2}$$

Results and discussions

Figure 3 shows graphs of the change in the above-mentioned movements of the slider in the x and y directions and the value of Δx_i depending on the rotation angle of the working body rack α_i.

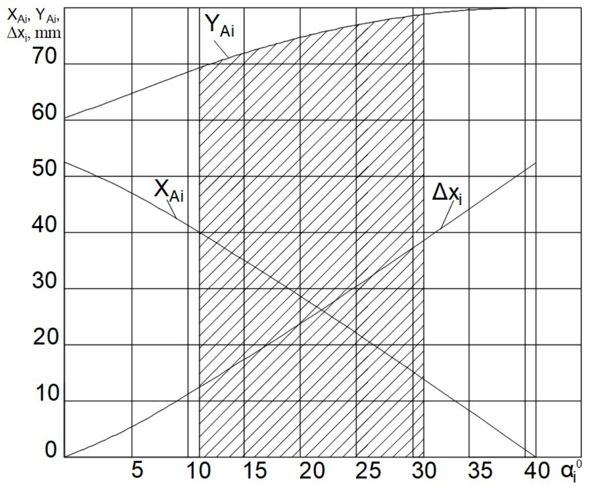

Figure 3. Dependencies of changes in the slider displacement x_i, y_i and the value of Δx_i depending on the angle α_i, at $m=80$ mm, $\varphi=41°$ *(composed by the authors)*.

Analysis of the graphs shows that with an increase in the angle α_i, the movement of the slider in the direction of the x-axis decreases, and in the direction of the y-axis it increases with different intensities and is 1.28 mm/deg and 0.479 mm/deg. respectively, while the intensity of the increase Δx_i is 1.28 mm/deg. It should be noted that as a result of numerous field measurements we conducted, the established range of values of t is (64.4-181.5 mm), at which the rod of the hydraulic cylinder for controlling the working body should be fixed in intermediate positions. Calculations performed for the given milling machine parameters ($\varphi = 41°$), stand length (580 mm), and remote working element diameter (320 mm), along with the structurally selected values of m and s, showed that the minimum value of t corresponds to $\alpha_i = 11°$, while the maximum is 31°. Therefore, to establish the adjustment interval of the slider length $\Delta\ell_s$, it is necessary to proceed from the condition $11° \leq \alpha_i \leq 31°$ (shaded area, Fig. 3), while it is necessary to take into account that the largest size ℓ_{smax} of the slider length corresponds to the lower limit of α_i, and the smallest size ℓ_{smin} to the upper limit. The length of the slider can be determined by the expression:

$$\ell_{si} = \ell_o + \Delta x_i, \tag{3}$$

where ℓ_0 is the design size (50 mm). Therefore:

$$\Delta\ell_s=\ell_{smax} - \ell_{smin}.$$

By determining the maximum and minimum values of Δx_i (respectively: 38.59 mm and 12.48 mm, shaded area,

Fig. 3), we obtain:

$$\ell_{smin}=\ell_0=50 \text{ mm},$$

$$\ell_{smax}=\ell_0+\Delta x_{imax}-\Delta x_{imin}=50+38.59-12.48=76.1 \text{ mm},$$

therefore:

$$\Delta\ell_s=\ell_{sma}-\ell_{smin},=76.1–50=26.1 \text{ mm}.$$

From Figure 3 we receive:

$$\ell= s – m sin\varphi + \ell_{smax} ,\ H= m cos\alpha_{imax}. \quad (4)$$

Putting the corresponding values into formula 4, we obtain: $\ell=123.6$ mm, $H=68.5$ mm.

The width of the slider contact is set based on design considerations - 5 mm, and the value of the length is determined by the expression:

$$c = 2(y_{imax}– y_{imin})=2(78.5– 68.5)=20 \text{ mm}.$$

In view of practical regulation of the slider length for a specific total value *t*, it is convenient to use the nomogram shown in Fig. 4.

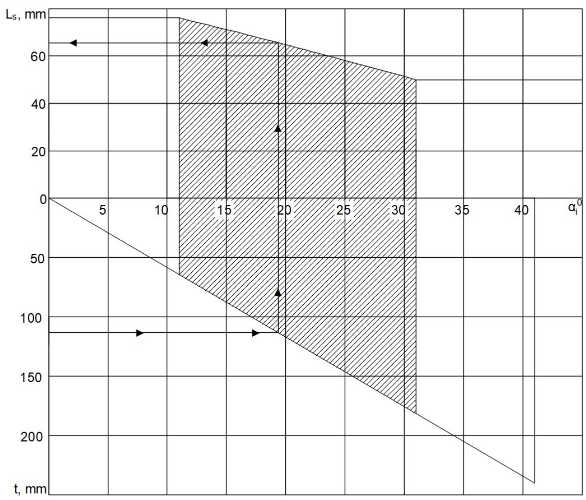

Figure 4. Nomogram for determining the length of the slider for specific values of *t* and α_i in practice *(composed by the authors)*.

Conclusion

A mechanism has been developed for fixing the hydraulic cylinder of the control system of the external working body of a garden milling machine in intermediate positions.

The intervals of changes *t* ($64.4 \le t \le 181.5$ mm) and α_i ($11° \le \alpha_i \le 31°$) are established, according to which the rod of the control cylinder of the remote working body should be fixed in intermediate positions.

A mathematical relationship was derived between the rotation angle of the remote working body and the main parameters of the cylinder locking mechanism in intermediate positions, and its optimal parameters were established: $m=100$ mm, $S=100$ mm, $\ell=123.6$ mm, $H=68.5$ mm, $c=20$ mm, $a=5$ mm, $\ell_{scmax}=76.1$ mm, ℓ_{smin}=50 mm, $\Delta\ell_s=26.1$ mm.

A nomogram for determining the length of a slider for specific values of *t* and α_i in practice has been developed.

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Declarations of interest

The authors declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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Justification of the Software Kinematic Parameters of a Horticultural Autonomous Robotic Platform

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ABSTRACT

The article discusses the issues related to the development and creation of a multifunctional horticultural robotic platform. The necessity of developing a robotic platform best suited to the soil and climatic conditions of the Republic of Armenia is substantiated. A multifunctional robotic platform has been proposed and developed for the cultivation of vineyards and orchards. It is designed for inter-row and inter-vine (inter-trunk) soil cultivation, weed mowing and shredding, fertilization, pest and disease detection, assessment, and chemical control. The platform is equipped with four independently controlled wheels. Kinematic and force analysis of the running gear of the developed robotic platform has been conducted. As a result of these analyses, expressions have been derived that will serve as the foundation for programming the electronic-computer control system of the platform's running gear. These expressions will be used to control the torque movement and angular velocity of all the driving wheels, as well as the rotation of the wheel axes during turning. This approach enables the creation of a robotic platform›s running gear that ensures high mobility, adherence to the designated route, and prevents wheel slippage and skidding during turns. This aspect is particularly important for ensuring the reliability and longevity of the machine, as well as minimizing the damage caused to the cultivated soil by the wheels.

Introduction

The current trends of agricultural development, both globally and in the Republic of Armenia, are determined by the following key factors: the need for increased production of foodstuffs driven by the sharp growth in population, the limited availability of arable lands worldwide, and the necessity to mitigate the irreversible environmental damage caused by the intensification of traditional agrarian production.

It is evident that under the conditions shaped by emerging challenges and demands, the primary direction for agricultural development is the enhancement of efficiency through the digitalization, automation, and robotization of production processes. Initial steps in this direction were taken at the end of the last century, and these approaches have become widely adopted in the current phase.

Advancements in mechanical design, sensor technologies, electronics, and algorithms in the fields of planning and management offer extensive opportunities to perform a wide range of field activities using autonomous robotic platforms (Zagazezheva, Berbekova, 2021; Skvortsov, et al., 2018; Bak and Jakobsen, 2004; Abrosimov and Raykov, 2022).

Robotic platforms possess undeniable advantages, which account for their rapidly increasing demand. These advantages primarily include sensitivity to field-specific conditions, precise operation without operator intervention, low metal consumption, minimal environmental impact, and the ability to perform technological processes over extended periods at relatively low speeds. Ultimately, these features ensure high productivity and efficiency (Akimov, 2017; Cho, et al.; 2002, Tillett, 1991; Abrosimov and Raykov, 2022).

The development of reliable robotic platforms capable of operating for extended periods with minimal human intervention under the changing conditions of cultivated fields is a critical and urgent issue at the current stage (Godin, et al.; 2020; Bak and Hans Jakobsen, 2004; Tillett, 1991).

Although robotic technology began to be introduced into agriculture 25–30 years ago, its widespread and large-scale application gained momentum only in the past decade. According to the International Federation of Robotics, between 2015 and 2020, the global production and deployment of robotics for agricultural purposes increased 30-fold compared to the entire preceding period (www.ifr.org/worldrobotics/, www.rossaprimavera.ru).

Current trends in the development and adoption of robotics indicate that by 2026, the scale of its deployment will increase approximately 20 times compared to 2020, with the market capacity projected to reach $16.6 billion USD (www.rossaprimavera.ru, www.bloomberg.com).

It is worth mentioning that the United States and European Union countries account for the largest share of these volumes, while the development, production, and implementation of robotics in the CIS region are comparatively lower (Abrosimov and Raykov, 2022).

According to leading international developers and manufacturers, robotics used in crop production is categorized into five main groups (Abrosimov and Raykov, 2022; Blasco, et al., 2002):

- soil cultivation (sampling, plowing, cultivation);
- sowing, seedling, rootstock planting;
- crop care (weeding, irrigation, spraying, introduction of fertilizers and herbicides, special care for vineyards and orchards, as well as nurseries);
- assessment and monitoring of parameters such as maturity stage, waste, physical damage, bacterial infection, and other characteristics of agricultural products including size, shape, and quality;
- harvesting (gathering, sorting, distribution, processing, and recycling).

From the perspective of the discussed issue, according to international classification (Abrosimov and Raykov, 2022), small autonomous agricultural robots used in crop production, weighing no more than one ton, are of particular interest. These robots are equipped with remote or semi-automatic control systems, and are outfitted with positioning systems that ensure centimeter-level accuracy. They also feature the ability to attach various implements that perform different functions for different crops.

The technical and software requirements for agricultural robots include marginal dimension and weight specifications, movement speed, accuracy of agrotechnological operations, communication mode and ease of interaction with the operator, the technical vision system, the ability to attach suspended technological iinstallations, and the capability to overcome potential obstacles in the field.

The operational requirements for agricultural robots include reliability, passability, adaptability to various working conditions, type of drive system, energy efficiency, the ability to adjust routes through software under different field conditions, and minimal environmental impact (Abrosimov and Raykov, 2022; www.dijital.gov.ru).

In summary, the characteristics of prospective small agricultural robots, which are expected to have high market demand, must meet the following requirements (Abrosimov and Raykov, 2022; Blasco et al., 2002; Cho et al., 2002):

- a working resource of at least 5–6 hours, with a reliable electric motor and battery;
- it must be equipped with a vision system that works in complex geophysical and natural conditions, including the ability to navigate rough terrain;
- the ability to form and adjust the route with or without the operator's assistance;

- wireless communication with the operator, and the ability to operate autonomously in case of signal loss;
- capability to recognize and solve situational and coordination issues in the field;
- the ability to attach various suspended tools and facilities;
- ease of maintenance and repair, with minimal requirements for tools and specialists.

Though agricultural robots are being widely adopted in the agri-food systems of many countries, their utilization in the Republic of Armenia remains relatively low. The primary reason for this is the high market price of agricultural robots. Additionally, it is important to note that these robots are often designed and developed for other soil and climatic conditions. As mentioned earlier, this factor is critically important for the effective operation of agricultural robots.

One of the solutions to the problem raised in the current situation is the development of a cost-effective, multifunctional robotic platform that is optimally adapted to the soil and climatic conditions of the republic. Based on studies, analyses, and comparative evaluations, a four-wheel robotic platform with all-wheel steered was selected. This design minimizes lateral slippage, which, in turn, reduces wear on the running gear and decreases damage to the soil being cultivated (Bak and Jakobsen, 2004; Torii, 2000).

An objective is set up to develop a robotic platform designed to perform tasks such as soil cultivation in the inter-row spaces of orchards and vineyards, mowing or removing weeds, and carrying out chemical treatments (spraying) to combat pests and diseases.

It has been confirmed that four-wheel robotic platforms with independently controlled wheels are the most suitable for performing the specified agrotechnical tasks in row crops. These platforms excel at maintaining a fixed direction of movement relative to the rows (Toda, et al., 1999; Orebäck and Christensen, 2003).

The recommended robotic platform is designed with three main components: a control system (or station), the robotic platform itself, and tools and devices for performing agrotechnological processes. Communication between the platform and the control system is wireless, allowing a single control system (station) to simultaneously manage multiple robotic platforms within the same field.

The current study focuses on the investigation of the robotic platform's driving train system, as mobility serves as the foundation for all other functional technical and technological characteristics.

Materials and methods

The conceptual diagram of the robotic platform under development is shown in Figure 1. It consists of the platform frame (1), four driving wheels (2), autonomous wheel drive units (3), and wheel steering units (4).

The drive units (3) ensure the movement of the robotic platform and include an electric motor, a gear transmission case (reducer), and a microelectronic control block for the motor. The steering of the wheels is accomplished through a separate steering module (4), which includes a steering electric motor and its electronic control module. The wheel steering unit is positioned above the wheel shaft to create a mechanism with two degrees of freedom.

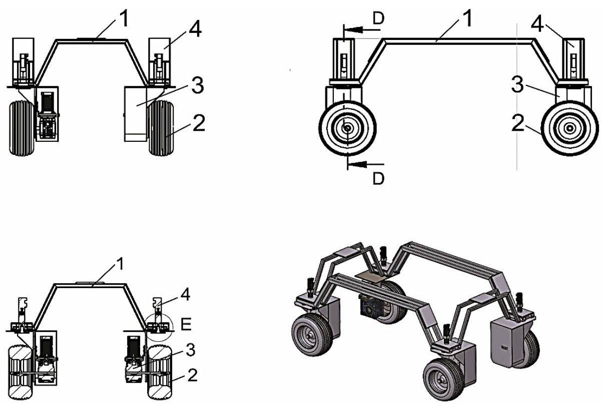

Figure 1. The conceptual diagram of the recommended robotic platform's running system *(composed by the authors)*.

The electronic-computer control unit manages the wheel steering (the rotation of the axles) around the vertical axis based on a software algorithm for the kinematic relationship of the steering angles. It also controls the torque (or current) of the four driving wheel electric motors. The electronics of the steering servomechanism provide feedback/reverse power link/ based on the steering rotation angle. This is a fundamental principle of the agrirobot's structural conceptual design (Bak and Jakobsen, 2004; Toda, et al., 1999; Torii, 2000).

As previously mentioned, the first step in the development and creation of the agrirobot is to identify the relationship and values of the kinematic parameters for stable movement and steering, under which lateral wheel slippage, a highly undesirable phenomenon, must be eliminated.

The movement of an agrirobot in the field (in orchards or vineyards) during the implementation of agrotechnological processes can be categorized into two types: linear movement within inter-row spaces, which involves a flat, parallel motion of the robot platform, and torque movement at the ends of the rows.

Regarding the flat parallel movement of the robot platform, it is executed and maintained in a stable condition through the software management and synchronization of the same rotational torque and angular velocity on all four independently driven wheels. Notably, if one or more wheels deviate from the designated path due to an obstacle, the software must restore the robot platform to its predefined trajectory after overcoming the obstacle. In other words, no turn should occur without an explicit command from the wheel rotation control system.

As for the torque movement of the robot platform, it is of particular interest in the context of the discussed problem. In general, various schemes are employed for the turning of wheeled vehicles. Each scheme features a unique turning kinematics, primarily determined by the position of the instantaneous center of rotation (ICR).

The closer the ICR (Instantaneous Center of Rotation) is to the vehicle's longitudinal axis, the smaller the turning radius, thereby enhancing the platform's maneuverability. From this perspective, preference should be given to a scheme where all wheels are steerable. The closer the ICR (Instantaneous Center of Rotation) is to the vehicle's longitudinal axis, the smaller the turning radius, thereby enhancing the platform's maneuverability. From this perspective, preference should be given to a scheme where all wheels are steerable.

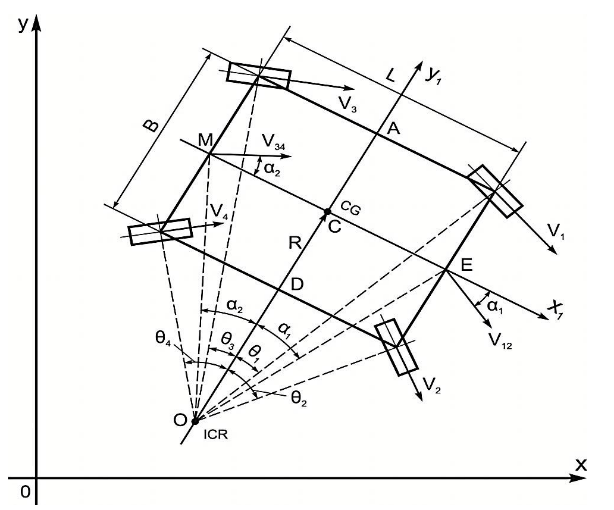

Figure 2. RA, Syunik marz, Syunik, pome fruit perennial plantings, February, 2018/2021. *(composed by the authors).*

The kinematic scheme of the robot platform with all-wheel turning control is presented in Figure 2.

Existing agricultural robots feature systems controlled by various steering mechanisms, which partially define their areas of application, as well as their degrees of mobility, flexibility, and maneuverability. The proposed design of the autonomous robotic framework allows for the implementation of all existing steering mechanisms, as all four wheels are independent and controlled. Additionally, each wheel can rotate up to a 90-degree angle. These characteristics provide optimal conditions for addressing issues related to the tracking and trajectory programming of the agricultural robot's path, offering a broad scope for the development of efficient algorithms within software control, unconstrained by structural solutions. Another important aspect is the design of the wheel suspension system, which enhances the vehicle's stability and allows it to be tested under varying dynamic loading conditions and speeds. The design and structural solutions extend beyond these elements, providing a broad research field for comprehensive and effective testing.

Results and discussions

When conducting a kinematic analysis of the robot platform's turning, it is important to specify the type of tires based on their stiffness. In the case of flexible tires, the side slip of the wheels must be taken into account, as it significantly affects the angular parameters. Since the robot platform is designed to use tires of a rigid class, this side slip can be neglected, and it can be assumed that the wheels roll without slipping during the turn.

Based on the objectives of the discussed issue, it is important to establish a connection between the turning angles *(θ)* of the wheels.

Let us assume that the turning angles of the front wheels are (θ_1) and (θ_2), with an average turning angle of α_1, similarly, the turning angles of the rear wheels are (θ_3) and (θ_4), with an average angle of α_2. The lateral velocity of the front section is V_{12}, and that of the rear section is V_{34}. If we consider θ_1, θ_2 and α_1 to be positive for the front section, then for the rear section, they are considered negative. According to the scheme represented in Figure, for the front wheels we have:

$$ctg\theta_1 = \frac{R + 0.5B}{0.5L}; \quad ctg\theta_2 = \frac{R - 0.5B}{0.5L}, \qquad (1)$$

or

$$ctg\theta_1 - ctg\theta_2 = \frac{2B}{L}, \quad (2)$$

For the rear wheels, considering that during the turn they rotate in the opposite direction around the vertical/longitudinal axis, the relationship between θ_3 and θ_4 will be:

$$ctg\theta_3 - ctg\theta_4 = \frac{2B}{L}, \quad (3)$$

The boundary values of θ_1 and θ_2 (θ_3 or θ_4) are determined by expression (1). In the case of linear motion $\theta_1=\theta_2=0$, and when $R=-0.5B$, $\theta_1 = \frac{\pi}{2}$; when $R=0.5B$, $\theta_2 = \frac{\pi}{2}$.

Considering that the midpoint (E) of the robot platform's front section moves with a velocity at an angle relative to the X_1 axis (Fig. 2), and the corresponding point M of the rear section moves with a velocity V_2 at an angle of a_2, the radius of curvature for the turn, based on the scheme will be:

$$R = \frac{L}{tg\alpha_1 + tg\alpha_2}. \quad (4)$$

Since the version with rigid wheels is being considered, we can practically assume that $\alpha_1=\alpha_2=\alpha$, in that case:

$$\mathrm{R} = \frac{L}{2tg\alpha}. \quad (5)$$

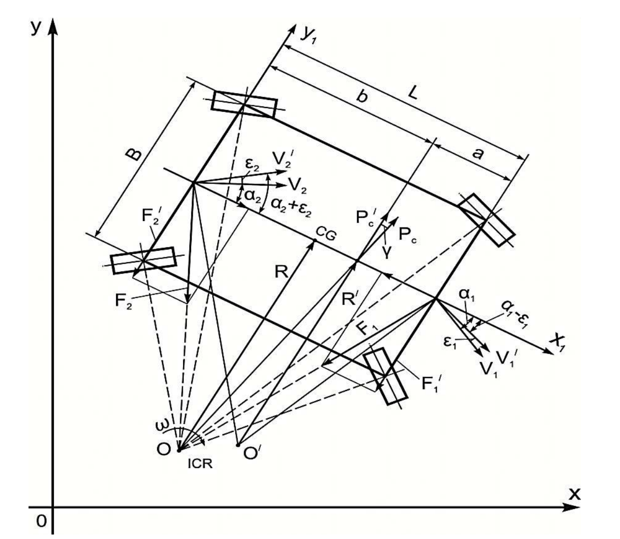

Figure 3. The diagram of forces acting on the robotic platform's drivetrain *(composed by the authors)*.

For a given L, α should take on a boundary value such that $R > \frac{B}{2}$, otherwise, the ICR (Instantaneous Center of Rotation) will fall within the platform's dimensions of BxL, which is undesirable from the perspective of unstable turning. This is also mentioned in other studies dedicated to the analysis of the driving/running mechanisms of robot platforms (Bak and Jakobsen, 2004; Orebäck and Christensen, 2003; Litvinov, 1971).

From the final expression (5), we can determine the turning angle (α) and the angular velocity (ω).

$$\mathrm{tg}\,\alpha = \frac{L}{2R} \text{ and } \omega = \frac{V}{R} = \frac{V \cdot 2tg\alpha}{L}. \quad (6)$$

To assess the stability of the robot-platform's movement, it is necessary to also study the forces acting on the frame during turning. Since turning can occur at relatively higher speeds in the robot-platform's transportation mode, the side slippage of the wheels must be also considered, as a result of which the velocity vectors V_1 *and* V_2 deviate from their initial directions by ε_1 and ε_2, respectively. The diagram in Fig. 3 illustrates the schematic of the forces acting on the robot-platform's running section.

When performing the force analysis, we assume that the driving and resistance forces acting on the wheels are balanced.

In that case, a centrifugal force acts at the center of mass of the platform $\mathrm{P_c} = \frac{mv^2}{R}$, while lateral reaction forces F_1 and F_2 act on the wheels. Assuming that the equivalent lateral reaction forces the wheels are applied at the front and rear points of E and M, let's decompose these forces in the directions of the longitudinal *(x_1)* and transverse *(y_1)* axes. From the diagram (Fig. 3), it follows that:

$$\left.\begin{aligned} F_1' &= P_c'\frac{b}{L} = P_c'\cos\gamma \cdot \frac{b}{L} \approx \frac{mv^2 \cdot b}{R'L}, \\ F_2' &= P_c'\frac{a}{L} = \frac{mv^2}{R'} \cdot \frac{a}{L}\cos\gamma \cdot \frac{b}{L} \approx \frac{mv^2}{R'} \cdot \frac{a}{L} \end{aligned}\right\}, \quad (7)$$

where R' is the turning radius accounting for the wheels lateral slippage. From the diagrams (Figure 2 and Figure 3) and (4) expression, it follows that:

$$R' = \frac{L}{tg(\alpha_1 - \varepsilon_1) + tg(\alpha_2 - \varepsilon_2)}, \quad (8)$$

γ is the angle of deviation of the turning radii caused by the lateral slip of the wheels. Since γ is relatively small (not exceeding 50), in practical calculations, we assume $cos\gamma \approx 1$.

