IMAGE: A MAP OF THE STARS OF THE ORION CONSTELLATION

JournalPreview

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 11 | Compilation 1.0

Great Britain
Journals Press

WWW.JOURNALSPRESS.COM

Journal Content

In this Issue

Great Britain Journals Press

Scan to know paper details and
author's profile

Consequences of a Rotating Universe for the Standard Model of Cosmology

Ardeshir Irani

ABSTRACT

Dark Energy from the void makes our Universe rotate. The centrifugal force due to the rotation flings galaxies in the outward direction which leads to the experimentally observed accelerated expansion of our Universe. We provide further experimental proof that out Universe is rotating which keeps it from being isotropic and homogeneous, a necessary and sufficient condition for the Cosmological Principle and the introduction of the scale factor a(t), a distance function only of time, while in fact distances measured must be functions of both time and space. This erroneous assumption invalidates all equations within the Cosmological Principle that contain a(t) and its derivatives. We point out some of these erroneous equations of the Cosmological Principle which is based on a non-rotating Universe since a Universe that is not rotating violates the Conservation of Angular Momentum Principle. Subatomic particles, atomic nuclei, planets, stars, galaxies, that are all rotating get their rotation from the Angular Momentum of the Universe.

Keywords: dark energy, rotating universe, non-isotropic universe, non-homogeneous universe, cosmological principle, scale factor a(t), conservation of angular momentum principle.

Classification: LCC Code: QB981

Language: English

Great Britain
Journals Press

LJP Copyright ID: 925621
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 11 | Compilation 1.0

Consequences of a Rotating Universe for the Standard Model of Cosmology

Ardeshir Irani

ABSTRACT

Dark Energy from the void makes our Universe rotate. The centrifugal force due to the rotation flings galaxies in the outward direction which leads to the experimentally observed accelerated expansion of our Universe. We provide further experimental proof that out Universe is rotating which keeps it from being isotropic and homogeneous, a necessary and sufficient condition for the Cosmological Principle and the introduction of the scale factor a(t), a distance function only of time, while in fact distances measured must be functions of both time and space. This erroneous assumption invalidates all equations within the Cosmological Principle that contain a(t) and its derivatives. We point out some of these erroneous equations of the Cosmological Principle which is based on a non-rotating Universe since a Universe that is not rotating violates the Conservation of Angular Momentum Principle. Subatomic particles, atomic nuclei, planets, stars, galaxies, that are all rotating get their rotation from the Angular Momentum of the Universe.

Keyterms: dark energy, rotating universe, non-isotropic universe, non-homogeneous universe, cosmological principle, scale factor a(t), conservation of angular momentum principle.

Author: Downey Research Institute, Downey, California, USA.

I. MAIN TEXT

1.1 Experimental Proof

1.) The accelerated expansion of the Universe is due to the centrifugal acceleration created by the rotation of the Universe caused by Dark Energy from the void.

2.) The dipole distortion of the CMB (Cosmic Microwave Background) temperature, which is a Picture of the birth of our 3-D Universe is shown in Figure 1. We see that the blackbody spectrum is shifted to higher brighter temperatures on the right and to lower dimmer temperatures on the left. This implies that our 3-D baby Universe was given a rotational spin in the westerly direction; counterclockwise as viewed from above.