Since we have assumed that $\alpha_1=\alpha_2=\alpha$,, we can also write:

$$F_1{}'=F_1 \cdot cos\alpha \approx K_1\, \varepsilon_1;\;\; F_2{}'=F_2 \cdot cos\alpha \approx K_2\, \varepsilon_2 \qquad (9)$$

where K_1 and K_2 are the lateral slippage coefficients of the front and rear wheels, respectively.

(7) and (9) expressions indicate that:

$$\frac{mv^2}{R'} \cdot \frac{b}{L} = K_1 \varepsilon_1 \quad \text{and} \quad \frac{mv^2}{R'} \cdot \frac{a}{L} = K_2 \varepsilon_2, \qquad (10)$$

wherefrom:

$$\varepsilon_1 = \frac{mv^2}{R'} \cdot \frac{b}{L \cdot K_1} \quad \text{and} \quad \varepsilon_2 = \frac{mv^2}{R'} \cdot \frac{a}{L \cdot K_2} \qquad (11)$$

From the last expressions (11) it follows that if the center of the robotic platform mass is located at its geometric center $a = b = \frac{L}{2}$ and all four wheels have the same lateral slippage (deviation) coefficients, then $\varepsilon_1=\varepsilon_2=\varepsilon$. Since it is intended to use rubberized rigid wheels in the design of the robotic platform, which inherently have a small lateral slip angle (ε), compared to the turning angle (α), the expression in (5) can provide sufficient results for practical calculations. For example, if we assume the following values: $L=1.85$ m, $a=b=0.925$ m, $m=600$ kg, $v=1.67$ m/s, $\alpha=45^0$, $R=0.925$ m and $K=1.7 \cdot 10^4$ N/rad (an average value for the mentioned rigid wheels), then according to the expression in (11) the value of will be 0.052 rad, which is much smaller than α=0.785 rad.

From the obtained expression (11), it follows that the turning angle (α) and radius (R or R') are related to the robot platform's maneuverability, which depends on the position of the mass center, the lateral slippage coefficient, and the velocity in the turning zone. Moreover, as the speed increases, the turning radius decreases, which increases the turning capacity which in turn can lead to loss of movement stability. However, in the discussed case, there is no such risk, as the speeds do not exceed 5÷10 km/h.

Conclusion

A multifunctional platform for the cultivation of orchards and vineyards has been recommended and developed. It is equipped with four independent, self-steering wheels, ensuring high maneuverability and precise execution of the designated routes and agrotechnological functions.

As a result of the kinematic and force analysis of the robotic platform's drivetrain, expressions have been derived that serve as the basis for programming the control algorithm of the driving wheels' electronic-computer system. This system must ensure high mobility, movement stability, and the elimination of lateral slip (deviation) in all wheels during turns.

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Declarations of interest

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Dynamics of Soil Moisture Deficit and its Impact on Irrigation Water Demand: A Case Study of Kotayk Region

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ABSTRACT

The research is dedicated to the justification of irrigation water demand to ensure the efficient use of irrigated lands in the context of climate change. To this end the dynamics of climate indicators from 1991 to 2023 at the «Yeghvard» meteorological station has been studied, and the total water consumption (evapotranspiration) together with the dynamics of the soil moisture has been calculated. To characterize the degree of annual dryness in conditions of insufficient moisture zones, years with 50 %, 75 %, and 95 % percentile of atmospheric precipitation during the vegetation period were used as reference points for calculations. Given the importance of the issue, the research was conducted using the example of semi-desert gray soils in the Kotayk region. The soil moisture deficit was calculated for both the vegetation period and the entire year. The calculations show that over the past five years, the soil moisture deficit in irrigated semi-desert gray soils in the Yeghvard area has exhibited a negative trend, resulting in a reduction of active soil moisture reserves by 1.410–4.400 m³/ha. This finding supports the observation recorded in recent years within irrigation systems that farming enterprises are using 2 to 3 times more irrigation water than the established norms.

Introduction

Currently, due to climate change, several issues have arisen related to efficient use of irrigated lands, among which the justification of irrigation water demand holds primary importance. One of the primary challenges in justifying crop water requirements on irrigated lands is determining the effective amount of atmospheric precipitation, assessing soil moisture deficit, and calculating reference/estimated evapotranspiration (Hoffman, et al., 1992, Meyer, et al., 1989, Richard, et al., 1998, Yeghiazaryan, et al., 2022). Total water consumption, also known as evapotranspiration, is calculated based on climate indicators.

However, it is evident that the water consumption requirements of crops vary from year to year, depending on changes in climatic conditions. In regions with insufficient moisture, the dryness degree during the year is typically characterized by considering the years with 50 %, 75 %, and 95 % percentile of precipitation during the vegetation period (Mkrtchyan, et al., 2004, Terteryan, et al., 2007, Yeghiazaryan, et al., 2008, Yeghiazaryan, et al., 2009). .In areas with unstable moisture levels, an extremely dry year - corresponding to 95 % of precipitation provision during the growing season - is used as a baseline for calculations. For different irrigation technologies, the recalculation of irrigation water demand is based on the already established water requirements for each crop (Armstat, 2023, Galstyan, et al., 2022). Identifying irrigation water demand is practically important in terms of concluding contracts between Water User Associations (WUAs) and water users, as well as for securing the necessary water volumes for irrigation from the water supply organizations such as “Jrar”. Considering the importance of the issue, the research was conducted using Kotayk Province as a case study, based on the climate data from the “Yeghvard” meteorological station for the years 2019–2023.

Materials and methods

The subject of this research is the justification of crop water requirements in irrigated soils, taking into account changes in climatic conditions and the soil’s hydro-physical properties. Using the average daily data from the Yeghvard hydro-meteorological station for 2019–2023, the monthly distribution of precipitation throughout the year was studied. At the same time, changes in key climate indicators were observed, including maximum (T_{max}), minimum temperatures (T_{min}), relative air humidity (RH), wind speed (V) and number of sunny/sunshine days (t). Based on these indicators the estimated evapotranspiration has been determined using CROPWAT software program. Following internationally practiced methods for determining crop irrigation water requirements, the estimated/reference evapotranspiration has been computed (ET_0) (Mkrtchyan, et al., 2004, Rao, et al., 2011, Salman, et al., 2024, Yeghiazaryan, et al., 2022).

The crops water requirement has been calculated through the following formula:

$$M_n=ET_0-P_{efektiv}. \qquad (1)$$

For different percentiles of atmospheric precipitations the following formula has been used:

$$M_{np\,\%} = ET_{0p\%} - P_{efektivp\%}. \qquad (2)$$

Brutto/gross irrigation water demand will be equal to:

$$M_{bp\%} = \frac{ET_{0\,p\%} - P_{efektivp\%}}{\sigma}, \qquad (3)$$

where σ is efficiency coefficient of intra-farm irrigation network.

Results and discussions

The research was conducted based on the analysis of climatic indicators recorded in the Yeghvard meteorological station for the years 1991–2023. To construct the curve of precipitation percentiles, the existing statistical series of atmospheric precipitation was processed. Based on the results of statistical data processing, both the theoretical (analytical) and empirical (observed) percentile curves were constructed (Fig. 1).

Figure 1. Theoretical and empirical curves depicting the percentiles of atmospheric precipitations per the data of Yeghvard meteorological station *(composed by the authors)*.

The calculations were conducted for atmospheric precipitation with the percentiles of 50 %, 75 %, and 95 %. Figure 2.1 and 2.2 show the variation in evapotranspiration for 2021 per the days of the month.

It should be noted that in 88 settlements across the Kotayk region, including Abovyan, Hrazdan, and Nayiri provinces, crop water requirements are planned in line with the existing 8, 9, 10, 11, 12, and 13 regimes according to which, the irrigation norms change per the described pattern.

For the justification of irrigation water requirements, the total water consumption (evapotranspiration) values were calculated by years and months, and the results are summarized in Figure 3.

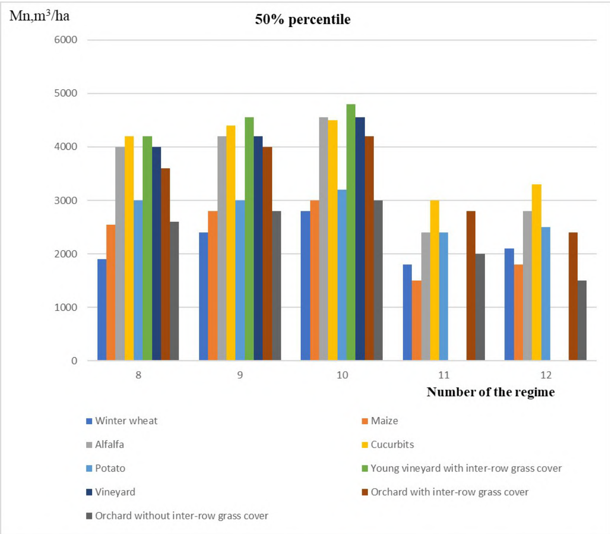

Figure 2.1. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

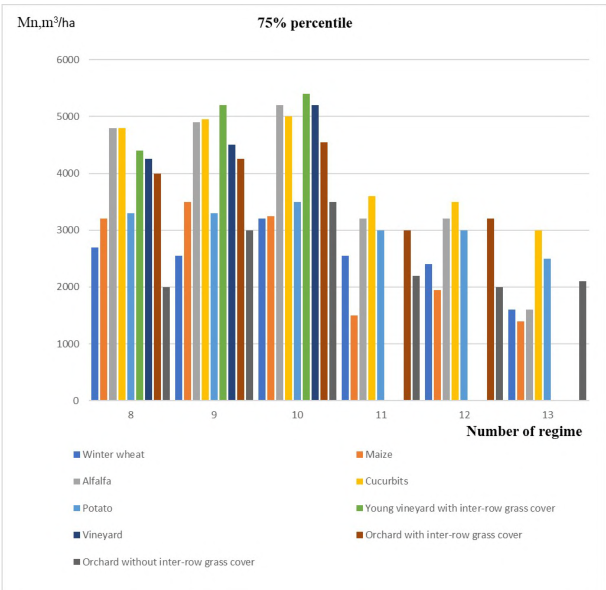

Figure 2.2. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

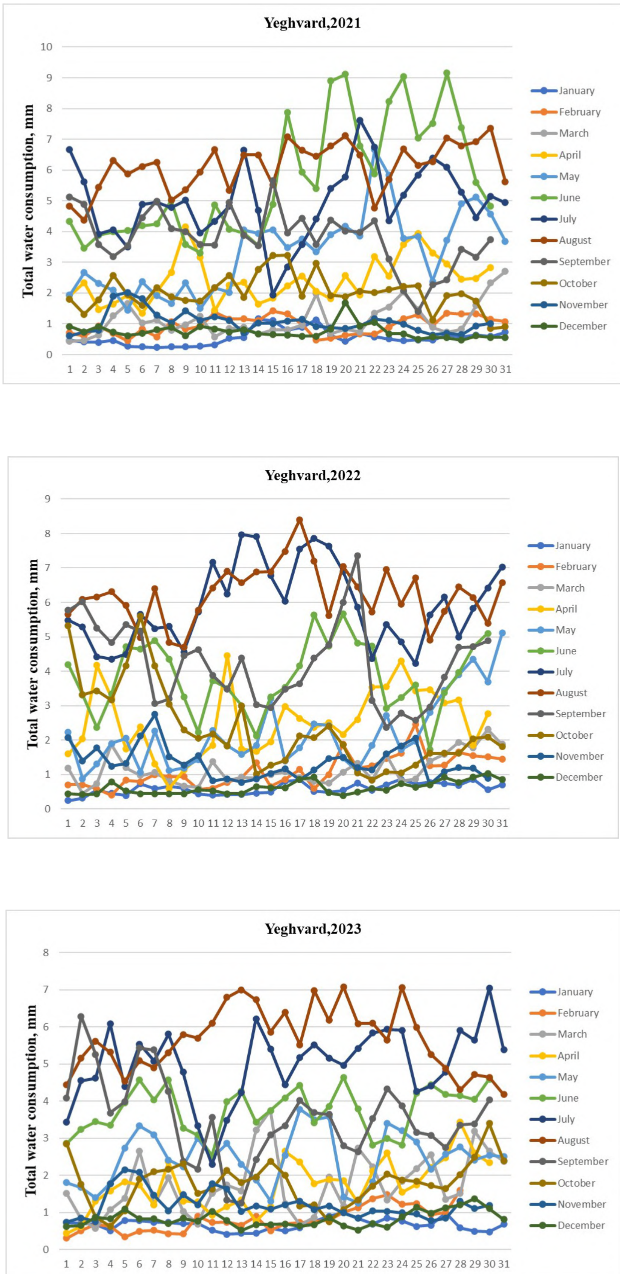

Figure 3. Estimated evapotranspiration *(composed by the authors)*.

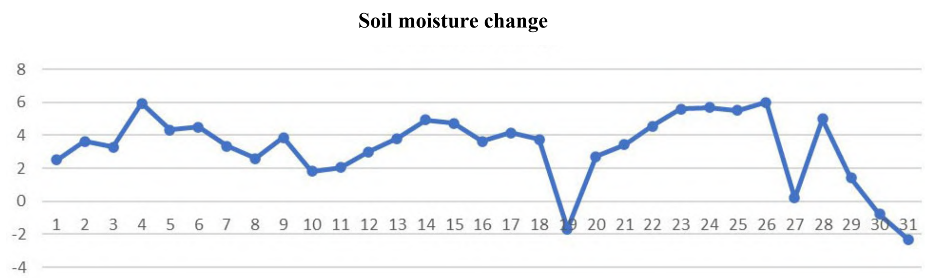

Figure 4. Planning irrigation water requirement per the current norms (50 % percentile) *(composed by the authors)*.

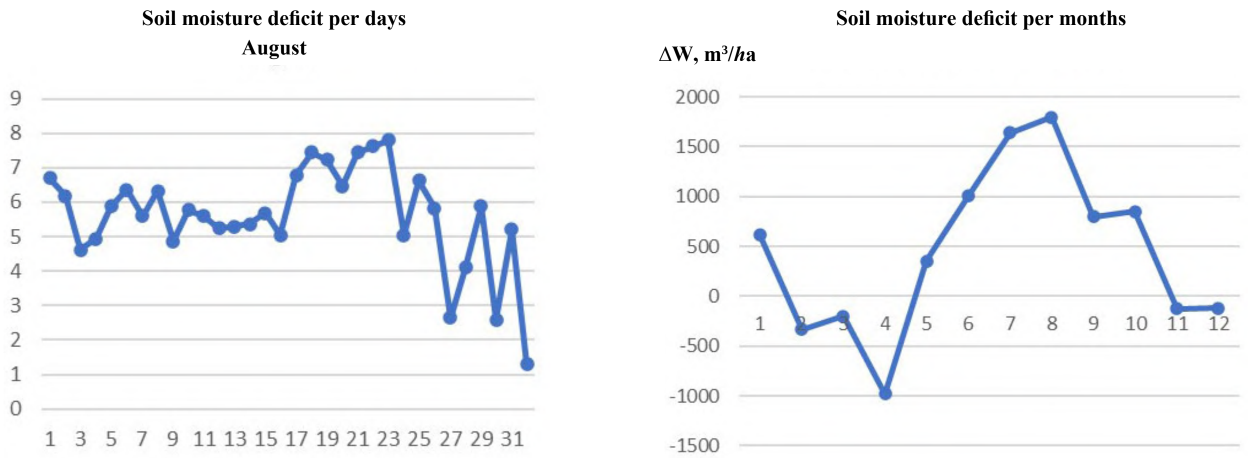

Figure 5. Dynamics of soil moisture deficit *(composed by the authors)*.

The soils in the calculation area are classified as semi-desert gray soils. In terms of mechanical composition, they are primarily medium to heavy clay-and-sandy soils. The soil density ranges between 1.3–1.33 g/cm^3, while the specific gravity of the soil is within 2.53–2.72 g/cm^3. The soil porosity is 49–51 %, and the field capacity moisture content ranges from 25–26 %.

The provided indicators allow for calculating the minimum moisture content in the soil at the beginning of the irrigation season, from the prospect of permanent wilting of plants. For crops with 50 cm root system, this amounts to 1.989 m^3/ha. Therefore, the soil moisture deficit in conditions of the minimum moisture reserve will be 1.526 m^3/ha. The soil moisture variation pattern for June is shown in Figure 4.

The calculations show that soil moisture decreases by 1,013 m^3/ha. Therefore, the deficit will be 2,539 m^3/ha. Respectively, in July, the moisture reduction will be 1,639 m^3/ha; in August, it will be 1.795 m^3/ha; in September - 800 m^3/ha; in October - 847 m^3/ha; in November the soil moisture will increase by 123 m^3/ha; and in December it will increase by 121 m^3/ha, whereas in June, the soil moisture deficit was 2.539 m^3/ha. Therefore, by December, the soil moisture deficit from the prospect of minimum moisture reserve will be:

$$\Delta W_2=2539+1639+1795+800+847-123-121=7376 \text{ m}^3/\text{ ha}.$$

For the year of 75% atmospheric precipitation, the soil moisture deficit throughout the year per months will have the following pattern:

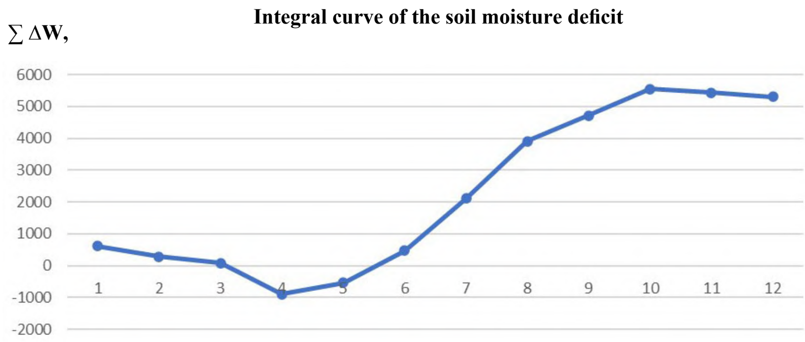

Figure 6. The integral curve of soil moisture deficit in semi-desert gray soils, based on data from the Yeghvard meteorological station *(composed by the authors).*

Table 1. The estimates of soil moisture deficit for the annual period*

Percentile, %	Atmospheric precipitations mm		Total water consumption (Evapotranspiration, ET_0), m^3/ha	
	Year	Vegetation	Year	Vegetation
50	4970	3290	8900	8440
75	3290	2900	9400	8600
95	2650	2280	9600	9200

Table 2. The estimates of soil moisture deficit for the vegetation period*

Minimum soil moisture reserve		Soil moisture deficit, 0…50 cm		Soil moisture deficit, 0…100 cm	
0…50 cm	0…100 cm	Year	Vegetation	Year	Vegetation
1260	2520	2670	3890	1410	2630
1260	2520	4850	4440	3590	3180
1260	2520	5690	5660	4430	4400

*Composed by the authors.

The estimates of soil moisture deficit for years with different precipitation percentiles, for both the annual and vegetation periods, are presented in Tables 1 and 2.

Conclusion

Based on the climatic data obtained from the Yeghvard meteorological station for the years 1991-2023, it is recommended to identify irrigation water demand in conditions of semi-desert gray soils based on the dynamics of soil moisture deficit during the vegetation and annual periods. The calculations show that, over the past five years, the soil moisture deficit in semi-desert gray soils of irrigated lands in the Yeghvard area, has demonstrated a negative dynamic. As a result, the active moisture reserve in the soil has decreased by a volume of 1.410–4.400 m^3/ha.

This finding helps to justify the fact observed over recent years in irrigation systems, where farming enterprises use irrigation water 2 to 3 times more than the established norms. Thus, in the case of surface irrigation, it is evident that the current irrigation norms should be increased by an average of 2.905 m³/ha. On the other hand, it is important to focus on the development of irrigation technologies, as surface irrigation with such volumes could pose significant risks to the entire irrigation system.

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Declarations of interest

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Analysis of Results from Experimental Research on a Combined Plow for Flat Tillage and Parameter Optimization

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combined machine,
frontal plough,
roller,
stubble cultivation

ABSTRACT

A combined machine has been proposed, consisting of an improved front plow design, special-profile disc batteries, and a roller through justifying the necessity of plowing and emphasizing the application of minimal soil cultivation technologies. Laboratory and field experiments have been conducted to study the structural, energy, and technological indicators of the proposed machine, as well as to outline ways to eliminate its technological shortcomings. The optimal angles of attack for individual discs of the disc batteries have been determined, considering traction resistance and cultivation quality as optimizing factors.

Introduction

Throughout history, soil cultivation has been accompanied by numerous shortcomings that have negatively impacted economic indicators while leaving undesirable effects on soil resources such as soil over-compaction, wind erosion, decreased fertility, and on slopes, water and mechanical erosion (Tsench, et al., 2018; Sobolevsky, 2023). The scientific community does not remain indifferent to these issues. New soil cultivation technologies, technical means, and approaches are being proposed (Gaifullin and Kashapov, 2022).

In the majority of improvement measures, many proposals relate to the application of combined machines (Kutsenko, 2016; Fedorov, et al., 2019). However, in almost all the aforementioned proposals, plowing is not included as a technological process, with certain justifications provided. Yet, in various studies, including those conducted by our working group, the opposite opinion is expressed, substantiating the importance of plowing with significant arguments (Fedorenko, et al., 2016).

We have proposed a combined machine consisting of three units: a frontal plough with improved parameters and without reversible plowshare, disc batteries of a special profile, and rollers (Yesoyan, et al., RA Patent No. AM 846Y, 2023). These three devices are intended to perform different technological processes, and their combination should result in obtaining a sufficient pre-sowing surface in a single pass of the aggregate.

In such a technological complex, the role of the first unit — the frontal plough without reversible plowshare is very important. If this plow works on a regular flat surface, the machine intended for the next technological process, i.e., stubble cultivation or harrowing, namely the disc batteries of special profile are forced to process the uneven surface cultivated/plowed by the first unit. The purpose of this research is to enhance the proposed combined machine. To achieve this goal, through laboratory experiments, it is planned to eliminate the shortcoming of the frontal plough without reversible plowshare forming the first unit of the combined machine and to improve and optimize the parameters of the disc battery in the machine's subsequent unit.

Materials and methods

The results of various experimental studies on the frontal plough of the first unit of the combined machine, both with and without reversible plowshare (including those conducted by us, Picture 1), showed that it is advisable to include the frontal plough in our proposed combined machine due to the compactness of its structure and frontal arrangement. The removal of reversible plowshare from the plow's design is justified, considering that their presence contributes to the emergence of numerous shortcomings.

Specifically, to reduce one of the main drawbacks of the frontal plough - high traction resistance - based on theoretical research we have proposed to form the plowshare-wing surface through a logarithmic spiral (Yesoyan, et al., 2023).

The appearance of the plowed field resulted from the frontal plough without reversible plowshares served as the basis for adjusting the parameters of the disc batteries that perform the next technological process. The experiments conducted showed that both on flat terrain and on slopes, the furrows plowed by the frontal plough are not fully overturned. According to the experimental results, the field plowed with this frontal plough acquires the appearance shown in Fig. 1. As can be seen from picture 1, the furrows overturned with opposing plough bodies mainly accumulate in the middle of the plough bodies. Similar results have been obtained during other studies conducted with the frontal plough (Yesoyan, et al., 2014; Sakun, et al., 1991; Gapich, et al., 2019).

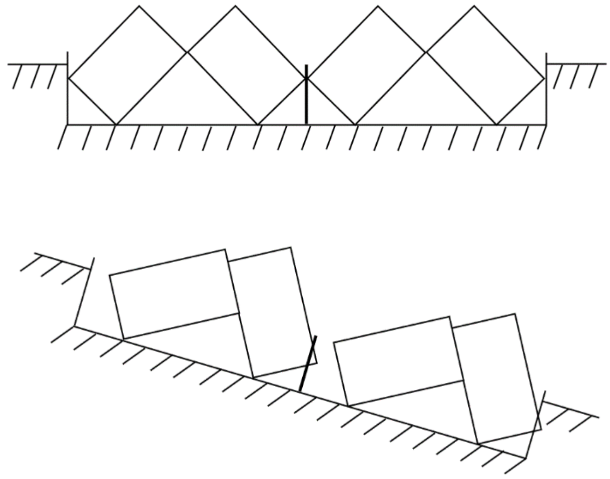

Fig. 1. The description of plowing process with a frontal plough without reversible plowshares on flat terrain and slopes. *(composed by the autors)*.

Picure 1. Field testing of the frontal plough on a slope without reversible plowshares.

In this work, we are dealing with a non-standard situation; accordingly, the chosen research methodology is also non-standard. The methodology was selected based on the experimental results of the modified frontal plough included in the proposed combined machine, which revealed a non-standard situation. Under standard conditions, a plow inverts the furrow to some extent, producing a generally uneven surface that subsequent processes must smooth out. However, in the case of the proposed combined machine, a non-standard situation arises: the furrow segments created by the modified frontal plough bodies are not inverted but rather accumulate in the middle section of those bodies, resulting in a mound-shaped surface. In this case, the machine that follows the plow faces a non-standard task: leveling out the mound formed between the plow bodies. In other words, whereas under standard conditions all the discs on a machine equipped with disc-type working tools would perform the same technological process, here different discs on the same machine must perform different technological processes.

Therefore, we attempted to solve the problem by using a non-standard method. Under laboratory conditions, a mound-shaped surface similar to what is produced in field tests by the frontal plough was formed in a soil trench. Using a specially designed stand capable of altering the disc's attack angle and working depth we were able to determine the optimal parameters for the different discs within the disc assembly.

Results and descussions

In order to increase the operating efficiency of the proposed combined machine, we have presented recommendations for improving its first and second sections the frontal plough without reversible plowshare, and in particular, the special-profile disc assemblies.

Experiments demonstrated that, to ensure the required technological process with the proposed combined machine, different discs of the disc battery will perform tasks of varying volumes and natures. For instance, the first disc of the battery, which passes over the crest of the ridge, is responsible for the loosening of the largest volume of soil and its transfer to the lateral area. This disc deals with a half-turned, unbroken furrow rich in weeds. Here, the disc penetrates the soil to the maximum possible depth — up to 25–30 cm. In other words, the first disc in this position functions as a disc plow.

The second disc encounters the ridge in the middle part, where the ridge height has relatively decreased. This disc penetrates into the ridge about 20 cm, part of which is soil already loosened and shifted by the first disc. In other words, the second disc performs the role of a stubble cultivator.

The third disc does not reach the furrow half-turned by the plow's body at all. It spreads the loosened soil mass presented by the first and second discs toward the sides of the furrow. The third disc penetrates the soil no more than 10–12 cm. In other words, the third disc functions as a disc harrow.

Numerous scientific studies have established that the attack angles of disc plows, harrows, and stubble cultivators vary within different ranges. Specifically, in the case of a plow, it is 40–45°, for a stubble cultivator 10–35°, and for a harrow 10–22° (Kokoshin and Tashlanov, 2019; Sokht and Kirichenko, 2004; Bashnyak, et al., 2014).

Based on the results of laboratory and field experiments, it is proposed to set different attack angles for the various discs included in the combined machine's disc batteries according to the nature of work each performs. Specifically, the first disc was designated with the attack angle range intended for plows, the second one — for stubble cultivators, and the third one — for harrows. The optimal values of these attack angles were determined through laboratory experiments.

For this purpose, laboratory experiments were conducted using a special stand attached to a movable cart over the soil trench at the Armenian National Agrarian University (ANAU). The disc's traction resistance was measured, and the quality of the technological process was visually assessed by using the degree of lateral displacement and leveling of the soil mound (expressed in percentages) across the disc's working width as an indicator. The following scale was applied: very poor (30–50 %), poor (50–60 %), average (60–80 %), good (80–90 %), very good (almost 100 %), and much worse (up to 30 %).

Scene from laboratory and field experiments of the disc battery of the combined machine (Picture 2).

The traction resistance of the disc battery pair was also determined.

The results of the laboratory experiments are summarized in Table, and based on these, graphs were constructed showing the dependence of the disc's traction resistance and cultivation quality on the disc's attack angle (Figures 2, 3, 4). From the graphs, it is quite evident that increasing the attack angle of the disc leads to an increase in traction resistance. Therefore, it's impossible to determine the optimal attack angle of the disc based solely on the traction resistance indicator.

Picture 2. View of the disc battery of the combined machine captured from laboratory and field experiments.

Table. Results of Laboratory Experiments of Disc Working Elements*

Disc Number in Battery	Cultivation Depth, cm	Attack Angle, degrees	Traction Resistance, N	Quality of soil cultivation degree of mound leveling (lateral displacement) as a percentage relative to the disc's coverage width, %
First Disc (as Plow)	30	30	393	Medium (60-80 %)
		35	431	Good (80-90 %)
		40	502	Very Good (almost 10 0%)
		45	614	Poor (50-60 %)
		50	677	Very Poor (30-50 %)
Second Disc (as Stubble cultivator)	20	10	155	Poor (50-60 %)
		15	208	Medium (60-80 %)
		20	304	Good (80-90 %)
		25	339	Medium (60-80 %)
		30	373	Poor 50-60 %)
		35	402	Very Poor (30-50 %)
		40	444	Much Worse (up to 30 %)
Third disc (as Harrow)	10	10	52	Medium (60-80 %)
		15	83	Good (80-90 %)
		20	123	Medium (60-80 %)
		25	161	Poor (50-60 %)

*Composed by the authors.

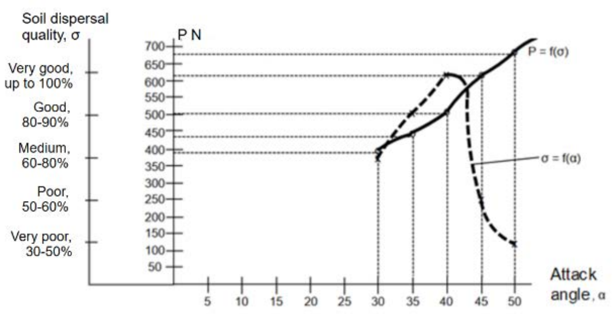

Figure 2. The dependence of the first disc's traction resistance and cultivation quality on the disc's attack angle *(composed by the authors)*.

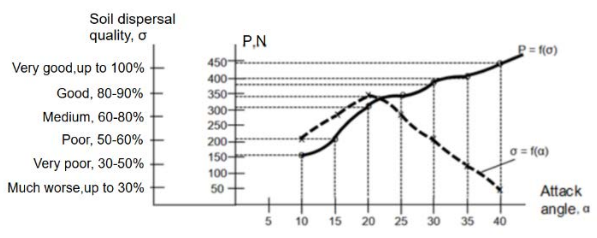

Figure 3. The dependence of the second disc's traction resistance and cultivation quality on the disc's attack angle *(composed by the authors)*.

The optimal angle has been determined by combining the indicators of traction resistance and cultivation quality, giving priority to the quality of cultivation. From Figure 2, it is apparent that the best cultivation quality for the first disc will be achieved at an attack angle of approximately 40 degrees (with a cultivation depth of 25 cm). Based on the same rationale, it can be stated from Figure 3, that the optimal attack angle for the second disc will be about 20 degrees (with a cultivation depth of 20 cm), and regarding Figure 4, the optimal attack angle for the third disc will be around 15 degrees (with a cultivation depth of 10 cm).

The technological scheme of the improved special-profile disc battery, based on the experimental results of the proposed combined machine, is presented in Figure 5.

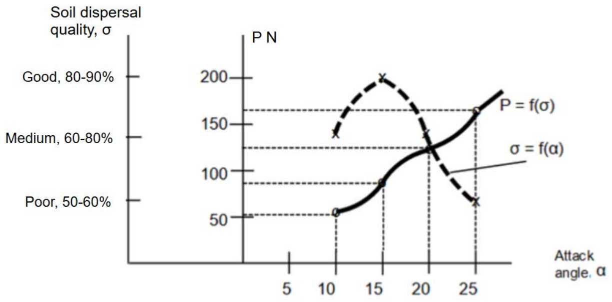

Figure 4. The dependence of the third disc's traction resistance and cultivation quality on the disc's attack angle *(composed by the authors)*.

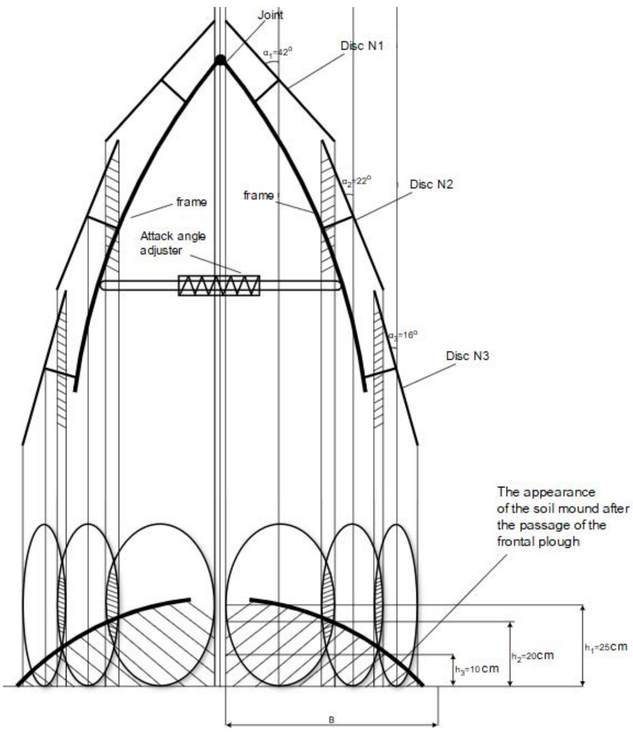

Figure 5. Improved scheme of the disc unit of proposed combined machine based on experimental results *(composed by the authors)*.

Conclusion

By justifying the importance of both plowing and minimum tillage, a combined frontal plough for smooth plowing has been proposed. This machine includes a frontal plough with improved design and parameters, special-profile disc batteries, and a roller.

Based on the results of laboratory and field experiments of the proposed machine, it was found that both on flat terrain and slopes, the frontal plough of the combined machine does not perform sufficient overturning and loosening of the furrows. After the passage of the plow, the furrows accumulate in the middle of the plough bodies without loosening, creating an unloosened mound-shaped surface. To fully execute the subsequent technological process, it was proposed to include special-profile disc batteries in the machine's design. Through these, the mound-shaped surface formed between the plough bodies is loosened and dispersed within the entire width covered by the plough bodies.

Considering the nature and volume of work performed by each disc in the disc assembly, we proposed arranging the discs with different attack angles. Specifically, we set the first disc to have attack angles corresponding to those used for disc plows; the second disc to have angles suitable for disc stubble cultivator; and the third disc to have angles appropriate for disc harrow. Within the ranges determined by laboratory experiments, we established the optimal attack angles by taking traction resistance and cultivation quality as the optimizing factors.

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Declarations of interest

The authors declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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Comparative Analysis of Cadastral and Market Values of Agricultural Plots in Armenia

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ABSTRACT

The procedure for conducting cadastral assessment of agricultural lands, cadastral net income from agricultural lands in the Republic of Armenia are determined by the Decision of the Government of the Republic of Armenia dated July 3, 1997 No. 237 “On approval of the data of the state land cadastre of agricultural lands and unsuitable lands of Republic of Armenia”. The article provides a comparative analysis of the cadastral and market values of agricultural lands in the Republic of Armenia. It clearly states that the cadastral and market values of agricultural lands very often differ from each other several times. The current cadastral values for agricultural lands are outdated and fail to reflect various factors that influence market values. These factors include land rights and restrictions, location, area, dimensions, contour, slope, irrigation, and others, none of which are adequately considered in the calculation of cadastral values for agricultural plots.

Introduction

The primary goal of cadastral assessment of lands is to ensure the normative and informational function of state regulation of land relations. Therefore, it is implemented as a state event (Varlamov, 2006). According to Article 35 of the Land Code of the Republic of Armenia (NO-185), land assessment is the determination of its cadastral value in accordance with fertility, other physical and qualitative characteristics, natural and economic conditions, zoning and intended purpose of the land plot. The assessment utilizes data from land monitoring, the state unified real estate cadastre, and other surveys and observations on the state of the land. It is conducted based on the cadastral and/or market value to fulfill various functions related to the land plot. Cadastral value data are used for determining real estate taxes, rental fees, and other functions concerning land, as outlined in the Land Code of the Republic of Armenia.

On January 1, 2021, the Law of the Republic of Armenia “On Establishing the Procedure for Cadastral Valuation Approximating the Market Value of Real Estate for the Purposes of Taxation by Real Estate Tax” (HO-225-N) was adopted, which established the cadastral assessment procedure for this purpose (www.arlis.am), through which an attempt was made to bring the cadastral value of real estate closer to the market value. The order applied to all lands, regardless of the form of ownership and purpose of the plot, with the exception of agricultural lands.

Materials and methods

The land assessment is expressed in comparative relatival indicators which show how good or bad is particular land for growing a particular crop (Yezekyan and Efendyan, 2008).

The procedure for conducting cadastral valuation of agricultural land in the Republic of Armenia, cadastral net income from agricultural land is determined by the Decision of the Government of the Republic of Armenia No. 237 dated July 3, 1997 "On Approval of the Data of the State Land Cadastre of Agricultural and Unused Lands". in the Republic of Armenia" (www.arlis.am), which is based on the still valid Decision of the Government of the Republic of Armenia No. 251 dated June 1, 1994 "On Approval of the Data of the State Land Cadastre as of January 1, 1994" (Decision of the Government of the Republic of Armenia, 1994, Resolution N 251). To date, Decision No. 251 has not been digitized or included in the legal information systems of Armenia, such as Arlis.am or IRTEK (www.irtek.am). The paper version of the decision was located in the National Archives of Armenia. Here's the revised version:

The net income values of agricultural lands have undergone several adjustments over time. These changes were implemented through various government decisions, including:

Decision No. 567 of December 10, 1994, which multiplied the values by a coefficient of 1.95 (source: www.arlis.am).

Decision No. 68 of October 11, 1995, which applied a coefficient of 1.14 (source: www.arlis.am).

Decision No. 327 of October 10, 1996, which used a coefficient of 1.12 (source: www.arlis.am).

As a result of these adjustments, the net income of agricultural lands was finalized under Decision No. 237 of 1997 as follows:

$$NI_{1997}=NI_{1994}\times 1.95\times 1.14\times 1.12$$

All subsequent decisions determining the cadastral net income of agricultural lands refer either to Decision No. 237, or each to the previous one. In other words, they have not changed over the past 27 years.

According to Appendix 2, Clause 3, Article 238 of the Tax Code of the Republic of Armenia (NO-165-N), the estimated net income of agricultural lands is calculated using the following formula:

$$N_{ll}= A_{al}\ x\ L_{ni},$$

where A_{al} is the area of agricultural land, expressed in hectares, L_{ni} – estimated net income of the relevant agricultural land, the relevant land-cadastral zone, the relevant assessment group, calculated per hectare (Tax Code of the Republic of Armenia).

In accordance with paragraph 9 of the methodology approved by the Decision of the Government of the Republic of Armenia No. 124, of March 3, 1999 "On Approval of the Methodology for Assessment of Agricultural Lands and Conducting Systematic Monitoring of the Condition of Agricultural Lands of the Republic of Armenia", the estimated value of land is determined based on the economic assessment of agricultural lands according to the following formula:

$$CA=NI/4\ x100\ or\ CA = (NIx25\ year),$$

where the calculation of the assessed value (*CA*) is based on the net income (*NI*), determined on the basis of the valuation of the unit area of the relevant plot and the bank capitalization interest rate of 4 percent (www.arlis.am).

Based on the above-mentioned decisions of the RA Government, we studied the cadastral and net income value of 1002 settlements, and in our previous works we presented a complete table of all assessment groups for all land plots in all 15 regions of the land cadastral contour, which did not exist before (Efendyan, et al., 2023; 2024).

Results and discussions

To conduct a comparative analysis of the cadastral and market values of agricultural lands and to obtain the cadastral value, we multiplied the determined net income of agricultural plots by 25 in accordance with the requirements of the above-mentioned normative-legal acts. Using the limited data available, we conducted a comparative analysis of the cadastral and market values of agricultural land plots to identify patterns and trends. Observations were carried out on the following groups of agricultural plots:

By land use type: arable lands, perennial plantings (vineyards and orchards, including pome fruits and stone fruits), and natural forage lands (grasslands and pastures).

By cadastral assessment groups: 1st to 5th classes.

By regions of land-cadastral zoning and cadastral value.

The primary factor influencing these values is the land-cadastral zoning.

For instance, the cadastral value of 5th-class arable land in the conditional Urts-Kotayk-Shamiram land-cadastral zone is identical across Aragatsotn, Armavir, Ararat, Kotayk, and Yerevan. However, it is evident that while the province (marz) does not influence the cadastral value of agricultural lands, the location of the land significantly impacts its market value.

Figures 1 and 2 illustrate that the market value of arable lands and pome fruit perennial plantings in Yerevan is considerably higher than in other provinces, sometimes differing by several multiples. Additionally, it is clear that cadastral values are generally lower than market values, often by a significant margin, though exceptions do exist.

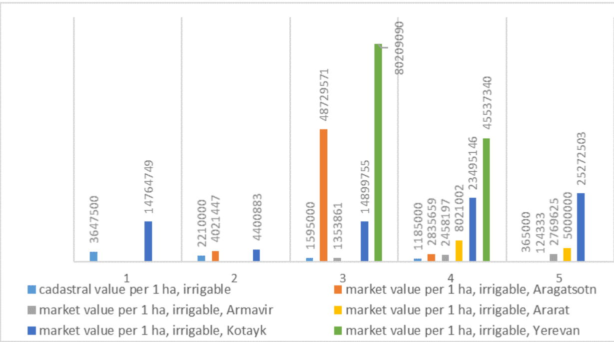

Figure 1. Urts – Kotayk - Shamiram, arable lands, irrigated, February, 2021 *(composed by the authors)*.

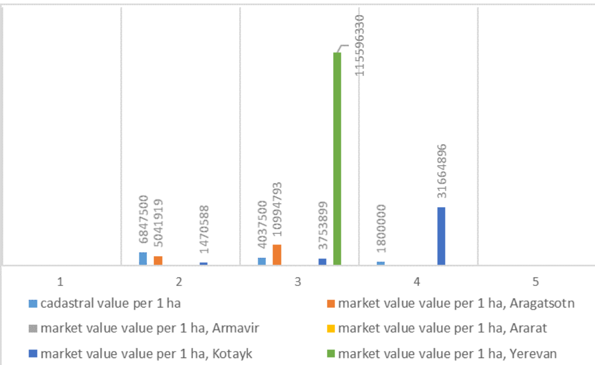

Figure 2. Urts – Kotayk - Shamiram, pome fruit perennial plantings, February, 2021 *(composed by the authors)*.

It is obvious that the market value of agricultural lands in Kotayk marz generally exceeds the corresponding values of other marz located in the same land valuation zone (and therefore having the same cadastral value, for example, the values of Aragatsotn and Ararat marzes in Figure 3).

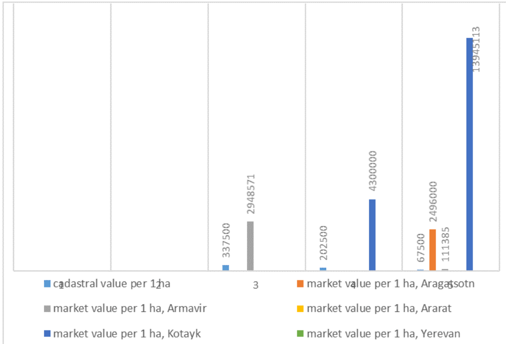

Figure 3. Urts – Kotayk - Shamiram, pastures, February, 2021 *(composed by the authors)*.

Figure 4 shows that the average market values of Tavush marz exceed the values of Lori marz in the arable land assessment groups.

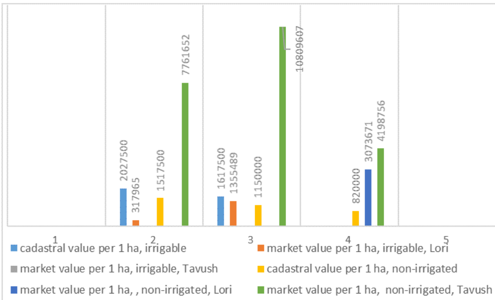

Figure 4. Verin Debed - Aghstev, arable lands, February, 2021 *(composed by the authors)*.

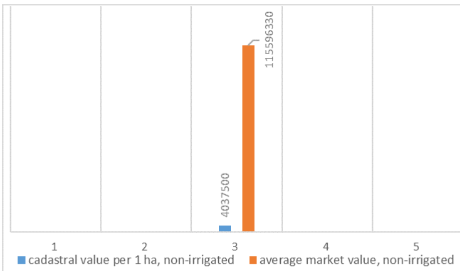

Figure 5. RA, Yerevan, Urts – Kotayk - Shamiram, pome fruit perennial plantings, February, 2021 *(composed by the authors)*.

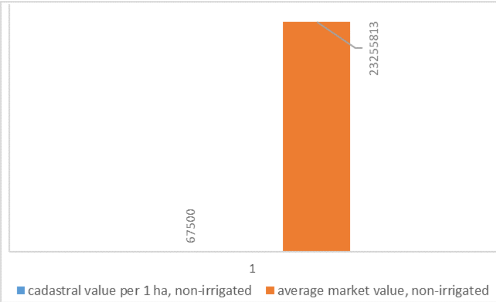

Figure 6. RA, Yerevan, Urts – Kotayk - Shamiram, other lands, February, 2021 *(composed by the authors)*.

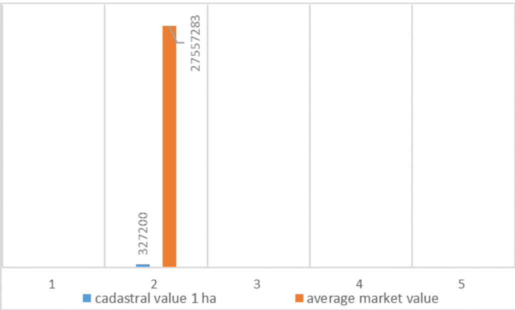

Figure 7. RA, Yerevan, Merdzaraksyan, vineyards, February, 2021 *(composed by the authors)*.

Especially in the case of Yerevan (figures 5, 6, 7) market values significantly exceed cadastral value (in different zones of land cadastral assessment (Urts-Kotayk-Shamiram, Merdzaraksyan), for different types of land (pome fruits, other type of land, grapes).

In other marzes the difference is not so emphatic.

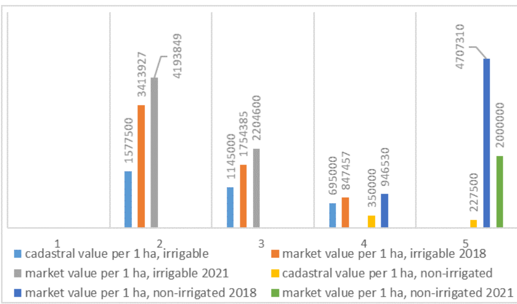

Figure 8. RA, Syunik marz, Syunik, pome fruit perennial plantings, February, 2018/2021. *(composed by the authors)*.

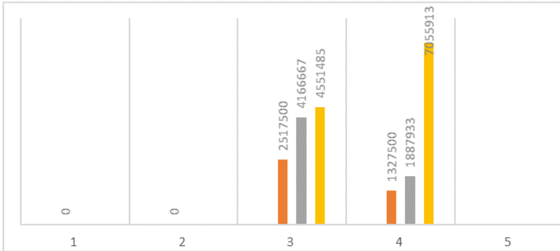

Figure 9. RA, Aragatsotn marz, Urts – Kotayk - Shamiram, stone fruit perennial plantings, February, 2018/2021 *(composed by the authors)*.