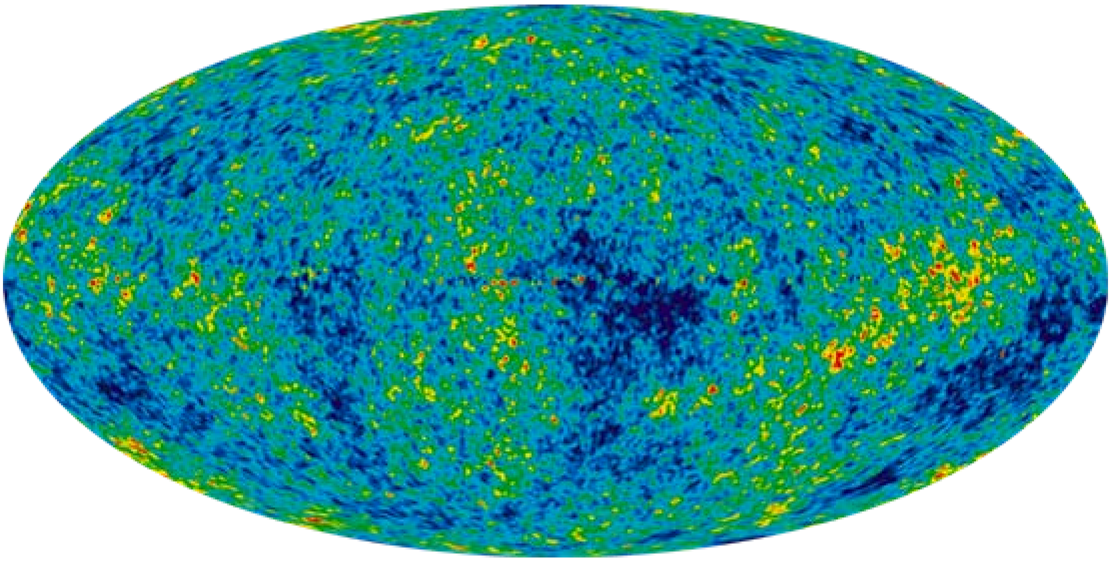


Figure 1: Cosmic Microwave Background Radiation (CMB).

3.) Everything in our universe is spinning which comes from the rotational energy of our Universe. Since our 3-D Universe is rotating in the counterclockwise direction all subatomic particles: the electron, proton, neutron, neutrino, muon, etc. are given a clockwise spin due to their inertia. Since Galaxies, Black Holes, Stars, Planets, and Subatomic particles rotate, this implies that our baby 3-D Universe was born with a rotational spin. Moreover, Stars revolve around their Galactic center while Planets revolve in orbits around their Star, and electrons revolve around the nucleus. Hence all these large and small structures have Angular Momentum due to their rotation and revolution motion. A Universe that is not rotating would have zero Angular Momentum which would go against the Conservation of Angular Momentum Principle since all matter within the Universe has Angular Momentum. The advantage of giving the Universe a spin is to keep it from collapsing on itself due to the inward gravitational force. The outward centrifugal force is greater than the inward gravitational force due to the rotational energy thereby flinging galaxies in the outward direction (Reference 1). This rotational motion is responsible for the experimentally observed outward acceleration of our 3-D Universe.

4.) Since a rotating Universe created from the Dark Energy of the void (Reference 2) has a preferred direction which is the axis of rotation, hence it cannot be isotopic. Being isotropic means that the Universe must be the same in all directions implying that it cannot have a preferred direction because only from the location of the preferred direction can it be isotropic, but it cannot be isotropic from all other locations within the Universe. Because of the rotation that causes the accelerated expansion of the Universe galaxies are being flung in the outward direction, hence our Universe cannot be homogeneous. Being homogeneous means the Universe must look the same from all points within it. The further away one goes from the axis of rotation, the more separated the galaxies become due to the centrifugal force. There is more space between galaxies further out from the axis of rotation, therefore the Universe can never be homogeneous. As secondary to the galaxies being flung in the outward direction due to the accelerated expansion of the Universe for its non-homogeneous nature, we consider the expansion of space within the gaseous region between galaxies being greater than the expansion of space inside a galaxy where matter is more solidified, just as the speed of light in air is greater than the speed of light in a transparent solid. The denser the object, the slower the speed of light and the expansion of space.

1.2 Consequences

Since the Cosmological Principle is based on the Universe being both homogeneous and isotropic at all points within it, parts of which contain the scale factor a(t) are erroneous. That is the reason the current theory of Cosmology does not give satisfactory results without Lambda (λ), but even with the inclusion of λ, it can explain in only a very small region of the energy density parameter with $\Omega_0 = 0.3$ and $\Omega_\lambda = 0.7$, several experiments (Reference 3), including the accelerated expansion of the Universe that was determined experimentally from observations of distant type 1a Supernovae, theoretical calculations for which have also been performed (Reference 4).

The Standard Model of Cosmology is built around the Cosmological Principle which leads to the scale factor a(t), a distance function only of time. Starting with the Friedmann Equation for calculating the total Energy U of the Universe, measured distances $\bar{r}$ within the Universe cannot be a function of time only but must also be a function of space since one cannot use the same scale factor a(t) at different positions of space, but that makes the mathematical calculations impossible to solve without knowing the exact nature of space at all positions within the Universe because space is not expanding at the same rate and in the same direction everywhere. *Mathematical convenience using the same* a(t) everywhere *does not prove physical reality.*

The Friedmann Equation based on the Cosmological Principle and the scale factor a(t) that it starts with are erroneous and all equations derived using a(t) and derivatives of a(t) also become erroneous. We use the equations and page numbers from "An Introduction to MODERN COSMOLOGY---Third Edition by Andrew Liddle" (Reference 5) to state all the equations below that are erroneous because they contain a(t) or derivatives of a(t). *Also, the Friedmann Equation is missing the term* $I\omega^2/2$ *for the rotational Kinetic Energy of the Universe, implying all equations derived using the Friedmann Equation would also be missing equivalent terms for rotational motion.*

Equation (3.8) Page 23: $\bar{r} = a(t)\bar{x}$ where $\bar{x}$ represents the comoving coordinate system that is carried along with the expansion of the Universe which is deemed to be uniform (a constant) because of the Cosmological Principle that depends on the Universe being homogeneous and isotropic.