Conclusion

The research and analysis conducted lead to the following conclusions:

There is a significant difference between the cadastral and market values of agricultural land, often by several multiples.

When calculating cadastral values, the province (marz) where the land plot is located is irrelevant. Instead, the determining factor is the land-cadastral zoning. Conversely, market values vary for plots within the same land-cadastral zoning, even if they have identical cadastral values. This variation depends on factors such as location, position, and the frontage length of the plot.

Market values are influenced by numerous factors, including geopolitical and regional conditions.

Many key factors affecting the market value of agricultural land are not considered in the calculation of cadastral values. These factors include:

a) Property rights and restrictions (including rights of use).

b) Plot classification, assessment group, and availability of irrigation water.

c) Plot characteristics, such as size, area, width, length, and shape.

d) Location and accessibility.

e) Slope and rockiness of the land.

f) Proximity to and accessibility of transport hubs.

g) Crop yield potential.

h) Other miscellaneous factors that may impact the overall value of agricultural land.

Based on the above, we recommend that the cadastral reassessment of agricultural lands should consider not only the net income of the plots but also the factors influencing their market value. Foremost among these is the location of the land plot—not only the land-cadastral zone but also the specific settlement where the plot is situated, as this directly affects the market value. Additionally, factors such as relief conditions (slope, aspect, rockiness) and others should also be taken into account.

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Declarations of interest

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The Impact of Soil Tillage Methods, Fertilizers of Various Origins and Bentonite on the Yield and Quality of Winter Wheat

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ABSTRACT

The article presents the results of a three-year study on the effects of different soil cultivation methods, equivalent doses of mineral fertilizers and biohumus, and the timing of bentonite application on the yield and quality indicators of winter wheat. Based on field experiments and production trials, it was substantiated that in the conditions of non-irrigated agriculture in Hrazdan region of Kotayk Province, cultivating winter wheat by loosening the soil to a depth of 10-12 cm (instead of conventional plowing to 22-25 cm or zero-tillage) contributes to the regulation of soil aeration, water properties, and nutrient regime. As a result, crop yield increases, and quality indicators improve. At the same time, laboratory studies revealed that the autumn application of bentonite at a rate of 3 tons/ha, on the background of equivalent doses of mineral fertilizers and biohumus, had a more favorable effect on the yield and grain quality of winter wheat grown in non-irrigated conditions compared to spring application of bentonite under the same background conditions.

Introduction

The correct management of the mineral nutrition process for agricultural crops, including cereals, should be aimed at obtaining high and stable yields, improving product quality, as well as ensuring the reproduction of soil fertility and enhancing the ecological state of the environment (Maksyutova, 2017; Chiriţă, et al., 2023).

Numerous studies by both local and foreign scientists have established that mineral and organic fertilizers have a beneficial effect on the yield and quality indicators of cereal crops, particularly intensive varieties of winter wheat. These fertilizers contribute to improved soil fertility by providing essential nutrients, which in turn supports better plant growth, higher productivity, and superior grain quality (Bertic, et al., 2007; Piskaeva, et al., 2017; Litke, et al., 2018; Lachutta & Jankowski, 2024).

Some authors noted that mineral fertilizers can have a more effective impact on winter crops when they create the right balance of nutrients in the soil, which determines the yield (Lazursky & Lebedinskaya, 1969; Alnaass, et al., 2021). D.N. Pryanishnikov's studies revealed that the effect of phosphorus fertilizers is largely dependent on the availability of other nutrients, especially easily hydrolyzed nitrogen, for cereals (Pryanishnikov, 1945).

V.G. Mineev, summarizing the results of scientists from various countries, pointed out that the level of nutrient absorption by winter wheat plants is highly dependent on the degree of availability of other nutrients. For example, in the absence or shortage of nitrogen, phosphorus, although accumulating in the plants, hardly contributes to the formation of organic matter. Potassium and phosphorus significantly promote nitrogen uptake by plants (Mineev, 2004; Mineev, et al., 2006).

According to I.A. Melnik, M.H. Galstyan, the average doses of mineral fertilizers tested on the Bezostaya 1 variety of winter wheat under different soil and climatic conditions resulted in yield increases of 5.5-16.0 c/ha or 20.0-42.0 %, and when combined with foliar feeding with micronutrients, the yield increase was 10.2-32.5 c/ha or 30.0-79.8 %. At the same time, these authors noted a positive correlation between fertilizer efficiency and nutrient availability in the soil: the fewer nutrients in the soil, the higher the fertilizer efficiency (Melnik, 1990; Galstyan, 2007; Galstyan, et al., 2024).

Spiryn and Tagirov highlight the importance of moisture-saving soil treatments and their impact on soil water-physical properties and wheat productivity (Spiryn, 2005; Tagirov, et al., 2015). Their findings emphasize the need for effective soil management practices to enhance water conservation and agricultural yields.

Bentonite plays a vital role in agriculture due to its distinctive properties. As a soil conditioner, it enhances soil structure by increasing its moisture retention capacity, which is particularly beneficial in dry regions and for crops requiring significant water, such as winter wheat (Hassan, 2018; Mi, et al., 2020). The chemical composition of bentonite is as follows: SiO_2 - 58.25 %, Al_2O_3 - 14.37 %, Fe_2O_3 - 4.37 %, FeO - 0.50 %, TiO_2 - 0.36 %, CaO - 2.07 %, MgO - 3.62 %, P_2O_5 - 0.18 %, S - 0.14 %, K_2O - 1.2 0 %, Na_2O - 2.25 %. The clay particles in bentonite aid in binding soil particles, leading to improved aeration. Additionally, bentonite's high cation exchange capacity allows it to retain essential nutrients, making them more readily available to plants. These combined advantages contribute to healthier soil conditions, promoting vigorous crop growth and boosting agricultural productivity (Zhou, et al., 2019; Kozlov, et al., 2023; Yomgirovna, 2023).

Since the privatization of land in Armenia (1991), the intensification of agriculture has been of particular importance in addressing strategic issues in the sector. This can be achieved through the application and adoption of scientific advances, new technologies, and best practices. The high level of agricultural chemicalization during the Soviet era led to the emergence of several negative environmental phenomena (Hayrapetyan & Shirinyan, 2003; Melkonyan, et al., 2004).

The increase in anthropogenic impact on the natural environment raised serious issues in the development and use of alternative agricultural methods. These included increasing the use of organic fertilizers and natural mineral resources, as well as developing and applying new soil cultivation technologies. This concerns the gradual ecological transition in agriculture, where biohumus and the natural mineral bentonite play key roles as valuable soil improvers.

Despite the extensive research conducted by local and foreign scientists to determine the effectiveness of mineral and organic fertilizers in winter wheat fields, comprehensive studies on the effectiveness of equivalent doses of mineral fertilizers and biohumus, combined with the timing of natural mineral meliorant bentonite application in the non-irrigated agricultural zone of Kotayk Province, especially under different soil cultivation methods, have not been conducted. This necessity prompted our studies, which are of great significance and relevance, aligned with the strategic requirements for food security and agricultural development in the Republic of Armenia.

Materials and methods

The studies were conducted from 2021 to 2024 in the conditions of non-irrigated agriculture in the Fantan administrative area of Hrazdan region, Kotayk Province (Gharakhanyan, 2022; Gharakhanyan, 2023; Gharakhanyan & Galstyan, 2023). The field experiments, as well as production trials in 2023-2024, were carried out on typical leached black soils, characteristic of this region. These soils are used primarily for the cultivation of winter cereal crops (mainly winter wheat), with humus content in the plow layer ranging from 4.9 to 5.5 %, a nearly neutral pH (6.9-7.1), and nutrient levels over the years showing 2.94-4.30 mg of easily hydrolyzable nitrogen, 3.41-6.9 mg of mobile phosphorus, and 37.0-37.72 mg of exchangeable potassium per 100 grams of soil.

The research aimed to study the effects of different soil cultivation methods in the non-irrigated conditions of the region, as well as the impact of equivalent doses of mineral fertilizers and biohumus, and the timing of bentonite application on winter wheat yield and grain quality indicators. The goal was to identify and justify through production trials the best soil cultivation method and fertilization technology for practical agricultural use.

The field experiments were conducted with three replications each year, with each fertilization treatment covering an area of 50 m². The production trials, without replications, tested the two best options, each over an area of 1000 m². The field experiments were organized according to the following variants:

1. Control (no fertilization),
2. $N_{60}P_{60}K_{60}$,
3. Biohumus 3.5 t/ha,
4. $N_{60}P_{60}K_{60}$ + Bentonite 3 t/ha (autumn),
5. Biohumus 3.5 t/ha + Bentonite 3 t/ha (autumn),
6. $N_{60}P_{60}K_{60}$ + Bentonite 3 t/ha (spring),
7. Biohumus 3.5 t/ha + Bentonite 3 t/ha (spring).

The specified variants of fertilizers and bentonite were applied under different soil cultivation methods: zero-tillage, soil loosening or disking (10-12 cm), and deep plowing (22-25 cm).

In all variants (except the control), the equivalent doses of mineral fertilizers and biohumus were applied to the soil in the fall, before sowing, by harrowing. The bentonite (3.0 t/ha) in the mineral fertilizer and biohumus variants (4th and 5th) was applied in autumn, while in the 6th and 7th variants, it was applied in spring and incorporated into the soil by harrowing.

The agrochemical indicators of the soils were determined using standard methods presented in the methodological guide on agrochemical analysis edited by B.A. Yagodin (Yagodin, et al., 1989). The quality indicators of winter wheat grain were determined as follows: 1000-grain weight by the gravimetric method, bulk density using a one-liter purka, ash content by dry combustion, crude protein using the Kjeldahl method, and fiber using the Henneberg-Stohmann method.

The yield data were subjected to mathematical analysis, determining the experimental error (Sx, %) and the least significant difference ($LSD_{0.95}$, c/ha) according to Dospekhov (Dospekhov, 1973).

Results and discussions

The results of the three-year field and laboratory studies revealed that both the soil cultivation methods and the equivalent doses of mineral fertilizers and biohumus, along with the timing of bentonite application at the same rate, had a significant impact on the yield and quality indicators of winter wheat.

The yield of winter wheat grain, averaged over three years, was 19.1 c/ha under the zero-tillage method, 19.5 c/ha under conventional plowing, and 23.1 c/ha when the soil was cultivated only by loosening. This represents an increase in yield of 20.9 % compared to zero-tillage and 18.5 % compared to conventional plowing.

This can be explained by the significant changes in the agrochemical and agrophysical properties of the soil, depending on the cultivation method. Organic matter and nutrients available to plants were distributed differently across the plow layer depths. Under conventional plowing, they were mostly concentrated at a depth of 20-30 cm, whereas under loosening and zero-tillage, they were concentrated at 0-10 cm. Regarding the nearly equal yields obtained under conventional plowing and zero-tillage methods, this is attributed not to differences in soil compaction or other agrophysical properties but rather to the level of frost damage to the plants grown under zero-tillage. In the zero-tillage method, the percentage of frost-damaged plants was 4.7 % higher than in conventional plowing. The number of plants per square meter lost due to frost damage was 131 in zero-tillage, 100 in conventional plowing, and 98 in loosening (Gharakhanyan, 2022).

In addition to this explanation, data from our studies on soil water permeability showed that, compared to conventional plowing, zero-tillage and especially loosening improved water permeability in both the plow layer and subsoil in winter wheat fields. The permeability in the plow layer exceeded conventional plowing by 0.42 mm/min or 10.8 %, and in the subsoil by 1.63 mm or 63.4 % (Gharakhanyan, 2024).

These factors undoubtedly contributed to the differences in yield of winter wheat grown using the loosening method compared to conventional plowing and zero-tillage. It is noteworthy that similar patterns were observed in all fertilization technology variants. In the case of zero-tillage, the grain yield of winter wheat either remained equal or increased slightly, with the difference averaging 1.3-5 c/ha over three years. However, with loosening and the appropriate technologies, the yield increase was as much as 10 c/ha (Table 1).

Table 1. The Impact of Different Soil Cultivation Methods, Equivalent Doses of Mineral Fertilizers and Biohumus, and the Timing of Bentonite Application on Winter Wheat Yield*

N	Variants	No-tillage (0 cm)							Only loosening (10-12 cm)							Conventional plowing (22-25 cm)						
		grain yield by year (c/ha)			average grain yield (c/ha)	average straw yield (c/ha)	grain yield increase		grain yield by year (c/ha)			average grain yield (c/ha)	average straw yield (c/ha)	grain yield increase		grain yield by year (c/ha)			average grain yield (c/ha)	average straw yield (c/ha)	grain yield increase	
		2022	2023	2024			c/ha	%	2022	2023	2024			c/ha	%	2022	2023	2024			c/ha	%
1	Control (without fertilization)	20.6	17.8	19.0	19.1	37.0	-	-	23.6	21.2	24.6	23.1	41.1	-	-	20.2	18.6	19.6	19.5	38.0	-	-
2	$N_{60}P_{60}K_{60}$	28.8	25.2	24.8	26.3	54.6	7.2	37.7	33.0	29.0	28.9	30.3	60.1	7.2	31.2	28.2	27.8	27.2	27.7	56.2	8.2	42.1
3	Bio-humus 3.5 t/ha	30.2	26.6	25.7	27.5	56.2	8.4	44.0	32.5	29.1	30.0	30.5	60.8	7.4	32.0	28.6	27.8	28.0	28.1	55.8	8.6	44.1
4	$N_{60}P_{60}K_{60}$ + bentonite 3 t/ha (in Autumn)	40.8	35.6	37.2	37.9	74.9	18.8	98.4	51.3	46.3	47.3	48.3	92.0	25.2	109.1	43.4	43.8	44.0	43.7	81.1	24.2	124.1
5	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Autumn)	44.8	38.8	39.0	40.9	79.5	21.8	114.1	54.9	49.1	50.3	51.4	98.0	28.3	122.5	45.2	44.8	45.5	45.2	84.0	25.7	131.8
6	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Spring)	29.8	26.2	27.0	27.7	56.2	8.6	45.0	38.6	34.2	36.6	36.5	70.4	13.4	58.0	32.2	32.0	33.3	32.5	60.0	13.0	66.7
7	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Spring)	31.9	26.1	25.9	28.0	57.4	8.9	46.6	38.0	35.6	37.4	37.0	69.9	13.9	60.2	31.4	32.4	31.3	31.7	61.2	12.2	62.6

LSD_{05} = 2.42 c

*Composed by the authors.

As the data show, the equivalent doses of biohumus and mineral fertilizers had a similar effect on the increase in grain and straw yield of winter wheat under all three soil cultivation methods. However, when bentonite was applied at a rate of 3.0 t/ha in these conditions, the yield of winter wheat increased compared to the same background without bentonite.

Thus, when bentonite at a rate of 3.0 t/ha was applied in autumn on the background of mineral fertilizers ($N_{60}P_{60}K_{60}$), the yield increase in grain compared to the same background was 11.6 c/ha (44.1 %) under zero-tillage, 16.0 c/ha (58.7 %) under conventional plowing, and 18.0 c/ha (59.4 %) under the loosening method. On the background of biohumus (3.5 t/ha), the autumn application of bentonite at the same rate resulted in additional grain yields of 13.4 c/ha (zero-tillage), 17.1 c/ha (conventional plowing), and 20.9 c/ha (loosening) compared to the respective background.

At the same time, as shown in Table 1, although the spring application of bentonite at the same rate (3.0 t/ha) on the mentioned backgrounds also increased the yield, these increases were almost half of those obtained from autumn applications across all soil cultivation methods. The significant differences in yield increases due to the timing of bentonite application in all soil cultivation methods are undoubtedly related to the duration of bentonite's presence in the soil and its beneficial impact on the soil's agrochemical and agrophysical properties.

In addition to increasing grain yield and improving the structural components of the crop, the impact of the fertilization technology on the quality indicators of food products is of great importance. According to scientific literature, the quality indicators of winter wheat grain vary depending on soil type, irrigation norms, and the level of nutrient availability. Various studies have shown that under the influence of mineral and organic fertilizers, the protein content in grain can range between 10-15 %, starch up to 60 %, ash content up to 2 %, and fiber up to 3.5 %. Fertilizers can also significantly affect both bulk density and the weight of 1000 grains (Agapie & Bostan, 2020; Lachutta & Jankowski, 2024).

Our laboratory studies showed that the different soil cultivation methods (zero-tillage, conventional plowing, and loosening) had no significant impact on the 1000-grain weight, ash content, fiber content, or crude protein content of winter wheat (Tables 2.1, 2.2, 2.3). However, the equivalent doses of mineral fertilizers and biohumus tested under different soil cultivation methods, along with the timing of bentonite application at the same rate, significantly improved the quality indicators of winter wheat grain.

For instance, in the variants without fertilization, the bulk density and 1000-grain weight of winter wheat grown under zero-tillage, loosening, and conventional plowing conditions (averaged over two years) were 783-790 g/L and 33.6-34.6 grams, respectively, while the ash, fiber, and crude protein contents were 1.73-1.80 %, 3.30-3.40 %, and 8.9-9.8 %, respectively. In the variants with mineral fertilizers, biohumus, and bentonite application, the bulk density of winter wheat grain increased by 10-49 g/L, the 1000-grain weight increased by 4.6-15 grams, ash and fiber contents decreased by 0.03-0.18% and 0.3-0.6 %, respectively, and crude protein increased by 0.7-2.1 %.

Table 2.1 The Impact of Zero-Tillage Soil Cultivation, Equivalent Doses of Mineral Fertilizers and Biohumus, and the Timing of Bentonite Application on Several Quality Indicators of Winter Wheat Grain*

№	Options / Variants	2022					2023					two-year average				
		1000-grain weight (g)	bulk density (g/l)	% ash	% fiber	% crude protein	1000-grain weight (g)	bulk density (g/l)	% ash	% fiber	% crude protein	1000-grain weight (g)	bulk density (g/l)	% ash	% fiber	% crude protein
1	Control (without fertilization)	34.0	798	1.78	3.15	8.8	33.2	768	1.82	3.35	9.0	33.6	783	1.80	3.25	8.90
2	$N_{60}P_{60}K_{60}$	37.5	806	1.80	2.90	9.0	38.9	794	1.74	2.90	10.2	38.2	800	1.77	2.90	9.60
3	Bio-humus 3.5 t/ha	41.2	812	1.70	2.88	9.2	38.8	792	1.65	2.80	10.6	40.0	802	1.68	2.84	9.90
4	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Autumn)	47.1	825	1.80	2.75	9.4	45.3	802	1.60	2.70	10.8	46.2	814	1.70	2.73	10.10
5	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Autumn)	46.8	829	1.65	2.80	10.0	47.2	815	1.58	2.67	12.0	47.0	822	1.62	2.74	11.00
6	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Spring)	40.8	801	1.78	2.70	9.0	41.2	784	1.70	2.82	11.2	41.0	793	1.74	2.76	10.10
7	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Spring)	43.4	809	1.88	3.00	9.2	40.6	799	1.68	2.80	11.4	42.0	804	1.78	2.90	10.30

*Composed by the authors.

Table 2.2 The Impact of Only Loosening Cultivation Method, Equivalent Doses of Mineral Fertilizers and Biohumus, and the Timing of Bentonite Application on Several Quality Indicators of Winter Wheat Grain*

№	Options / Variants	2022					2023					two-year average				
		1000-grain weight (g)	bulk density (g/l)	%			1000-grain weight (g)	bulk density (g/l)	%			1000-grain weight (g)	bulk density (g/l)	%		
				ash	fiber	crude protein			ash	fiber	crude protein			ash	fiber	crude protein
1	Control (without fertilization)	35.2	795	1.70	3.20	9.60	34.0	785	1.76	3.40	10.0	34.6	790	1.73	3.30	9.80
2	$N_{60}P_{60}K_{60}$	42.0	829	1.65	3.00	10.00	38.4	811	1.68	3.00	10.8	40.2	820	1.67	3.00	10.40
3	Bio-humus 3.5 t/ha	41.9	830	1.60	2.92	10.60	41.3	818	1.64	2.90	11.2	41.6	824	1.62	2.91	10.90
4	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Autumn)	47.3	841	1.60	2.88	11.00	48.3	813	1.62	2.96	11.2	47.8	827	1.61	2.92	11.10
5	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Autumn)	48.7	845	1.56	2.78	11.20	48.5	819	1.62	2.80	11.6	48.6	832	1.59	2.79	11.40
6	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Spring)	40.5	832	1.70	2.90	10.48	42.3	798	1.72	2.88	11.0	41.4	815	1.71	2.89	10.74
7	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Spring)	41.3	833	1.60	2.90	10.76	42.7	796	1.62	2.94	11.2	42.0	815	1.61	2.92	10.98

Table 2.3 The Impact of Conventional plowing Soil Cultivation Method, Equivalent Doses of Mineral Fertilizers and Biohumus, and the Timing of Bentonite Application on Several Quality Indicators of Winter Wheat Grain*

№	Options / Variants	2022					2023					two-year average				
		1000-grain weight (g)	bulk density (g/l)	%			1000-grain weight (g)	bulk density (g/l)	%			1000-grain weight (g)	bulk density (g/l)	%		
				ash	fiber	crude protein			ash	fiber	crude protein			ash	fiber	crude protein
1	Control (without fertilization)	34.2	792	1.70	3.30	10.0	33.8	780	1.80	3.50	9.6	34.0	786	1.75	3.4	9.8
2	$N_{60}P_{60}K_{60}$	39.8	822	1.60	3.00	10.9	38.6	802	1.72	3.20	10.1	39.2	812	1.66	3.1	10.5
3	Bio-humus 3.5 t/ha	40.7	821	1.50	2.96	11.2	40.1	803	1.66	3.00	10.4	40.4	812	1.58	2.98	10.8
4	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Autumn)	46.2	832	1.48	2.90	11.6	45.6	810	1.54	2.86	10.6	45.9	821	1.51	2.88	11.1
5	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Autumn)	46.7	828	1.46	2.84	11.8	46.9	812	1.48	2.86	11.0	46.8	820	1.47	2.85	11.4
6	$N_{60}P_{60}K_{60}$ + bentonite 3t/ha (in Spring)	41.1	805	1.60	2.98	11.0	41.3	791	1.64	2.98	10.4	41.2	798	1.62	2.98	10.7
7	Bio-humus 3.5 t/ha + bentonite 3t/ha (in Spring)	41.0	806	1.58	2.92	11.3	41.8	796	1.60	2.96	10.8	41.4	801	1.59	2.94	11.05

*Composed by the authors.

The patterns of the impact of fertilizers and bentonite have been generally preserved in both the loosening and conventional plowing soil cultivation methods (Tables 2.1 and 2.2).

It is known that the lower the ash and fiber content and the higher the crude protein in wheat grain, the better the quality indicators of the wheat (Khan, et al., 2010). The experimental results indicate that under arid conditions, the optimal doses of mineral fertilizers and equivalent amounts of biohumus, along with the autumn application of bentonite at a rate of 3.0 t/ha, positively influenced the growth, development, yield, and quality of winter wheat.

The best variants from our field experiments were $N_{60}P_{60}K_{60}$ + bentonite 3 t/ha and biohumus 3.5 t/ha + bentonite 3 t/ha, where all fertilizers and bentonite were applied in autumn during the loosening soil cultivation method. These were also tested in production trials over 1000 m² for each variant.

According to the results of the production trials, the variant with mineral fertilizers and bentonite produced 482 kg of wheat and 770 kg of straw per 1000 m², equivalent to 48.2 c/ha of grain and 7.7 tons of straw per hectare. The variant with biohumus and bentonite yielded 497 kg of wheat and 790 kg of straw, which corresponds to 49.7 c/ha of grain and 7.9 tons of straw per hectare.

Conclusion

Summarizing the results of the three-year field experiments and one-year production trials, as well as the laboratory research conducted, the following conclusions and recommendations can be made:

Among the three tested soil cultivation methods for winter wheat in the non-irrigated conditions of the Fantan administrative area of Hrazdan region in Kotayk Province, the most effective method is soil loosening (to a depth of 10-12 cm). Compared to conventional plowing and zero-tillage, this method increased yield, with the yield increase amounting to 18.5 % and 20.9 %, respectively.

Under all soil cultivation methods, the equivalent doses of mineral fertilizers and biohumus had a similar impact on the yield and quality indicators of winter wheat. However, the highest results were recorded with soil loosening, which provided a grain yield increase of 3.1-4.1 c/ha compared to deep plowing and zero-tillage, as observed in the variants without fertilization.

The autumn application of bentonite, alongside equivalent doses of mineral fertilizers and biohumus, proved more beneficial for the yield and quality of winter wheat than the same rate applied in spring.

The results of the field studies, as well as the effective soil cultivation method (tilling only by loosening to a depth of 10-12 cm) and the application of equivalent doses of mineral fertilizers and biohumus, showed that the use of bentonite at a rate of 3.0 t/ha in the autumn, based on production trial results, achieved winter wheat grain yields of 48.2 and 49.7 c/ha, respectively. These findings have been recommended for widespread implementation and adoption in Kotayk Province and similar soil-climatic conditions (in non-irrigated agricultural settings) as resource-saving and environmentally friendly technologies.

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Declarations of interest

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Monitoring the Onset of Phenological Phases "Stem Elongation" and "Heading" of Winter Wheat in the Republic of Armenia Using Remote Sensing Methods

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ABSTRACT

Winter wheat constitutes a significant share of Armenia's grain production, but can be severely affected by the spread of fungal diseases. According to recent scientific studies, methods based on the dynamics of spectral signatures of crops allow for the timely detection of early signs of crop diseases, prevention of epidemiological threats, and minimization of economic losses. The paper addresses the problem of determining optimal monitoring periods for phytopathogens across the republic of Armenia using these methods. The study covers various regions of Armenia, taking into account their climatic and agronomic characteristics, as the Normalized Difference Vegetation Index (NDVI), weather conditions and digital elevation model. The data show potential for determining the timing of key phenological stages in winter wheat development, which is essential for this type of monitoring. Cartographic materials have been created to indicate recommended start dates for monitoring, based on average data from 2018-2024. The paper also outlines necessary steps to improve the outcomes of the proposed methodology, as well as key actions for implementing this approach in practice.

Introduction

Despite the high significance of orchards, vineyards, and forage crops (approximately 18 % and 24 % of agricultural land, respectively), winter wheat remains one of the leading agricultural crops in Armenia, representing a significant part of grain production. In 2022, statistical data show that grain crops covered more than 44 % of Armenia's sown areas, with over half dedicated to winter wheat (Statistical Committee of the Republic of Armenia).

This study aims to determine the phenological stages of crop development using remote sensing methods and to map these timings for the territory of Armenia. The core idea is that the phenological stages of crop development can be determined based on the seasonal trends in NDVI, temperature, and precipitation (Longchamps & Philpot, 2023; Li, et al., 2023; Bhatti, et al., 2024).

One of the most striking examples may be the early diagnosis of cereal crop diseases. Armenia's climate promotes the development of certain phytopathogens affecting grain crops, such as yellow and brown rusts, powdery mildew, smut diseases, and root rot. Each of these diseases has its own set of risk factors and requires integrated plant protection approaches, including the use of resistant crop varieties and fungicide treatments.

Recent scientific studies have consistently shown a stable correlation between pathogen infections in cultivated plants and changes in their spectral signature dynamics, confirmed through extensive field and laboratory research (Lin-Sheng, et al., 2015; Wang, et al., 2015; Wang, et al., 2016; Jung, et al., 2021). These approaches describe that the most significant period for the early detection of winter wheat diseases is the stage between stem elongation and heading, when fungal plant diseases actively develop (Kremneva, et al., 2022; Sereda, et al., 2023; Danilov, et al., 2024). Therefore, this study focuses on determining the timing of these phenological development stages.

To implement this technology effectively, sensing of agricultural fields is necessary during the significant phenological stages of pathogen development on regular, ideally daily basis (Zhang, et al., 2012; Mahlein, et al., 2019; Bohnenkamp, et al., 2019; Rieker, et al., 2023), especially when plant diseases are in the incubation phase. During this period, visual symptoms are not yet visible to the naked eye but can already be detected through spectral analysis. For wheat, this corresponds to the stem elongation to heading stages. Relying solely on satellite data for this imaging frequency is challenging, mainly due to potential cloud cover. Unmanned aerial vehicles (UAVs) equipped with multi- and hyperspectral cameras offer a viable solution to this limitation.

The hypothesis of this study is that this approach will facilitate the scheduling and organization of phytopathological monitoring using multi-temporal spectral measurements of crops.

Through disease monitoring of crops using remote sensing data, it is possible to localize pathogen hotspots at both the regional (field group) and local (individual plot) levels. This technology shows promise in precision agriculture, as timely disease management can reduce economic losses, enhance product quality, lower the risk of large-scale epidemics, and contribute to efficient resource use and ecosystem sustainability.

The complexity of this work for the territory of Armenia is associated with additional challenges, as the country has diverse climatic zones and significant altitude variation. Different regions have varying soil types and microclimatic characteristics. Further complexity is added by the heterogeneity of agrotechnical practices and the limited availability of data.

Materials and methods

As the initiation of phytopathological monitoring for winter wheat using the dynamics of crop spectral imagery dynamics aligns with the onset of the BBCH-40 phenological stage (Stem Elongation), it was essential to determine the multi-year average date for this stage across regions of Armenia.

According to the methodology presented in the reference literature "Agroclimatic Resources of the Armenian SSR" (Kalantarova, et al., 1976), in order to determine the phenological stages of winter wheat while adhering to the sowing recommendations for the crop, information on the growing elevations, as well as the temperature and precipitation during the season, is required. The methodology includes a series of reference tables that outline the following necessary steps:

1. Determine the elevation at which the crop is grown separately for the Northeastern regions (Lori, Tavush) and the internal regions. For each elevation, the multi-year average date of the onset of each phenophase is provided in the case of 100% provision of heat and moisture for the crops.
2. Determine the percentage of moisture provision for the crops. If the moisture provision was below the required level, adjust the dates of phenophase onset for this period according to the tables.
3. Determine the percentage of active temperature provision for the crops. If the heat provision was below the required level, adjust the dates of phenophase onset for this period according to the tables.

Since the sowing and resumption of vegetation dates for all winter wheat crops across Armenia are unknown, applying this methodology sequentially to each phenophase is not feasible for this study. However, we hypothesize that the heading stage corresponds to the peak NDVI value, as confirmed by numerous studies (Dížková, et al., 2022; Zhao, et al., 2021; Zhao, et al., 2022). In the current study, we further validate this hypothesis.

Furthermore, since “stem elongation” and “heading” are consecutive phenophases, validating the methodology requires only one reverse calculation: determining the duration of the “stem elongation” phase by counting backward from the heading stage. This will provide the recommended start date for monitoring to assess the pathogenic background of the crops.

Study Area

The current administrative division of Armenia into 10 marzes was considered too broad for this study’s purposes. Therefore, Armenia was divided into 39 parts corresponding to the 39 districts (hamaynks) that existed in Armenia prior to the 1995 administrative reform. This division was chosen for several reasons: the datasets used in the research offer sufficient detail for this level of subdivision, and it aligns conveniently with historical maps and reference data from 40–50 years ago.

Figure 3 illustrates the contribution of administrative districts to grain production, based on the “Atlas of Agriculture of the Armenian SSR” (Bogatova, 1984) and on modern statistical data (Statistical Committee of the Republic of Armenia). Modern statistics are collected at the marz level (10 regions), so a full comparison of this indicator is difficult.

In 2024, for the plots near the village of Nerkin Sasnashen (Talin municipality of the Aragatsotn region), the author conducted field studies on spring wheat from April 26 (BBCH 29, maximum tillering) to June 18 (BBCH 68, beginning of wax ripeness) (Fig. 1). These studies included multispectral and thermal imaging using UAVs and ground observations.

It was initially assumed that this site would allow for the testing of an early disease detection method based on remote sensing data. However, due to significant contamination of the crops by weeds, this was challenging. Nevertheless, actual field data were collected, data on the timing of key phenological stages of development according to the BBCH scale (Meier, 2001) for spectral pathogen monitoring (Table 1).

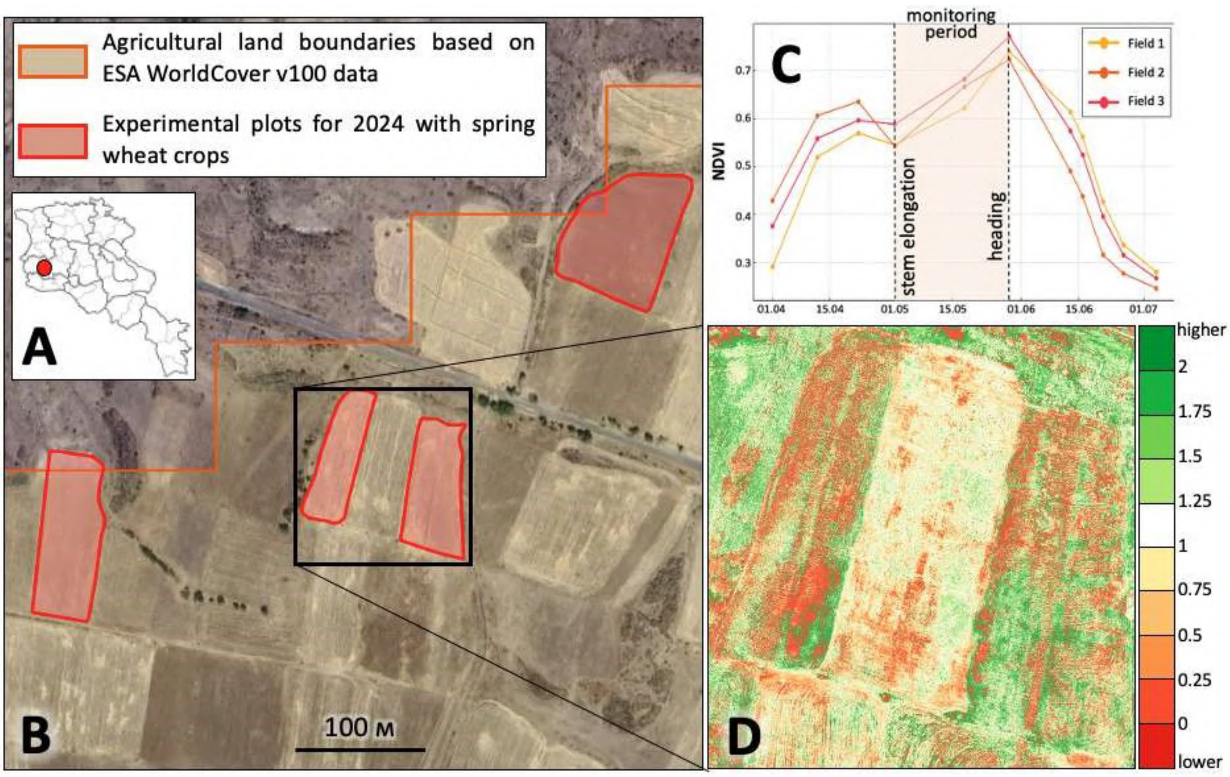

Figure 1. Research on spring wheat plots near Nerkin Sasnashen: A – Location of the plots within Armenia; B – Local positioning of the plots; C – Seasonal NDVI trend for 2024 based on Planet Scope data; D – NDVI ratio on 05.20 compared to 04.26.2024 derived from multispectral UAV imaging *(composed by the author).*

Table 1. Dates of phenological stages of spring wheat development for the fields near Nerkin Sasnashen in 2024*

Date	Phenophase	BBCH Code
04.26	Maximum tillering, stem elongation	29-31
05.16	Stem elongation, flag leaf	35-39
05.20	Heading, beginning of spike emergence from the sheath	41-44
05.23	Heading, full spike emergence	45-49
05.27	Flowering	51-59
06.03	Grain filling, beginning of milk ripeness	61-63
06.10	End of milk ripeness	64-68
06.18	Beginning of wax ripeness	69-73

*Composed by the author.

Data Sources

Various sources of information were used in this study. Some of the data were obtained using the Google Earth Engine (GEE) platform, a cloud-based tool for analyzing geospatial data with capabilities for accessing and processing remote sensing data and their products (Google Earth Engine, n.d.).

Agricultural lands of the Republic of Armenia: This represents a vector layer of areas where agricultural activities are conducted. It was obtained from the ESA WorldCover 10m v100 dataset, provided by the European Space Agency (ESA) (Zanaga, et al., 2021). The dataset classifies the Earth's surface into 11 categories at a 10-meter spatial resolution, including a "cropland" class. Using the GEE platform, the dataset was clipped to Armenia's borders, and the "cropland" class was extracted as a binary mask and then vectorized (Fig. 2).

Seasonal NDVI Dynamics: NDVI (Normalized Difference Vegetation Index) data (Rouse, et al., 1974) for plots near the village of Nerkin Sasnashen were derived from PlanetScope data (SuperDOVEs satellites, PSB.SD imaging system). Surface Reflectance level images were acquired for the plot areas on the following dates: 01.04.2024, 12.04.2024, 22.04.2024, 01.05.2024, 18.05.2024, 29.05.2024, 13.06.2024, 16.06.2024, 21.06.2024, 26.06.2024, and 04.07.2024. For the entire territory of Armenia, NDVI data were sourced from Sentinel-2 (MSI) satellites via the GEE platform, covering the period from 01.09.2017 to 31.12.2023. This period was selected due to the availability of images with the necessary sensing frequency.

Weather Data: This dataset includes historical daily average air temperatures and daily precipitation totals from 01.09.2017 to 31.12.2023 (consistent with the NDVI data). These data were obtained using the GEE platform based on the ERA-5 atmospheric and surface reanalysis developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), combining meteorological observations, satellite data, and numerical modeling methods. The data were obtained separately for each district (Herbach, et al., 2020) (Figure 2).

Relief Data: This dataset includes absolute elevation values and slope angles, sourced from the GEE platform using ALOS World 3D (AW3D30) data, a global elevation dataset provided by the Japan Aerospace Exploration Agency (JAXA, 2019). For each district, statistical values of elevation and slope angles were calculated for agricultural land polygons.

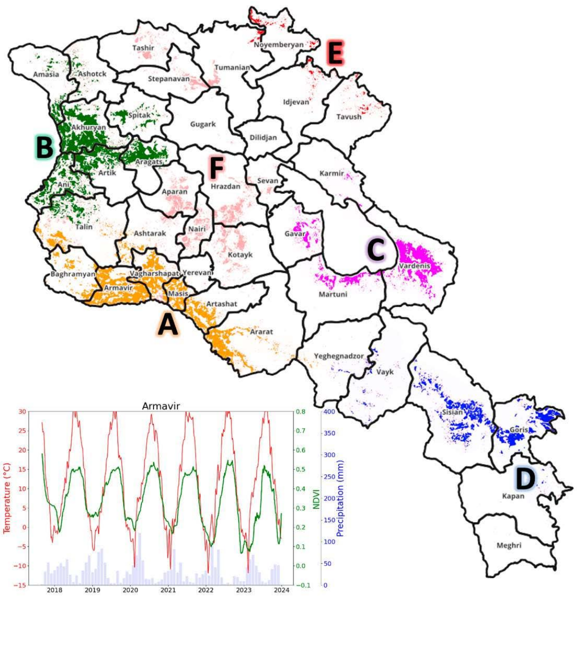

Figure 2. Agricultural lands of Armenia based on ESA WorldCover 10m v100 data, classified according to the seasonal dynamics of temperature, precipitation, and NDVI (classes A, B, C, D, E, F). Seasonal trends of these indicators from 2017 to 2023 are shown for several regions *(composed by the author).*

Historical data: These data are represented by the following maps: “Average Dates of Termination and Resumption of Vegetation in Winter Wheat,” “Average Data on Heading and Wax Ripeness of Winter Wheat,” “Average Dates of Heading and Wax Ripeness of Spring Wheat” from the “Atlas of Agriculture of the Armenian SSR” (Bogatova, 1984). Additionally, reference information was drawn from the book “Agroclimatic Resources of the Armenian SSR” (Kalantarova, et al., 1976).

Data Processing

For the plots near the village of Nerkin Sasnashen, UAV imaging data were processed, although the results are used indirectly in this study. From these data NDVI and simple ratio images for different dates, were obtained (Fig. 1D), to evaluate the potential for early detection of pathogenic contamination using spectral data. Zonal statistics for these plots were calculated from PlanetScope data using a Python script and the GDAL library (Open Source Geospatial Foundation). Based on these data, a seasonal NDVI trend graph was created for each plot (Fig. 1C).

Data collection for the Republic of Armenia was conducted using the agricultural land layer derived from ESA WorldCover 10m v100 data. For each dataset, including terrain, meteorological data, and NDVI, information was collected within this vector layer for each of the 39 studied regions. This ensured that the necessary data were collected exclusively within agricultural areas. For instance, in mountainous regions, only data from valleys where agricultural land is located were included.

NDVI values were calculated from Sentinel-2 satellite images. To ensure a complete data series, the resulting values were processed using the Savitzky-Golay filter (Savitzky and Golay, 1964) and recalculated for each date within the specified time period, even on days without available images. Daily available meteorological data, required no additional recalculation. Elevation data are static, so statistical values were calculated for each region, with arithmetic mean values.

All collected data were aggregated within the studied regions. The timing of the heading phenophase for winter wheat was identified by the peak NDVI value, while the onset of the stem elongation phenophase was established using reference data, following the previously described methodology (Kalantarova, et al., 1976).

Results and discussions

In the current work on the spring wheat plots near Nerkin Sasnashen, an attempt was made to apply an early disease diagnosis method for winter wheat based on the dynamics of remote sensing spectral data. However, data processing revealed a high degree of field heterogeneity, largely due to extensive weed growth and soil variability. These factors had a significantly stronger impact on the spectral level of the crops, making it difficult to identify zones with increased pathogenic contamination (Fig. 1D).

Despite these challenges, phenological field observations (Table 1) and the seasonal NDVI trend (Fig. 1C) enabled the establishment of a correlation between these indicators. For spring wheat, maximum NDVI values were found to correspond to the end of heading and the beginning of flowering (BBCH 58-60). The observed time interval between stem elongation and the vegetation peak was approximately 30 days (27 days based on observations). According to reference data (Kalantarova, et al., 1976), this corresponds to the average duration of the phenophases from stem elongation to heading for both spring and winter wheat (24-40 days).

Although spring and winter wheat are different crops, they share similar plant architecture, phenophase timing after tillering, and spectral image dynamics. However, winter wheat reaches its NDVI peak several weeks earlier (typically around 3 weeks) than spring wheat, and the NDVI peak in most of the studied regions corresponds to winter crops.

To determine the timing of phenological development phases, the previously mentioned cartographic, meteorological, reference materials, and remote sensing data were utilized. Historical data facilitated the creation of maps showing the onset of phenological stages for winter wheat based on multi-year averages from 1976–1980. The vector layer boundaries of agricultural lands of the Republic of Armenia were used as areas of interest for data extraction. NDVI data enabled the determination of the estimated phenological phase “heading” for winter cereal crops. Data on topography, temperature, and precipitation were used to calculate the duration of the phenological stage “stem elongation” for various regions. Together, these datasets provided insights into how the territory of Armenia can be zoned according to the seasonal dynamics of these indicators.

Among the regions with the highest share of winter wheat crops, three main groups can be identified: the Western districts (Akhuryan, Artik, Ani, Talin), the Vardenis district, and the Goris and Sisian districts. In terms of elevation, four main regions stand out: the Ararat Valley (Ararat and Armavir), Tavush, the Southeastern regions (Gegharkunik, Vayots Dzor, Syunik), and the Northwestern regions (Shirak, Lori, Kotayk, Aragatsotn). Based on climate and NDVI, 5-6 regions can be identified: the Ararat Valley (Ararat, Artashat, Masis, Vagharshapat, Armavir), the Western regions (Akhuryan, Spitak, Aragats, Artik, Ani, Talin), the southern shore of Lake Sevan (Vardenis, Martuni, Gavar), Syunik (Sisian, Goris), Tavush (Noyemberyan, Shdjev, Tavush), and a number of central and northwestern districts, where climate and NDVI indicators are intermediate (Aparan, Hrazdan, Sevan, Nairi, Kotayk, Tashir, Stepanavan, Tumanyan). This zoning can be considered the main one, as it is more detailed and also includes larger zoning categories based on elevation and the main zones of winter wheat cultivation (Fig. 2).

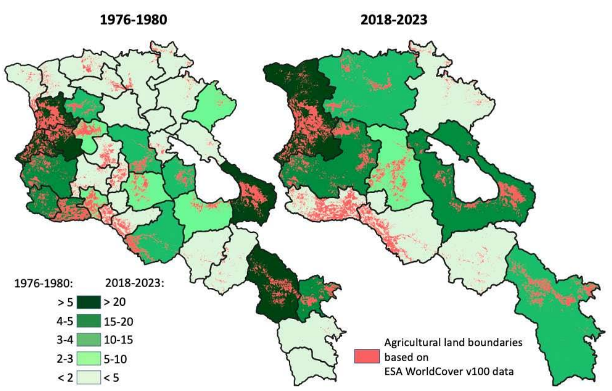

Figure 3. Share of administrative districts in grain production (in percentages) *(composed by the author).*

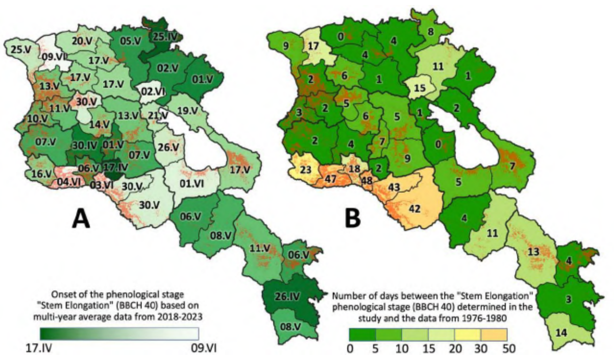

Figure 4. Results of determining the dates of the phenological stage "Stem Elongation" (BBCH 40) for the regions of Armenia: A – Start dates of the phenophase based on data from 2018-2023; B – Difference in days between the start dates of the phenophase based on data from 2018-2023 and the reference data from 1976-1980. *(composed by the author).*

The results of the assessment for the start date of monitoring to identify an increased pathogenic contamination in winter wheat are presented in maps (Fig. 4). The map showing the timing of the "stem elongation" phenological stage (Fig. 4A) displays the estimated start dates of monitoring calculated in this study. The map showing the number of days between the start dates of "stem elongation" based on data from 2018-2023 and 1976-1980 (Fig. 4B) is also presented.

It can be observed that the discrepancies between the calculations and the historical data (Bogatova, 1984) in most regions of Armenia do not exceed 10 days. The model takes into account the specific features of the territory. For instance, in the mountainous Aragats region, the onset of the targeted phenophase occurs significantly later than in the surrounding regions but no significant discrepancies with historical data are observed.

The largest discrepancies with historical data are found in the Ararat Valley (regions of Baghramyan, Armavir, Vagharshapat, Masis, Artashat, Ararat). Noticeable differences are also present in certain individual regions (Ashotsk, Dilijan, Ijevan, Vayq, Sisian, Meghri).

The NDVI dynamics show that in the Ararat Valley, the seasonal maximum of this index occurs in July-August. It can be concluded that grain crops are not sufficiently represented in these regions. This can be confirmed by looking at the maps of the share of administrative districts in grain production (Fig. 3). Similar factors likely account for the discrepancies observed in Ashotsk, Dilijan, Ijevan, Vayq, and Meghri. We do not have statistical data on the areas of winter wheat cultivation in Sisian, but it can be assumed that the crop rotation structure in this region may have significantly changed over the 40 years since the release of the historical map.

It is important to note that this study used generalized and aggregated data on agricultural lands. Consequently, the spectral signatures of the vegetation were influenced not only by winter cereals but also by row crops, orchards, vineyards, forage grasses, and other types of vegetation.

Even with these factors considered, the method for calculating the "stem elongation" phenological stage (BBCH-40) for winter wheat proves effective and correlates well with the characteristics of Armenia's environmental territorial systems. The presence of regions where this method shows poor results only confirms its reliability, as it assumes that certain conditions must be met for its proper operation (a high proportion of plots with winter crops). Nonetheless, it is clear that this method can and should be improved.

To implement this approach in practice, it is essential to account for the specifics of the current season, which often differ from multi-year averages. Additionally, the method for accurately determining the NDVI peak date may need adjustments. Possible solutions include calculating phenophase timings sequentially from the time of crop emergence, using multi-year climate data that are continuously refined based on current weather conditions, or dynamically updating the NDVI peak date in response to real-time weather conditions. Several studies address this issue (Dížková, et al., 2022; Zhao, et al., 2021; Zhao, et al., 2022).

It is also necessary to consider the NDVI of winter crops separately from all other crops. For the method of early disease detection based on spectral image dynamics to be applied effectively to spring cereals, it is equally important to differentiate between spring cereals and other crop types. Numerous scientific advancements in this area have already been successfully implemented in practice (Bartalev, et al., 2011; Vorobyeva, et al., 2016).

However, determining the specific composition of crops on agricultural lands through remote sensing methods is not always feasible in real time, particularly for distinguishing spring crops. Therefore, crop rotation characteristics can be more accurately tracked by using a geoinformation system (GIS) for agricultural land monitoring, where details about cultivated crops are entered in advance, taking into account annual changes in cultivated areas. Even without such a system, similar monitoring can still be conducted on a case-by-case basis for interested organizations and entrepreneurs, provided they supply data on field locations, crop types, and sowing dates for the current season.

As possible recommendations for conducting phytosanitary monitoring to detect winter wheat diseases early using remote sensing methods, the following sequence of actions can be proposed. This can be schematically represented as a data flow diagram (Fig. 5). The main analytical operations in this diagram are:

Establishing whether the weather conditions of the current season are favourable for the emergence of certain pathogens. This is done based on phytopathological reference materials using weather data.

Determining the timing of the monitoring

Identifying zones with an increased pathogenic contamination. During active spectrometry, it is recommended to use imaging systems with the necessary spectral resolution, placed on UAVs, as this provides the most comprehensive coverage of the area without the problems associated with satellite imaging (low frequency, cloud cover).

The spectrometry results are expected to yield maps highlighting zones of increased pathogenic contamination, which will require additional field validation studies. It's also important to emphasize that implementing this approach necessitates the involvement of both remote sensing specialists and agronomists.

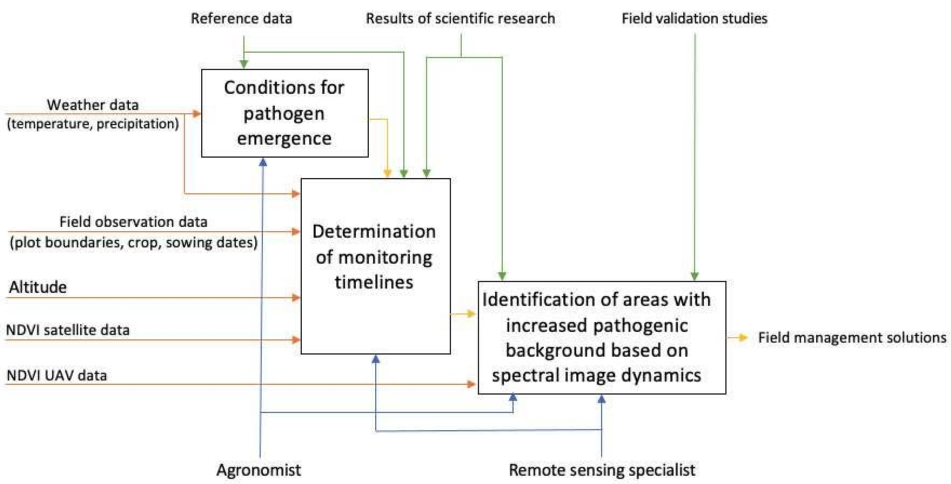

Figure 5. Proposed data flow diagram for monitoring cereal crop diseases *(composed by the author).*

Agronomists' expertise is crucial at each stage, as they play an integral role in interpreting data and ensuring the practical application of findings. Their expertise is essential at each stage, and the outcome of the work is the creation of field management solutions for which they are responsible.

Conclusion

This study has demonstrated the possibility of indicating the phenological stages for winter wheat in the various regions of the Republic of Armenia using remote sensing methods and, thus, it can be implemented as a model for the phytopathological monitoring.

This was demonstrated using a set of multi-temporal data from 2018 to 2024. Regional variations in the monitoring timeline results underscored the need for local adaptation of the methods, taking into account each region's specific climatic and agronomic characteristics. Recommendations for refining the proposed methodology were provided, along with a suggested implementation procedure.

The proposed approach has the potential to become a valuable tool in precision agriculture, enabling reduced crop losses and enhancing the resilience of Armenia's agricultural systems to phytopathogens. However, further efforts are needed to optimize the methodology and integrate remote sensing data with agricultural land monitoring geoinformation systems for its successful application.

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Declarations of interest

The author declare no conflict of interest concerning the research, authorship, and/or publication of this article.

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The Study of Lentil Samples from Global Collection in Different Agroclimatic Conditions of Ararat and Gegharkunik Regions

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ABSTRACT

Lentil (Lens culinaris Medik.), is a valuable and accessible source of plant proteins. Thanks to their symbiosis with nitrogen-fixing bacteria, they help in the accumulation of nitrogen in the soil. In the climatic conditions of the Ararat and Gegharkunik regions, lentil samples from ICARDA collection were studied, including: plateflat forms Flip2006-4L, Flip2007-12L, Flip2007-15L, Flip2006-10L, Flip2007-3L, Flip2007-30L; drought-resistant Bilsen-365, EP-54; early-maturing Flip2005-42L, Flip 2005-53, Sellfrom LL1 767, Flip2006-79L; frost-resistant Flip2003-30L, Flip 2007-26L, AKM-46, Flip2005-25L. For the lentil samples, the climatic conditions of the Gegharkunik region proved to be more favorable, and the samples Flip2007-12L, Flip 2007-15L, and Flip2007-3L demonstrated 21 %, 35 %, and 14 %, higher yields compared to the Ararat region, respectively. In the Ararat region, the highest yield among all studied samples was shown by the drought-resistant Ep-54. The mentioned varieties are recommended for use in breeding work and production sowings.

Introduction

Lentil (Lens culinaris Medik.) is one of the oldest legume crops cultivated by humanity. In many developing countries with food insecurity, it serves as a vital source of nutrition (Pugliese, et al., 2024). Lentil is a drought-resistant crop that is an excellent source of food-grade protein and starch, making it ideal for everyday consumption, while in its green form, it is also a valuable animal feed (Moezalislam, et al., 2012; Minhao, et al., 2023). As a legume crop, lentil stands out for its high protein content, which ranges from 22-30 % in the seeds (Shaboyan, et al., 2024).

The root system of lentil forms a symbiotic relationship with nitrogen-fixing bacteria, thereby enriching the soil with nitrogen (Mukherjee, et al., 2023). When included in crop rotation as a preceding crop, lentil significantly increases the yield of subsequent crops (20-30 %) (Ali, et al., 2022). The introduction of new, high-yielding, erectness, disease- and pest-resistant lentil samples, suitable for mechanical harvesting, is an important and current priority in agricultural development (Barbaryan, et al., 2020).

According to statistical data from the Republic of Armenia, in 2023, lentil was grown on 123 hectares, with total harvested crop 1772 c. Lentils are primarily cultivated in the Kotayk, Shirak, Armavir, and Gegharkunik regions (Sown Areas of Agricultural Crops, Planting Area of Permanent Crops, Gross Harvest and Average Crop Capacity for 2022). The low crop areas and yields of lentil are mainly due to the lack of high-yielding, erectness, disease-resistant varieties suitable for mechanical harvesting, as well as improper choices of sowing methods, timing, and areas (Anil, et al., 2022).

Both abiotic and biotic factors have a strong negative impact on the physiology of lentil plants, in particular pod and lentil production; environmental conditions and both abiotic and biotic stresses affect the potential response of plants to caffeine when used as a potential ingredient for biostimulant formulations (Jené, et al., 2022).

In 2008-2009, 101 lentil samples from the ICARDA global collection were studied in the climatic conditions of the Ararat and Gegharkunik regions based on yield data. Among these, 25 were plate-shape, 25 were drought-resistant, 34 were early-maturing, and 17 were frost-resistant samples. From 2019 to 2021, we selected and studied 16 relatively high-yielding samples from this collection for further evaluation based on their biological and agronomic particularities, with the aim of including them in future breeding programs.

Materials and methods

The studies conducted between 2019-2021 were carried out in the climatic conditions of the Ararat and Gegharkunik regions at the experimental farm of the Scientific Center for Vegetable and Technical Crops of the Ministry of Agriculture of the Republic of Armenia, located in the Darakert community, which has irrigated meadow gray soils. The region is situated at an altitude of 850-1000 meters above sea level. The average temperature in January is −2.6°C, and in July, it is 26.2°C. The annual average precipitation is 289 mm. In the Martuni community of the Gegharkunik region, at the farm of Grigori Khlyghatyan the crops were grown in irrigated gray meadow soils. The experimental plot was located at an altitude of 1800-2000 meters above sea level, with an average temperature of −6.0°C in January and 22.0°C in July. The annual average precipitation is approximately 350 mm.

Seeding in Darakert was carried out in the last decade of April, while in Martuni, it was done in the first decade of May. The following lentil samples were studied:

Plate-shaped: Flip2006-4L, Flip2007-12L, Flip2007-15L, Flip2006-10L, Flip2007-3L, Flip2007-30L; Drought-resistant: BILSEN-365, EP-54; Early-maturing: Flip2005-42L, Flip2005-53, Sellfrom1767L, Flip2006-79L; Frost-resistant: Flip2003-30L, Flip2007-26L, AKM-46, Flip2005-25L. The accepted sowing norm for lentil is 2.5-3 million viable seeds per hectare, determined through multiple years of trial data, or 80-100 kg/ha (Ansari, et al., 2015).

The trials were conducted with three replications, each in 16.6 m² plots. The sowing was carried out using the (15+15) x15 cm scheme, with each variety planted at a density of 22 plants per m². The seed germination rate for all the studied samples ranged between 97-98 %. The plant lodging until the end of the vegetation period averaged 4%. Yield data were calculated based on the average yield per plant in each replication within a 50 m² plot, which was then extrapolated to a per-hectare basis. Agronomic practices were carried out according to accepted agricultural standards, ensuring the normal growth and development of the plants. The studies were conducted in accordance with the methodology for state variety testing of agricultural crops (Methodology for State Variety Testing of Agricultural Crops, 1975).

The samples were evaluated based on the average data from five randomly selected plants in each replication. The local Talin-6 was used as a control variety. Measurements included the height of formation of the first node, plant height, erectness, the mass of the pods per plant, the mass of seeds per plant, and overall yield. The yield was calculated using the harvesting and weighing method. The profitability level of all the promising samples was also determined. The price of seed was set as 600 drams. The cultivating cost per hectare was also calculated. In the Ararat region, during the vegetation period, the plants were irrigated four times, while in the Gegharkunik region, cultivation took place under dryland conditions. The costs included expenses for irrigation, sowing, seed purchase, weed control, and harvesting.

The data were subjected to statistical analysis using the ANOVA method with a significance level of $P \leq 0.05$.

Results and discussions

The effect of different ecological conditions on yield and yield components of lentil has been investigated. The economically valuable data for the lentil samples in the conditions of the Ararat region, are presented in Table 1, while the data for the Gegharkunik region are shown in Table 2. According to the study results, among the plate-shaped samples, those with the best erectness were Flip 2006-4L, Flip 2007-3L, and Flip 2007-30L (Table 1), while in the Gegharkunik region, only Flip 2007-3L exhibited notable erectness (Table 2). Overall, in the Ararat region, the plate-shaped samples were more erect than in the Gegharkunik region.

The plant height in both regions ranged from 31 to 56 cm. In Ararat Marz, plate-shaped samples were 2-11 cm taller than the standard. The tallest were Flip20064L (11 cm taller) and Flip20610L (2 cm taller). Only Flip2007-3L was shorter than the control. Drought-resistant samples, like BILSEN-365, surpassed the control by 3 cm in plant height. The early-maturing sample Sellfrom 767L had a height similar to the control, with no significant difference. Other samples were 7-14 cm shorter, with Flip2006-79L being the shortest. Frost-resistant samples were 5 cm taller than the control, except for Flip2003-30L, which showed no significant difference. In Gegharkunik Marz, plant height of all plate-shaped samples was similar to that of Ararat Marz, except for Flip2007-3L, which was 5 cm shorter than in Ararat Marz and 7 cm shorter than the control. Height differences were only observed in frost-resistant samples Flip2007-26L and AKM-46, which were 2-3 cm shorter in Gegharkunik Marz compared to Ararat Marz.

Table 1. Economically valuable traits of lentil samples in the conditions of the Ararat region*

Samples	Erectness, unit	Height, sm		Per plant, g		Yeild, g/m²
		plants	formation of first pods	pods mass.	grains mass	
Talini 6 (control)	3	45±0.3	20±0.1	4.7±0.3	4.4±0.2	198±1.4
Plate shape						
Flip2007-15L	3	50±0.3	19±0.2	4.6±0.1	4.2±0.3	189.0±1.2
Flip2007-12L	4	48±0.2	25±0.1	5.6±0.2	5.2±0.1	234.2±1.3
Flip2006-4L	5	56±0.3	25±0.1	5.1±0.5	4.8±0.1	216.0±0.9
Flip2006-10L	4	47±0.4	9.5±0.2	4.8±0.1	4.5±0.4	202.1±0.6
Flip2007-15L	5	43±0.3	18±0.1	6.8±0.1	6.5±0.3	292.2±2.2
Flip2007-30L	5	55±1.1	28±0.2	6.6±0.2	6.3±0.4	283.2±1.4
$LSD_{0.05}$		1.2	1.5	0.2	1.4	4.2
Drought-resistant						
BILSEN-365	4	48±1.1	25±0.1	4.9±0.3	4.6±0.5	207.2±1.3
EP-54	5	43±0.2	12±0.1	6.8±0.1	6.1±0.2	274.4± 2.1
$LSD_{0.05}$		2.1	2.2	2.1	1.1	21.4
Early-maturing						
Flip2005-42L	5	32±0.9	11±0.1	3.3±0.2	2.8±0.2	126.1±1.2
Flip2005-53L	4	38±0.5	12±0.2	3.6±0.3	3.0±0.2	135.3±1.7
Sellfrom 1767L	5	44±1.2	9±0.1	6.2±0.2	5.5±0.2	247.2±2.1
Flip2006-79L	5	31±1.4	13±1.3	4.6±0.1	4.1±0.2	184.1±1.4
LSD0.05		1.2	1.1	0.4	0.3	3.2
Frost-resistant						
Flip2003-30L	5	44±0.4	20±1.1	4.4±0.1	4.1±0.4	184.2±2.1
Flip2007-26L	5	50±0.3	33±1.0	2.5±0.1	2.1±0.2	115.2±2.5
AKM-46	4	50±0.5	12±1.3	2.8±0.1	2.6±0.2	115.2±1.2
Flip 2005-25L	5	50±0.4	27±0.8	2.6±0.1	2.2±0.3	119.6±1.2
$LSD_{0.05}$		2.4	1.5	0.6	0.8	4.2

*Composed by the author.

For the mechanical harvesting of lentils, one of the key indicators is the height of formation of the first node.

In the Ararat region, the first node height ranged from 9.0 to 33 cm, with the highest in Flip2007-26L and the lowest in Sellfrom 1767L. In Gegharkunik Marz, the first node ranged from 9.5 to 30 cm. Most drought-resistant and plate-shaped samples formed pods at similar heights in both regions, except Flip2007-3L, which formed pods 6 cm higher in Gegharkunik. Early-maturing Sellfrom 1767L formed pods 3 cm higher, while frost-resistant Flip2007-26L formed pods 3 cm lower in Gegharkunik.

In the Ararat region, pod mass per plant ranged from 2.5g to 6.8g. Plate-shaped samples exceeded the control by 0.4g to 2.1g. The heaviest pods were in Flip2007-3L and drought-resistant EP-54 (6.8 g). Sellfrom 1767L, an early-maturing sample, surpassed the control Talini 6 variety by 1.5 g in pod mass per plant. Frost-resistant samples had a pod mass per plant of 2.5g to 4.4 g, which was 0.3g to 2.2g lower than the control.

In the Gegharkunik region, pod mass per plant ranged from 1.7 g to 8.8g, with plate-shaped samples exceeding the control by 1.6g to 3.3g, except for Flip2007-15L (2.5 g lighter) and Flip2006-10L (equal to control). Drought-resistant samples had a pod mass 2.3g to 3.1g heavier than the control variety Talini 6. Early-maturing samples Flip2005-42L and Sellfrom 1767L surpassed the control by 1.1g and 0.6g, respectively. Pod mass in all frost-resistant samples was lighter than the control.

Table 2. Economically Valuable Traits of Lentil Samples in the Conditions of the Gegharkunik Region*

Samples	Erectnes, unit	Height, sm.		Per plant, g		Yeild, g/m^2
		plants	of formation first pods	Pods mass.	Grains mass	
Talini 6 (control)	4	45±0.9	19±1.0	5.5±0.2	5.0±0.1	230±1.5
Plate shape						
Flip2007-15L	4	50±0.8	19±0.8	3.0±0.4	2.6±0.2	117±2.2
Flip2007-12L	3	48±0.5	25±0.5	7.1±0.1	6.6±0.2	297±1.7
Flip2006-4L	3	56±1.1	25±0.7	8.1±0.3	7.5±0.5	337±1.1
Flip2006-10L	4	47±0.9	9.5±0.5	5.5±0.4	5.0±0.2	230±1.2
Flip2007-3L	5	38±0.3	24±0.7	8.8±0.2	7.6±0.1	342±1.5
Flip2007-30L	4	55±03	28±0.7	8.4±0.2	7.4±0.2	331±1.1
$LSD_{0.05}$		0.6	2.1	1.2	1.8	5.4
Drought-resistant						
BILSEN-365	4	48±03	25±1.2	7.8±0.7	7.4±0.1	333±1.4
EP-54	5	43±03	12±1.0	8.6±0.4	7.8±0.2	351±1.75
$LSD_{0.05}$		1.0	1.4	0.5	0.6	8.2
Early-maturing						
Flip2005-42L	5	32±0.4	11±0.2	6.6±0.4	5.0±0.3	225±1.2
Flip2005-53L	4	38±1.0	12±0.1	4.8±0.3	4.0±0.2	180±2.4
Sellfrom1767L	5	44±0.8	12±0.3	6.1±0.2	5.7±0.4	259±3.2
Flip2006-79L	5	31±0.7	13±0.1	5.1±0.2	4.8±0.2	202±1.2
$LSD_{0.05}$		1.2	0.5	0.3	1.1	15.2
Frost-resistant						
Flip2003-30L	5	44±07	20±0.3	5.1±0.3	4.6±0.1	207±3.2
Flip2007-26L	5	48±0.5	30±0.5	1.7±0.2	1.6±0.1	72±1.2
AKM-46	4	47±0.8	14±0.2	2.8±0.1	2.6±0.3	117±2.3
Flip2005-25L	5	50±0.5	27±0.3	3.1±0.1	2.9±0.2	130±3.0
$LSD_{0.05}$		2.2	4.1	0.9	0.2	10.2

*Composed by the author.

There is a direct correlation between pod mass and grain mass per plant. In the Ararat region, only Flip2007-15L from plate-shaped samples had lighter grains, while others were 0.3g to 2.1g heavier than the Talini 6 variety. Per heavy grains mass drought-resistant samples and early maturing sample Sellfrom 1767L were selected.

In the Gegharkunik region, grain mass per plant ranged from 1.6g to 7.6g. Plate-shaped samples exceeded the control by 1.6g to 2.6g, except for Flip2007-15L (2.4g lighter) and Flip2006-10L (equal to control). Drought-resistant samples had 2.4g to 2.8g heavier grain mass than the control Talini 6, while early-maturing Sellfrom 1767L surpassed the control by 2.4g. All frost-resistant samples had lighter grain mass than the control.

In the Ararat region, the highest yields were obtained from the plate-shaped samples Flip 2007-3L, Flip 2007-30L, and Flip 2007-12L, which surpassed the control variety by 1.4, 1.4, and 1.2 times, respectively. The drought-resistant sample EP-54 also outperformed the control variety by 1.3 times (Table 1).

Table 3. Economic Efficiency of the Studied Lentil Varieties in the Climatic Conditions of the Gegharkunik and Ararat Regions*

Sample	Marketable yield, q/ha	Income, thousand drams	Production costs, per ha (thousand drams)	Cost price per 1 kg, drams	Net profit, thousand drams	Profitability level, %
Gegharkunik Region						
Talini 6 (control)	23.0	1380	372	161.7	1008	271.0
Plate shape						
Flip 2007-30L	33.1	1986	385	116.3	1601	415.8
Flip 2007-3L	34.2	2052	400	116.9	1652	413.0
Flip 2007-12L	29.7	1782	378	127.2	1404	371.4
Flip 2006-4L	33.7	2022	385	114.2	1637	425.2
Drought-resistant						
EP-54	35.1	2106	410	116.8	1696	413.7
Bilsen365	33.3	1998	385	115.6	1613	419.0
Early-maturing						
Sellfrom1767L	25.9	1554	380	146.7	1174	308.9
Ararat region						
Talini 6(control)	19.8	1188	447	225.7	741	165.8
Plate shape						
Flip 2007-30L	28.3	1698	475	167.8	1223	257.5
Flip 2007-3L	29.2	1752	453	155.1	1299	286.8
Flip 2007-12L	23.4	1404	460	196.6	944	205.2
Flip 2006-4L	21.6	1296	485	224.5	811	167.2
Drought-resistant						
EP-54	27.4	1644	480	175.1	1164	242.5
Bilsen365	20.7	1242	455	219.8	787	173.0
Early-maturing						
Sellfrom1767L	24.7	1482	460	186.2	1022	222.2

*Composed by the author.

The drought-resistant EP-54 sample stood out for its high yield, surpassing the control variety by 2.6 times in the Ararat region and by 1.3 times in the climatic conditions of the Gegharkunik region. The first node of the EP-54 sample formed at a lower height in both regions compared to the tested BILSEN-365 sample, but it exceeded the control variety in terms of pod and seed mass.

The early-maturing Sellfrom1767L sample provided higher yields than the control variety in the climatic conditions of the Gegharkunik region, producing 1.2 times higher yield than in the Ararat region. The Sellfrom1767L sample also surpassed the control variety in terms of pod and seed mass per plant.

In the Gegharkunik region, the Flip 2007-3L sample provided 1.1 times higher yield than that of in the climatic conditions of the Ararat region.

As seen from the data in the table, lentils in the conditions of the Gegharkunik region provide a high level of profitability, which ranges from 308.9 % to 425.2 %, exceeding the control variety by 37.9 % to 154.2 %. In the climatic conditions of the Ararat region, the profitability level ranged from 167.2 % to 286.8 %. The highest profitability in Gegharkunik regions was provided by the Flip 2006-4L sample ,in Ararat region Flip 2007-3L.

Conclusion

The study results conclude that ecological conditions significantly impact the economically valuable traits of the samples. In the Gegharkunik region, conditions are more favorable for lentil samples than in the Ararat region, highlighting the importance of selecting more adaptive samples for each region.

Based on the findings, the lentil varieties Flip2007-3L, Flip2007-12L, and Flip2006-4L are recommended for further breeding programs due to their high yield and favorable economic returns in both the Ararat and Gegharkunik regions. Drought-resistant variety EP-54 and early-maturing Sellfrom1767L also showed promising results, particularly for areas with limited irrigation resources. The study emphasizes the importance of selecting varieties that are well-adapted to local climatic conditions to maximize both yield and profitability.

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Sodium Hypochlorite as an Effective Means of Combating *Dermanyssus Gallinae* Mites in Chickens

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ABSTRACT

The chicken tick *Dermanyssus gallinae* is widespread across all climatogeographic zones of the Republic of Armenia. The invasion occurs with relatively high intensity in large poultry farms (such as in Arzni, Lusakert, and Jrarat). In 1 cm^3 of substrate collected from poultry houses, the number of ticks ranges from 1,100 to 2,800 specimens. These parasites attack birds at night, while during the day they remain in the dust on the walls and under the feed conveyor. To disinfect poultry houses, organophosphate compounds are commonly used. However, these substances are toxic, requiring the removal of birds from the premises before use, which is a time-consuming process. In laboratory and production experiments, we tested a 20 % aqueous solution of sodium hypochlorite, achieving 100 % effectiveness. The solution was used without the need to remove the birds from the premises.

Introduction

Among the factors hindering the development of poultry farming, parasitic diseases play a significant role. There are numerous works that study blood-sucking ectoparasites of birds and poultry houses, including the *D. gallinae* mites (Frolov, 1975).

The red bird mite (*Dermanyssus gallinae*), an ectoparasite belonging to the phylum Arthropoda, class Arachnida, order Mesostigmata, and family Dermanyssidae, poses a significant threat to poultry and chicken health worldwide. With *D. gallinae* increasingly suspected of being a disease vector and reports of attacks on alternative hosts, including humans, becoming more frequent, the economic importance of this pest has grown substantially. As poultry production shifts away from conventional cage systems in many regions, *D. gallinae* is expected to become more prevalent and increasingly difficult to control (Sparagano, et al., 2014).

Dermanyssus gallinae mites have an unsegmented, oval-shaped body measuring 0.75–1 mm in length. They possess four pairs of legs in their nymph and adult stages, while larvae have only three pairs. Their color is grayish-white but turns reddish-brown after feeding on blood.

These blood-feeding mites can infest other bird and animal species, including humans. They are nocturnal, seeking shelter in dark, hidden areas during the day.The life cycle of *D. gallinae* includes the following stages: egg, larva, protonymph, deutonymph, and sexually mature adult. They are bisexual, with a full development cycle lasting between 6 and 12 days. When deprived of food, they can survive for up to 10 months. *D. gallinae* primarily parasitizes the featherless areas under birds' wings and in the armpits, causing anemia, exhaustion, and, in severe cases, limb paralysis. Young birds are particularly vulnerable to infection and often become ill.

The poultry red mite (*Dermanyssus gallinae*) is highly prevalent across Greek poultry production systems and regions. In the future, factors such as global warming, reduced acaricide availability, and the ban on cage systems are expected to contribute to a wider spatiotemporal distribution of PRM. These challenges highlight the urgent need for effective monitoring and control strategies to safeguard hen production, poultry welfare, and workers' health (Sioutas, G., et al., 2024). Various approaches have been employed to investigate the relationship between *D. gallinae* and pathogens. In this comprehensive review, we critically examine the available strategies and methods for conducting trials, assessing their strengths and weaknesses. Our analysis aims to provide researchers with valuable tools for accurately studying the vectorial role of *D. gallinae* (Schiavone, et al., 2022). We assume that an effective and sustainable approach to controlling poultry red mite infestations is urgently needed. This includes the implementation of integrated pest management strategies (Flochlay, et al., 2017).

The poultry red mite *Dermanyssus gallinae* is best known as a threat to the laying-hen industry; adversely affecting production and hen health and welfare throughout the globe, both directly and through its role as a disease vector. Nevertheless, *D. gallinae* is being increasingly implemented in dermatological complaints in non-avian hosts, suggesting that its significance may extend beyond poultry. The main objective of the current work was to review the potential of *D. gallinae* as a wider veterinary and medical threat (George David, et al., 2015). *D. gallinae* mites are widespread in poultry farms of Republic of Armenia, and they cause a serious economic demage (Ohanjanyan, 1979, Harutyunyan and Hakobyan, 2001, Hakobyan and Gasarjyan., 2001).

Organophosphorus compounds are mainly used to combat these mites, but they are toxic, and before using them, the poultry farm must be temporarily freed from birds, which is very difficult and time consuming. Therefore, we had a goal to search for a non-toxic, but effective means combating the mites.

Materials and methods

Dermanyssus gallinae is a mite that normally parasitizes small birds but may occasionally bite humans. We report an unusual case of an 82-year-old woman who presented with pruritus and bite-like lesions over her trunk. In the case of *D. gallinae*, the small size of the mites and the fact that they leave the host after feeding means that they may not be seen at presentation, thus such infestations are likely to be underdiagnosed. Physicians should be aware that infection with this mite is possible even in patients from urban areas, and it should be included in the differential diagnosis of conditions causing recurrent pruritus unresponsive to standard treatments (Collgros, et al., 2013).

Avian mite bites skin lesions can remain unrecognized or misdiagnosed. Inquiry about contact with pigeons or poultry may be helpful in patients with nonspecific skin lesions (Cheikhrouhou, et al., 2020).

To determine the infestation of poultry houses with *D. gallinae* mites, we took samples from various poultry houses in the republic: we've collected dust of the walls of the building and equipment, and by counting the number of mites in laboratory (based on the volume in 1 cm^3), we determined the intensity of infestation of the farms with mites.

Research was conducted in the poultry farms of Yerevan, Arzni, Lusakert, and Jrarat.

We've tested the new chemical compound in laboratory first, and in farms (Jrarat and Arzni poultries) afterwards.

Results and discussions

Thanks to regularly conducted surveys, we have determined the degree of contamination of some of the largest poultry farms with *D. gallinae* mites.

The data obtained is shown in the designed Table.

Table. Infestation intensity of farms with mites*

Poultry Farm	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
	Number of mites in 1cm³ sample											
Yerevan	1100	1120	1152	1150	1200	1200	1300	1250	1250	1150	1125	1025
Jrarat	1200	1200	1230	1250	1300	1360	1350	1350	1000	1250	1230	1210
Lusakert	2255	2250	2275	2300	2350	2370	2410	2350	2330	2330	2300	2270
Arzni	2550	2570	2580	2610	2600	2650	2700	2800	2670	2670	2600	2580
Smaller farms	300	330	400	480	600	570	580	545	420	420	400	350

*Composed by the authors.

The data in the table show that all poultry farms surveyed are infected with the poultry mite. According to the data obtained the number of mites collected (in 1cm^3 material) from the walls of the poultry, around the bowls and feeders ranges from 1025 to 2800 in large farms, and from 300 to 600 in smaller individual poultry farms.

Since *D. gallinae* mites attack chickens at night, only a few mites are found during daytime inspections, even in case of intensive infection of the farm.

The data in the table also show that the intensity of poultry infestation is remaining almost at the same levels during all months of the year. This results in the fact that poultry farms have similar conditions for the development and reproduction of mites (temperature and humidity) in all months of the year. Although all the poultry farms studied are vulnerable to poultry mites, Lusakert and Arzni poultry farms had a higher intensity of infestation.

It's important to note that there were a few buildings in poultry houses that were not infected with *D. gallinae* mites. Further analysis of this situation could provide additional data to better understand how to address it from an epidemiological perspective.

To combat mites in infected poultry houses we've tested different concentrations of sodium hypochlorite. Sodium hypochlorite is one of the main compounds of perchloric acid (NaOCl). It is a volatile compound that releases chlorine and oxygen upon decomposition, which have antiseptic and disinfecting effects. Aqueous solutions are used in a cold state so that chlorine is not released when heated. Tests were conducted both in laboratory and in poultry houses. We've also tested the sodium hypochlorite on the chickens in Arzni branch of Institute of Zoology and Jrarat poultry farm.

In those farms chickens were treated by spraying 20 % sodium hypochlorite aqueous solution. The buildings themselves were also treated with 20 % sodium hypochlorite aqueous solution by spraying 200 ml of the solution on each 1m^2 of the surface. The procedure was repeated twice with an interval of 7 days.

It is important to note that no alive mites were found in the samples collected from farmhouses after the full procedure. The treatment was done in poultry farms without moving the birds. No changes were detected in the physiological state of the birds. Therefore, the 20 % sodium hypochlorite aqueous solution is recommended for widespread production use.

Conclusion

The results achieved allow us to come to the following conclusions:

1. *D. gallinae* mites are widespread and are found in all the farms examined. Moreover, some of the farms have very high infection intensity.
2. The 20 % sodium hypochlorite aqueous solution has a high insecticidal property, and thus, we recommend it for mass use.
3. It can be used in all times of the year, if necessary, as there is no need to temporarily move the birds out of the farm.
4. The advantages of sodium hypochlorite over organophosphorus compounds (chlorophosphite, neostomazan, diazinon) are that it has at least the same insecticidal properties and is environmentally friendly and does not cause any pollution.

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Declarations of interest

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Physicochemical Properties and Health Implications of Cow's Milk from Armenian Manufacturers

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ABSTRACT

This study evaluates the physicochemical properties of milk samples from six different Armenian manufacturers to assess their quality and suitability for dairy product production. The milk samples were analyzed for key parameters including pH, fat content, solid non-fat (SNF), density, protein, lactose, salts, and freezing point. Results revealed slight variations in pH, fat, and protein content, with goat milk showing the highest protein, lactose, and SNF levels, and a lower freezing point compared to other milk types. Temperature, fat content, and protein concentration were identified as significant factors influencing milk quality, with implications for dairy product formulation. This research provides valuable insights into the nutritional profiles of Armenian milk and can inform the development of targeted dairy products based on these physicochemical characteristics.

Introduction

Milk is a fundamental agricultural product consumed globally, prized for its nutritional benefits, including proteins, fats, vitamins, and minerals (Górska-Warsewicz, et al., 2019, Fox, et al., 2021, Antunes, et al., 2022). As one of the most widely consumed liquids in the world, milk has been integral to human diets for centuries, providing essential nutrients and promoting growth and development, particularly in young children. The quality of milk plays a pivotal role not only in human health but also in the dairy industry, as it influences its use in producing various dairy products, such as cheese, butter, and yogurt (Rozenberg, et al., 2016). The physicochemical properties of milk—including pH, fat content, solid non-fat (SNF), density, and protein levels—have profound effects on its sensory characteristics, nutritional profile, and shelf life (Huppertz, et al., 2024). These properties also contribute to the texture, taste, and stability of milk-based products, which are often highly valued by consumers. Furthermore, additional factors such as temperature, water content, lactose concentration, salts, and freezing point contribute to determining milk quality and its suitability for different dairy products (Wu, et al., 2024).

Milk composition is influenced by several factors, including breed, diet, and geographical location (Ahuja, et al., 2022). Variations in these factors lead to differences in the physicochemical properties of milk produced by different manufacturers. For instance, the type of feed, environmental conditions, and even seasonal changes can lead to significant fluctuations in the milk's composition. Such variations ultimately affect the overall quality of the milk and, by extension, the quality of the dairy products made from it (Lind, 2007). While numerous studies have investigated the milk composition of various animal species, including cows, goats, and sheep (Ferro, et al., 2017), there is limited research on comparing milk samples from different producers within a specific region. This gap is especially noticeable in Armenia, where a detailed and comprehensive study on the physicochemical properties of milk from local producers is still lacking.

Understanding the variations in the physicochemical properties of milk from different Armenian manufacturers is vital for both consumers and producers. For consumers, this knowledge can inform their choices based on factors like taste, nutritional value, and product consistency. For producers, it can help optimize milk production to meet specific demands for quality and quantity. In addition, local milk variations can have an impact on the production of specific dairy products, which are integral to Armenia's agricultural economy. In countries with rich dairy traditions, like Armenia, optimizing the quality of milk is essential for producing a diverse range of products that meet both local and international market needs.

Previous studies have demonstrated that factors such as fat content, protein concentration, and pH significantly influence milk quality and the resulting dairy products (Cheng, et al., 2019). However, comprehensive research specifically addressing these factors in the context of Armenian dairy production remains sparse. Moreover, the relationship between these physicochemical parameters and the production of particular dairy products—such as cheese, yogurt, and cream—has yet to be fully explored. Fat content plays a crucial role in determining the texture, mouthfeel, and flavor of products like cheese, cream, and butter, whereas protein concentration is essential for curd formation and contributes to the nutritional content of dairy products (Silva, et al., 2021). Therefore, investigating the physicochemical properties of milk from different Armenian producers is of utmost importance, as it will provide insight into the functional characteristics of milk and its suitability for various dairy products.

In this study, the physicochemical properties of milk from several Armenian manufacturers will be analyzed, with a focus on key parameters such as pH, fat content, SNF, protein levels, and density. By exploring these properties and identifying variations between different producers, this research aims to contribute to a deeper understanding of milk quality in Armenia. Ultimately, this study seeks to inform dairy production practices and contribute to the broader knowledge of how regional factors affect milk composition and dairy product quality.

Materials and methods

Milk samples were collected from six different Armenian manufacturers, selected based on the diversity of dairy production practices within the region. The sampling process considered both the production date and storage conditions of the milk to ensure consistency and minimize any external factors that could affect the milk's physicochemical properties.

The physical properties and biochemical components of cow's milk were measured using the Lactoscan Milkanalyzer (Farm Eco, Bulgaria), commonly used for the analysis of milk quality and composition (Bork, et al., 2015).

The following parameters were analyzed to evaluate the differences and similarities in the composition across milk samples: pH, temperature (°C) (Lan, et al., 2024), fat (%), Solid Non-Fat (SNF) (%) (Assen and Abegaz, 2024), density (kg/m^3) (Fox, et al., 2021), proteins (%), lactose (%), salts (%) (Woźniak, et al., 2022) and Freezing Point (°C) (Kumar, 2024) .

To assess the differences between milk samples from different manufacturers, a t - and Mann-Whitney U tests were conducted.

Results and Discussions

This study evaluates the physicochemical characteristics of six samples of milk: "Ani milk," "Marianna pasteurized milk," "Marianna ultra-pasteurized milk," "Chanakh milk," "Yeremyan milk," and "Goat milk." The analysis focuses on key parameters, including pH, temperature, fat content, SNF, density, water content, protein, lactose, salts, and freezing point, as detailed in Table 1.

Table. Physicochemical properties of milk samples from different Armenian manufacturers*

Milk Type	pH	Temperature (°C)	Fat (%)	SNF (%)	Density (kg/m³)	Proteins (%)	Lactose (%)	Salts (%)	Freezing Point (°C)
Ani Milk	6.67	20.7	2.9	8.52	29.73	3.12	4.07	0.69	-0.534
Marianna Pasteurized Milk	6.64	19.2	2.99	9.46	33.21	3.46	5.19	0.77	-0.604
Marianna Ultra-Pasteurized Milk	6.64	19.2	2.99	9.46	33.21	3.46	5.19	0.77	-0.604
Chanakh Milk	6.78	19.9	2.94	9.01	31.56	3.3	4.94	0.73	-0.572
Yeremyan Milk	6.87	18	2.85	9.24	32.53	3.39	5.07	0.75	-0.588

*Composed by the authors.

pH Levels. The pH values of the milk samples range from 6.62 (Goat milk) to 6.87 (Yeremyan milk), indicating a slightly acidic nature. A lower pH indicates higher acidity, which can have an impact on the milk's preservation, shelf life, and its microbial stability (Rahman & Rahman, 2020). Yeremyan milk shows the highest pH, which may reflect its different processing techniques compared to other samples. Studies have shown that pH levels play a crucial role in the overall quality of milk and dairy products (Fox, et al., 2021).

Temperature. The temperatures range from 18.0°C (Yeremyan milk) to 20.7°C (Ani milk). Temperature plays a significant role in controlling the growth of bacteria and maintaining the milk's freshness. Lower temperatures contribute to a reduction in microbial activity, thereby increasing the shelf life of milk (Li, et al., 2023). The variations in milk temperature may be attributed to the conditions under which the samples were stored or processed (Toghdory, et al., 2022).

Fat Content. Fat content ranges from 2.84% (Goat milk) to 2.99 % (Marianna pasteurized and ultra-pasteurized milk). Fat is a crucial component that affects milk's texture, flavor, and nutritional value. Higher fat content enhances the sensory properties, making milk creamier and richer in taste (Bakke, et al., 2015). These variations can also be linked to the milk's processing methods, as pasteurization can influence the fat content without significantly altering it (Bakke, et al., 2015).

Solid Not Fat. SNF values range from 8.52 % (Ani milk) to 9.49 % (Goat milk), with Marianna milk (both pasteurized and ultra-pasteurized) showing the highest SNF value of 9.46 %. SNF is a measure of the total solids excluding fat and water, and it plays an essential role in determining the milk's nutritional value. A higher SNF indicates a higher concentration of proteins, lactose, and minerals, contributing to milk's higher overall nutritional profile (Olsen, et al., 2023).

Density. The density of the milk samples varies between 29.73 kg/m³ (Ani milk) and 33.48 kg/m³ (Goat milk). Density is influenced by the fat content and the concentration of solids in the milk. Goat milk's higher density can be attributed to its richer composition in proteins and minerals. Density is an important parameter that influences the processing behavior of milk, such as its suitability for producing various dairy products (Magan, et al., 2021).

Proteins. Protein content in the samples ranges from 3.12% (Ani milk) to 3.48 % (Goat milk). Proteins are essential for milk's nutritional value and affect its functional properties in dairy products such as cheese and yogurt (Fox, et al., 2021). The higher protein content in goat milk suggests it may offer superior nutritional benefits, which is in line with other studies on goat milk's higher protein profile compared to cow's milk (ALKaisy, et al., 2023).

Lactose. Lactose content in the samples ranges from 4.07% (Ani milk) to 5.21% (Goat milk). Lactose is the primary carbohydrate in milk and contributes to its energy value. The higher lactose concentration in Goat milk is consistent with the overall richer composition of the milk, however, lactose content may cause issues for individuals with lactose intolerance (Lind, 2007).

Salts. Salt content in the milk samples varies from 0.69 % (Ani milk) to 0.77 % (Goat milk). Salts, primarily in the form of minerals such as calcium and magnesium, are critical for milk's nutritional properties and contribute to its flavor and preservation (Woźniak et al., 2022). The higher salt content in goat milk may reflect its richer mineral profile.

Freezing Point. The freezing point of the milk samples ranges from -0.534°C (Ani milk) to -0.606°C (Goat milk). A lower freezing point correlates with higher total solid concentrations, particularly lactose and minerals. Freezing point depression is often used to measure milk's overall quality and the concentration of dissolved solids, indicating that Goat milk has a higher concentration of solids (Kumar, 2024).

Milk's physicochemical properties, such as fat, protein, lactose, and mineral content, play a significant role in influencing its nutritional value and its applicability in managing various health conditions. Understanding the specific milk composition is crucial for the formulation of dietary interventions aimed at preventing or managing diseases. The milk samples in this study, with varying concentrations of fat, proteins, lactose, and other components, offer a valuable dataset for assessing the potential dietary impacts of milk on different health conditions.

Familial Mediterranean Fever (FMF) is a genetic disorder that is highly prevalent in Armenia (Pepoyan, et al., 2022a, 2024). During the disease, various therapeutic approaches are recommended, including the use of probiotics (Pepoyan, et al., 2023, Balayan, et al., 2023, Tsaturyan et al., 2024, Pepoyan, 2024), such as dairy-based probiotics like yogurts.

Impact of Milk on Cardiovascular Health and FMF

The fat content in milk is of particular interest when considering its role not only in cardiovascular health but also in its potential influence on FMF. Elevated saturated fat levels, commonly found in full-fat milk, have been associated with an increased risk of heart disease due to their role in raising low-density lipoprotein (LDL) cholesterol (Siri-Tarino, et al., 2010). The fat content in the samples ranged from 2.84 % to 2.99 %, which aligns with the fat concentrations typically found in commercially available cow's milk. Studies have shown that milk fat, especially in whole milk, may contribute to cardiovascular risk factors; however, emerging research suggests that dairy fat might not have as negative an effect on heart disease as previously thought (Givens, et al., 2009). Specifically, milk with a lower fat content may be more suitable for individuals managing hypertension or high cholesterol levels.

When it comes to FMF, the impact of milk is less clear. Some studies suggest that the high-fat content found in dairy products may trigger FMF attacks due to its potential to increase inflammation. For instance, in the study by Yenokyan, et al. (2012), it was found that a high-fat diet was associated with an increased risk of FMF attacks, implying that milk and other high-fat dairy products could contribute to exacerbations of the disease (Yenokyan, et al., 2012). However, other studies, such as the one conducted by Mansueto (2022), did not find a significant link between the consumption of cow's milk or breastfeeding and FMF severity, suggesting that milk may not be a primary trigger for FMF symptoms in some individuals (Mansueto, et al., 2022).

Furthermore, FMF patients who were on a strict low-fat or anti-inflammatory diet, including limited dairy intake, have shown improved responses to treatments like colchicine (Mansueto, et al., 2022). In these patients, reducing fat intake, which includes cutting back on dairy, appears to reduce inflammation and potentially ease disease flare-ups. However, the direct relationship between milk consumption and FMF remains under-researched, and further studies are needed to conclusively determine whether specific components in milk—such as lactose, proteins, or fat—contribute to FMF symptom exacerbation.

In conclusion, while the impact of milk on cardiovascular health is relatively well-documented, its role in FMF is more ambiguous. Some evidence suggests that high-fat dairy may contribute to inflammatory responses that trigger FMF attacks, but further research is necessary to understand how milk, especially low-fat varieties, interacts with the underlying mechanisms of FMF. For now, patients with FMF might benefit from monitoring their milk intake, particularly full-fat dairy products, and opting for lower-fat alternatives when managing their disease.

In this study, Yeremyan Milk and Goat Milk exhibited slightly higher fat contents, which may suggest a richer texture but also may be less favorable for individuals aiming to limit saturated fat intake for cardiovascular health.

Milk in Diabetic Diets

The carbohydrate content, primarily in the form of lactose, also influences milk's suitability for individuals with diabetes. Milk's natural lactose, which ranges from 4.07 % to 5.21 % in the current samples, is a sugar that can impact blood glucose levels. Despite this, dairy products like milk have a relatively low glycemic index (GI), meaning they do not cause significant spikes in blood sugar (Shkembi, et al., 2023). Goat milk, with a higher lactose content (5.21 %), may be beneficial for individuals with diabetes in moderation, as it is often considered easier to digest than cow's milk due to its unique protein structure. This could potentially enhance its suitability for managing blood glucose levels without causing abrupt increases in insulin levels. Additionally, proteins present in milk, which ranged from 3.12 % (Ani Milk) to 3.48 % (Goat Milk) in the study, play a significant role in slowing down the absorption of carbohydrates, thereby helping in blood sugar regulation. Higher protein content may benefit those with type 2 diabetes by improving satiety and reducing postprandial glucose levels (Minari, et al., 2023).

Bone Health and Mineral Deficiencies

Milk is a key dietary source of calcium, which is essential for bone health. The salt content in milk, which includes minerals such as calcium and magnesium, plays a significant role in bone mineralization and preventing conditions like osteoporosis. In this study, the salt content ranged from 0.69 % (Ani Milk) to 0.77 % (Goat Milk). Calcium, a major component of milk's mineral content, is particularly beneficial for preventing bone diseases such as osteoporosis, which is a concern for postmenopausal women and the elderly. Furthermore, higher salt concentrations, such as in Goat Milk, may contribute to an increased mineral profile, which could enhance the bioavailability of calcium, aiding in better bone health management. On the other hand, individuals with kidney disease or hypertension may need to limit salt intake, in which case milk with lower mineral content (such as Ani Milk) may be more suitable (Fox, et al., 2021).

Lactose Intolerance and Dairy Sensitivity

Lactose intolerance is a common condition where individuals have difficulty digesting lactose due to insufficient lactase enzyme activity. This can lead to gastrointestinal discomfort when consuming dairy products (Lind, 2007). The lactose content in the milk samples in this study varies, with Goat Milk showing the highest concentration at 5.21 %, followed by Yeremyan Milk at 5.07 %. For individuals with lactose intolerance, goat milk may still be better tolerated compared to cow's milk due to the difference in milk protein structure and fat composition. Goat milk's smaller fat globules and higher protein content can make it more digestible for lactose-intolerant individuals (Liao, et al., 2024). This may allow consumers with sensitivity to cow's milk to benefit from the nutritional advantages of dairy without the typical discomfort associated with lactose digestion.

Role of Milk in Weight Management and Satiety

The protein and fat content of milk also affect feelings of fullness and overall calorie intake, which has implications for weight management. Proteins in milk play an important role in promoting satiety, which may help in controlling calorie intake (Givens, et al., 2009). In this study, Goat Milk, with its higher protein and fat content, might be more satiating compared to Ani Milk, which has relatively lower protein and fat concentrations. Therefore, incorporating higher-protein milk types may help in reducing overall food intake and may be beneficial for individuals trying to manage their weight. Additionally, the fat content in milk can influence the absorption of fat-soluble vitamins, such as Vitamin A and D, which are important for metabolic health and immune function (Itkonen, et al., 2019).

Milk's Effect on Gut Health and Probiotic Potential

The fermentation potential of milk is also relevant for individuals looking to incorporate probiotic-rich foods into their diet. The SNF content, which includes proteins and lactose, is a key determinant of milk's ability to undergo fermentation (Li, et al., 2023). Higher SNF content, such as in Goat Milk (9.49 %) and Marianna Pasteurized Milk (9.46 %), may be more suitable for the production of probiotic dairy products such as yogurt, which are beneficial for gut health. Probiotic-rich (Pepoyan, et al., 2022b) dairy products support the balance of gut microbiota, which can influence immune function, digestion, and even mental health.

Conclusion

This study demonstrates significant variability in the physicochemical properties of milk from different Armenian manufacturers, with notable differences in fat, protein, lactose, solid non-fat (SNF), density, and other parameters. Although these differences are relatively small, they may still play a role in managing specific health conditions, such as cardiovascular diseases, osteoporosis, and lactose intolerance. The analysis of these milk samples reveals that goat milk stands out due to its higher protein, lactose, and SNF content, as well as its lower freezing point and higher density, making it a nutritionally richer option. These characteristics make goat milk a potential candidate for targeted dairy products, especially for consumers with specific dietary needs or health conditions.

The findings have important implications for the dairy industry, particularly in the formulation of milk-based products designed to address health concerns. For instance, individuals with cardiovascular disease may benefit from milk products with lower fat content, while those with osteoporosis or lactose intolerance could benefit from higher protein or lactose-free alternatives. Additionally, the higher SNF content in goat milk, which includes more protein and minerals, may provide additional nutritional benefits, particularly in managing bone health or supporting muscle maintenance.

Furthermore, processing methods such as pasteurization do not significantly alter the overall nutritional profile of milk but may influence parameters like fat content and microbial stability. The insights provided by this study can assist dairy producers in tailoring their products to meet the nutritional needs of various populations, including those managing chronic conditions like diabetes and osteoporosis. By understanding these physicochemical differences, dairy producers can optimize their product offerings to align with consumer health requirements and contribute to better health outcomes.

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Declarations of interest

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Dietary Trials and Gut Candidate Phyla Radiation Bacteria: The Effect of Placebo on the Prevalence of *Saccharibacteria* in Healthy Armenian Women and Women with Familial Mediterranean Fever

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ABSTRACT

"Candidate Phyla Radiation" (CPR) bacteria, representing ~15 % of bacterial diversity and over 70 phyla, are extremely small bacteria that primarily survive in parasitic or symbiotic forms. CPR bacteria, including Candidatus *Brownbacteria*, Candidatus *Hugbacteria*, and Candidatus *Saccharibacteria* (formerly TM7), were first identified in humans in 2007. They are linked to the microbiota of healthy and diseased individuals, being present in the oral cavity, gastrointestinal, and reproductive tracts. CPR bacteria, such as *Saccharibacteria*, are associated with dysbiotic conditions like periodontitis and can act as pathogens and potential protectors against inflammatory damage caused by host-associated bacteria.This study aimed to assess the effect of a placebo on gut *Saccharibacteria* in healthy Armenian women and those with Familial Mediterranean Fever (FMF) disease, a condition with high prevalence in Armenia and often associated with oral microbiota disturbances. Stool samples were analyzed using a culture-independent, high-density DNA microarray method, and statistical analyses were performed with Multibase 2015 Excel Add-in program (NumericalDynamics, Tokyo, Japan). Results indicate that *Saccharibacteria* respond variably to placebo depending on health status, with some showing significant quantitative or qualitative changes while others remained unchanged. In conclusion, this study confirms the presence of CPR bacteria in the gut microbiota of both healthy women and those with FMF. The distinct responses of intestinal CPR bacteria to placebo highlight the importance of placebo-controlled trials in microbiota research. Furthermore, the findings emphasize the potential role of *Saccharibacteria* in gut-brain processes and their implications in health and disease.

Introduction

Candidate Phyla Radiation bacteria, which make up about 15 % of total bacterial diversity and over 70 phyla, represent a recently discovered group. The latter show minimal functional variability and are classified as obligate fermenters. (Danczak, et al., 2017). CPR bacteria are characterized by their extremely small cell sizes, simplified genomes, and limited metabolic capabilities. They are hypothesized to survive in parasitic or symbiotic forms (Ji, et al., 2022). Examples of CPR bacteria include Candidatus Brownbacteria and Candidatus *Hugbacteria* (Danczak, et al., 2017). The presence of nirK in four *Parcubacteria* genomes, which encodes nitrite reductase, indicates the potential role of these microorganisms in the denitrification process (Danczak, et al., 2017). Some representatives found in various underground niches show potential for carbon processing, which allows them to degrade a wider range of carbon substrates compared to other CPR phyla (Danczak, et al., 2017). Certain proteins unique to CPR bacteria regulate certain cell-to-cell interactions, which are crucial for their episymbiotic lifestyle (Méheust, et al., 2019). A detailed analysis of the CPR-C4 protein has enabled the identification of a non-canonical cysteine-histidine-leucine (carbonyl) catalytic triad in this protein. Structural and functional similarities between CPR-C4 and human vaso-hemoglobins suggest evolutionary relationships (Cornish, et al., 2022).

CRISPR targeting in the *Microgenomates superphylum* has identified three phages and prophages with complete genomes. Interestingly, one of these phages encodes a Cas4-like protein. *Roizmanbacteria*, which possess CRISPR loci, include a fragmented CasY gene (fCasY). These studies on CPR bacteria expand our understanding of CasY diversity and, more broadly, provide insights into the CRISPR-Cas systems and the phages associated with CPR bacteria (Chen, et al., 2019). CPR bacteria were first identified in humans in 2007 as part of the oral microbiota (Liu, et al., 2024; Allison, et al., 2024; Hu, et al., 2024; Rajasekaran, et al., 2024; van der Ploeg, et al., 2024; Baker, et al., 2017; DeDe Kwun Wai et al., 2024). In both healthy and diseased states, the human oral microbiota is associated with CPR bacteria such as *Gracilibacteria*, *Absconditabacteria*, and *Saccharibacteria* (formerly known as TM7). Subsequently, CPR bacteria have also been described in the human gastrointestinal and reproductive tracts, indicating that these bacteria constitute a minor part of the human microbiota. The prevalence of CPR bacteria is also noted in pathological states, under dysbiotic conditions. (Naud, et al., 2022, Jaffe, et al., 2024, Zhu, H., et al., 2024). Candidatus *Saccharibacteria* are regarded as the most widespread bacteria found in the oral microbiota. (Bor, et al., 2019). They have "host" bacteria and, in fact, act as epibionts residing on the surface of the latter (Chipashvili, et al., 2021). The presence of *Saccharibacteria* is primarily associated with periodontitis, suggesting that these bacteria may act as pathogens. However, Chipashvili and co-authors also conclude that the species isolated from individuals with periodontitis may protect mammals from inflammatory damage caused by host-associated bacteria (Chipashvili, et al., 2021).

In dietary and clinical trials, the effects of nutrients or drugs on the composition and prevalence of gut microbiota and its individual members are frequently compared to the effects of a placebo, an "inert" substance (Munnangi, et al., 2023; Khneizer, et al., 2022; Gupta, et al., 2013; van de Put, et al., 2024; Staudacher, et al., 2017; Pepoyan, 2024a; Lieb, et al., 2020; Jung, et al., 2023; Pepoyan E., et al., 2024). Probiotics have become increasingly used in recent years to regulate dysbiotic conditions in organisms humans (Latif, et al., 2023; Sulaimany, et al., 2024; Tsaturyan, et al., 2022; Jan, et al., 2024; Jangi, et al., 2024; Mirzabekyan, et al., 2023; Pepoyan, et al., 2018a; Pepoyan, et al., 2009), animals (Mirzabekyan, et al., 2023; Pepoyan, et al., 2020a, b, c, d; Manvelyan, et al., 2023; Pepoyan, et al., 2023, 2024) and plants (Harutyunyan, et al., 2022). In nutritional and clinical trials involving probiotics, comparisons are also made against placebo (Kazemi, et al., 2019; Lazou-Ahrén, et al., 2024; Jukic Peladic, et al., 2021; Colletti, et al., 2023; Virk, et al., 2024).

Considering that the composition of the normal human intestinal microbiota is influenced by factors such as genetics (Goodrich, et al., 2014; Goodrich, et al., 2017; Tsaturyan, et al., 2023; Hou, et al., 2022), diet (Rinninella, et al., 2023; Martínez, et al., 2024; Zhang, 2022; González Olmo, et al., 2021), sex (Kim, et al., 2020; Fransen, et al., 2017; Tsai, et al., 2022; Pepoyan, et al., 2021; Galstyan, et al., 2008), healthy or diseased states (Belli, et al., 2023; Yeoh, et al., 2021; Borzan, et al., 2023; Hou, et al., 2022; Van Hul, et al., 2024; Afzaal, et al., 2022; Kho, et al., 2018), environmental factors (Pepoyan, et al., 2023; De Filippis, et al., 2024; Singh, et al., 2022; Jernfors, et al., 2024; Chiu, et al., 2020), and given that Familial Mediterranean Fever (FMF) is relatively common in Armenia (Balayan, et al., 2015; Pepoyan, et al., 2015a; Pepoyan, et al., 2019a, b) and that individuals with FMF often experience oral cavity-related issues (Sogur, et al., 2013; Abouzaid, et al., 2022), the aim of this preliminary study was to characterize the effect of placebo on the prevalence of *Saccharibacteria* (TM7) in the intestinal microbiota of healthy and FMF-affected Armenian women.

Materials and methods

Our previous works describe the approaches and methods (Tsaturyan, et al., 2023; Pepoyan, et al., 2015b) for conducting the present research, and the datasets are available www.ncbi.nlm.nih.gov ((GSE111835 study at: www.ncbi.nlm.nih.gov) accessed on March 16, 2008, last modified on July 16, 2018)). This method also made it possible to study differences in the relative abundance of bacterial taxa based on differences in hybridization intensity.

The bacterial analysis of stool samples was performed using the third-generation, culture-independent, high-density DNA microarray method described by Kellogg and co-authors. As a placebo, high-quality empty gelatin capsules commonly used in pharmaceutical preparations were utilized (Kellogg, et al., 2013; Pepoyan, et al., 2018b). PhyloChip™ DNA microarray, which allows the evaluation of more than 50,000 individual bacterial taxa, also made it possible to study differences in the relative abundance of bacterial taxa based on differences in hybridization intensity. Seven operational taxonomic units (OTUs) of Candidatus *Saccharibacteria spp.* in the human intestinal microbiota were analyzed using the Multibase 2015 Excel Add-in program (NumericalDynamics, Tokyo, Japan).

Results and discussions

The hybridization scores for gut Candidatus *Saccharibacteria* species (formerly TM7) were analyzed to evaluate their response to placebo administration in healthy and FMF-affected women (Table). The data indicate distinct response patterns between the two groups, highlighting potential differences in microbiota dynamics based on health status.

In FMF-affected women, no statistically significant changes in hybridization scores were observed for any strains (P>0.05) following placebo administration. Strains Str.1, Str.3, and Str.4 exhibited minimal fluctuations in scores, with values before and after placebo administration remaining comparable (e.g., Str.1: 6208±1320 vs. 6034±1297, P=0.83). Strain Str.6 showed a notable increase in intensity (3334±936 before vs. 4273±691 after); however, this change was not statistically significant (P=0.16).

In healthy women, in contrast to the FMF group, several strains demonstrated changes in hybridization scores following placebo administration: strain Str.5 showed a significant reduction in intensity after placebo (558±330 vs. 358±194, P = 0.04), indicating a placebo response, Strain Str.6 also exhibited a significant decrease in scores post-placebo administration (4609 ±1761 vs. 3346 ±1047, P=0.02). Strain Str.7 approached statistical significance (P=0.05), with a decrease in hybridization scores from 3151±1581 to 2352±784. Other strains, including Str.1, Str.3, and Str.4, showed no significant differences before and after placebo administration (P>0.05).

In summary, the stability of scores across all strains in FMF-affected women contrasts with the changes observed in healthy women, particularly for strains Str.5, Str.6, and Str.7. This divergence suggests that the gut microbiota response to placebo may depend on underlying health conditions, with FMF potentially influencing the resilience or responsiveness of Candidatus Saccharibacteria species.

At the same time, a study of the quantitative/qualitative prevalence of Candidatus Saccharibacteria in the intestinal microbiota of healthy women and women with FMF disease showed that there were no significant quantitative differences between these bacteria in the intestinal microbiota of healthy and FMF patients (P > 0.05; P values not shown in Table).

Table. The intensity of hybridization scores of gut Candidatus Saccharibacteria (former TM7) spp. before/after placebo administration in healthy and FMF-affected women*

Strains	Intensity					
	FMF women			Healthy women		
	Before	After	P before/after	Before the placebo	After the placebo	P before/after
Str.1	6208±1320	6034±1297	0.83	5254±1203	5266±992	0.29
Str.2	910±323	867±205	0.64	846±587	539±318	0.06
Str.3	202±118	402±310	0.28	1023±1499	403±633	0.12
Str.4	6178±2494	5388±2567	0.58	4244±1805	4576±1692	0.45
Str.5	422±165	438±205	0.91	558±330	358±194	0.04
Str.6	3334±936	4273±691	0.16	4609±1761	3346±1047	0.02
Str 7	3552±1793.54	2960±830	0.47	3151±1581	2352±784	0.05

*Composed by the authors.

An intriguing finding is that Saccharibacteria exhibit no significant quantitative differences in the gut microbiota between healthy women and those with familial Mediterranean fever (FMF). As previously noted, oral diseases are prevalent among FMF patients. In light of these observations, it can be hypothesized that women with FMF may experience a shift in the oral-intestinal microbiota.

Additionally, it is noteworthy that intestinal Candidatus Saccharibacteria may exhibit variable responses to placebo, contingent upon the individual's health status. This variability could potentially be attributed to the unique characteristics of the gut-brain axis in healthy versus diseased individuals.

The current study reaffirms the existence of these features and provides evidence of the involvement of intestinal Saccharibacteria in gut-brain axes. The distinctive characteristics of this relationship, influenced by the manifestations of depression in female patients with familial Mediterranean fever, have been demonstrated in our previous studies (Pepoyan, et al., 2021). Based on the findings of this study, role of basibiont bacteria of Candidatus Saccharibacteria in the gut-brain axis is also suggested. However, these hypotheses necessitate further investigation through advanced molecular biological studies, which are planned for future research endeavors.

Conclusion

Currently, microbiological research is undergoing rapid development. The advancements have led to the discovery of CPR bacteria. These bacteria were first described as "ultramicrobacteria" with cell sizes smaller than 0.1 μm^3 in 1981. CPR bacteria are predominantly found in the microbiomes of subsurface waters and are characterized by low biomass. Although CPR bacteria are relatively rare within the human microbiota and are predominantly associated with the oral microbiota, they are also present, albeit in low concentrations, as constituents of the normal intestinal microbiota. The presence of Saccharibacteria in individuals with conditions such as familial Mediterranean fever may highlight their role in mediating specific health responses through the gut-brain axis. This group of bacteria, while still under investigation, could offer insights into how gut microbiota composition influences health conditions with a neurological component. This study highlights the potential role of Candidatus Saccharibacteria in the gut microbiota, particularly in the context of FMF. Although their quantitative prevalence did not differ significantly between healthy women and those with FMF, notable differences in responsiveness to placebo administration were observed. In healthy women, certain strains exhibited significant changes, whereas FMF patients showed no significant alterations, suggesting that FMF may influence microbiota stability and responsiveness.

The findings support the potential involvement of Candidatus Saccharibacteria in the gut-brain axis, with their dynamics influenced by host health status. Additionally, the potential shift in oral-intestinal microbiota in FMF patients highlights the interconnectedness of microbiota across anatomical sites.

These results emphasize the need for further molecular studies to confirm the functional role of Candidatus Saccharibacteria in human gut and gut-brain health and their implications for conditions like FMF.

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Declarations of interest

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ՑՈՒՑՈՒՄՆԵՐ ՀԵՂԻՆԱԿԻՆ **УКАЗАНИЯ АВТОРУ** **AUTHOR GUIDELINES**

ՊԱՐԲԵՐԱԿԱՆԸ ՆԵՐԱՌՎԱԾ Է ԴՈԿՏՈՐԱԿԱՆ ԵՎ ԹԵԿՆԱԾՈՒԱԿԱՆ ԱՏԵՆԱԽՈՍՈՒԹՅՈՒՆՆԵՐԻ ԱՐԴՅՈՒՆՔՆԵՐԻ ԵՎ ԴՐՈՒՅԹՆԵՐԻ ՀՐԱՊԱՐԱԿՄԱՆ ՀԱՄԱՐ ՀՀ ԿԳՄՍՆ ԲՈԿ-Ի ԿՈՂՄԻՑ ԸՆԴՈՒՆԵԼԻ ԳԻՏԱԿԱՆ ՀԱՆԴԵՍՆԵՐԻ ՑԱՆԿՈՒՄ:

ИЗДАНИЕ ВКЛЮЧЕНО В ПЕРЕЧЕНЬ ВЕДУЩИХ НАУЧНЫХ ЖУРНАЛОВ ВАК МНОКС РА, В КОТОРЫХ ДОЛЖНЫ БЫТЬ ОПУБЛИКОВАНЫ ОСНОВНЫЕ РЕЗУЛЬТАТЫ И ПОЛОЖЕНИЯ ДИССЕРТАЦИЙ НА СОИСКАНИЕ УЧЕНОЙ СТЕПЕНИ ДОКТОРА И КАНДИДАТА НАУК.

THE JOURNAL IS INVOLVED IN THE LIST OF SCIENTIFIC PERIODICALS RELEVANT FOR PUBLICATIONS OF THE RESULTS AND PROVISIONS OF DOCTORAL AND PHD THESES AND APPROVED BY THE HIGHER EDUCATION QUALIFICATION COMMITTEE OF THE RA MoESCS.

ՀՈԴՎԱԾՆԵՐԻ ԸՆԴՈՒՆՄԱՆ ԿԱՐԳԸ

1. Հոդվածներն ընդունվում են հայերեն, ռուսերեն և անգլերեն լեզուներով:
2. Հոդվածի առավելագույն ծավալը չպետք է գերազանցի 15 համակարգչային էջը (ներառյալ ամփոփագրերը):
3. Հեղինակների թիվը չպետք է գերազանցի չորսը:
4. Հեղինակների տվյալներում պետք է ներառվեն հեղինակ(ներ)ի անունը, ազգանունը, հայրանունը, գիտական աստիճանը, աշխատավայրը, էլ. հասցեն:
5. Հոդվածը ներկայացվում է տպագիր և էլեկտրոնային (WORD ձևաչափով) տարբերակներով:
6. **Հոդվածը շարադրվում է հետևյալ կառուցվածքով.** վերնագիր, 5 բանալի բառ, «Նախաբան», «Նյութը և մեթոդները», «Արդյունքները և վերլուծությունը», «Եզրակացություն», «Գրականություն»:
7. Գրականության հղումները կատարվում են տեքստում՝ փակագծում նշվում են հեղինակը և հրատարակման տարեթիվը:
8. Հոդվածները պետք է ունենան ամփոփագրեր. հայերենով և ռուսերենով ներկայացված հոդվածների դեպքում՝ հայերեն (առնվազն 60 բառ), ռուսերեն (առնվազն 60 բառ) և անգլերեն (150-250 բառ), անգլերենի դեպքում՝ անգլերեն լեզվով (առնվազն 60 բառ):
9. Հայերեն և ռուսերեն հոդվածների վերնագրերը, հեղինակ(ներ)ի տվյալները և բանալի բառերը ներկայացվում են հայերեն, ռուսերեն և անգլերեն լեզուներով:
10. Գրականության ցանկը ներկայացվում է առնվազն 10 անուն, շարադրվում է այբբենական կարգով:
11. Մեջբերված գրականության աղբյուրների առնվազն 30%-ը պետք է հրատարակված լինի վերջին տասը տարիներին:
12. Էլեկտրոնային հղումը որպես աղբյուր մեջբերելիս գրականության ցանկում նշվում է դիտման ամսաթիվը:

Հոդվածներին ներկայացվող տեխնիկական պահանջներն են. անգլերեն և ռուսերեն հոդվածների տառատեսակը՝ Times New Roman, հայերեն հոդվածներինը՝ GHEA Grapalat, տառաչափը՝ 12, միջտողային տարածությունը՝ 1.5, վերնագիրը՝ մեծատառերով, գծապատկերները՝ Word, Excel ծրագրերով, աղյուսակները՝ ուղղահայաց դիրքով (Portrait), բանաձևերը՝ Microsoft Equation 3.0 ձևաչափով:

Կարգին չհամապատասխանող հոդվածները չեն ընդունվում: Հոդվածներն ուղարկվում են գրախոսման: Մերժված հոդվածները չեն վերադարձվում հեղինակին: Հոդվածները չեն հրատարակվի, եթե ամբողջությամբ կամ համառոտ տպագրված լինեն այլ պարբերականում:

ПОРЯДОК ПРИЁМА СТАТЕЙ

1. Статьи принимаются на армянском, русском и английском языках.
2. Объём статьи не должен превышать 15 компьютерных страниц (включая аннотации).
3. Число авторов не должно превышать четырёх.
4. В сведениях об авторах должны быть включены имя (имена), фамилия, отчество, научная степень, место работы, эл.адрес.
5. Статья представляется в печатном и электронном (в формате WORD) вариантах.
6. **Статья должна быть изложена следующим образом:** заглавие, 5 ключевых слов, “Введение”, “Материал и методы”, “Результаты и анализ”, “Заключение”, “Литература”.
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9. Заглавия, данные автора (авторов) и ключевые слова статей на армянском и русском языках представляются на армянском, русском и английском языках.
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11. Не менее 30% цитируемых литературных источников должны быть опубликованы в течение последних десяти лет.
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Технические требования к статьям: для статей на английском и русском языках – шрифт Times New Roman, для армянского – GHEA Grapalat; размер букв – 12; межстрочное расстояние – 1.5; заголовок – прописными буквами; графические изображения – программой Word, Excel; таблицы – вертикально (Portrait); формулы – в формате Microsoft Equation 3.0;

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1. The articles are accepted in Armenian, Russian and English languages.
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6. **The article should have the following structure:** title, 5 keywords, “Introduction”, “Materials and Methods”, “Results and Discussions”, “Conclusion”, “References”.
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