Equation (3.9) Page 24: $U = T + V = m\dot{a}^2x^2/2 - 4\pi G\rho a^2x^2m/3$ where U is the total energy of the system and $\dot{a} = \frac{da}{dt}$. Note that $\dot{x}^2a^2$ has been left out of the equation since x has been assumed to have a constant value. The same term $\dot{x}^2a^2$ has also been left out of the Friedmann Equation below to simplify it.

Equation (3.10) Page 24: $\left(\frac{\dot{a}}{a}\right)^2 = 8\pi G\rho/3 - kc^2/a^2$ where $kc^2 = -2U/mx^2$ which is the standard form of the Friedmann Equation. The habit of setting c = 1 means that the Friedmann Equation is written without c in the above equation which gives us:

Equation (3.19) Page 28: $\left(\frac{\dot{a}}{a}\right)^2 = 8\pi G\rho/3 - k/a^2$. The geometry of the Universe is based on 3 values of k as stated on Page 33:

Spherical for k > 0 implies a Closed Universe.

Flat for k = 0 implies a Flat Universe.
Hyperbolic for k < 0 implies an Open Universe.

Most of the equations described below are derived by omitting x, $\dot{x}$ and $\ddot{x}$, containing only a, $\dot{a}$ and $\ddot{a}$. Unless we know all these three values of x and a, at all locations of the Universe, these equations would become impossible to solve correctly.

Equation (3.15) Page 26: $\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + p/c^2) = 0$ is the fluid equation.

Equation (3.18) Page 27: $\frac{\ddot{a}}{a} = -4\pi G(\rho + 3p/c^2)/3$ is the acceleration equation.

Equation (5.4) Page 38: Hubble's Law $\bar{v} = H\bar{r}$ becomes $H = \frac{\dot{a}}{a}$ as is being used throughout the equations below when in fact it should be written as $H = (\dot{a}x + \dot{x}a)/(ax)$. As soon as we use the incorrect value of $H = \frac{\dot{a}}{a}$, all the equations derived using H become erroneous.

Equation (5.5) Page 38: $H^2 = 8\pi G\rho/3 - k/a^2$ is the Friedmann Equation as an evolution equation for H(t). $\frac{\lambda}{3}$ is added to the above equation to include the Cosmological Constant λ as in:

Equation (7.1) Page 55: $H^2 = 8\pi G\rho/3 - k/a^2 + \frac{\lambda}{3}$

Equation (5.10) Page 39: $1 + z = \lambda_r/\lambda_e = a(t_r)/a(t_e)$ as the definition of redshift z in terms of the scale factor, and λ_r/λ_e, in this case is the ratio of the wavelength of light received at the detector and the wavelength of light emitted by the source, not to be confused with the Cosmological Constant λ.

Equation (5.12) Page 40: $\rho \propto 1/a^3$ for matter from the fluid equation.

Equation (5.18) Page 41: $\rho \propto 1/a^4$ for radiation from the fluid equation.

Equation (6.9) Page 52: $\Omega - 1 = k/(a^2H^2)$ where $\Omega = \rho/\rho_c$ is the energy density parameter; and according to which for $\Omega > 1$ (positive k) we have a Closed Universe, for $\Omega = 1$ (zero k) we have a Flat Universe, and for $\Omega < 1$ (negative k) we have an Open Universe.

Equation (6.14) Page 53: $q_0 = -a(t_0)\ddot{a}(t_0)/\dot{a}^2(t_0)$ for the deceleration parameter q_0 at the present time t_0.

Equation (7.2) Page 55: $\frac{\ddot{a}}{a} = -4\pi G(\rho + 3p/c^2)/3 + \lambda/3$ for the Cosmological Constant λ added to the acceleration equation.

Equation (13.6) Page 105: $\ddot{a}(t) > 0$ for the Inflationary Expansion of the Universe which also indicates erroneously that our Universe is flat.

Equation (A1.5) Page 122: $ds^2 = -c^2dt^2 + a^2(t)[dr^2/(1 - kr^2) + r^2(d\theta^2 + \mathrm{Sin}^2\theta d\phi^2)]$ which is the Robertson-Walker Metric.

II. CONCLUSION

Having provided experimental proof that our Universe is rotating, we have pointed out some of the incorrect equations of the Cosmological Principle based on the scale factor a(t) and its derivatives, to which must be added all others that come from the false assumption of the Universe being isotropic and homogeneous. A non-rotating Universe based on the Cosmological Principle violates the Conservation of Angular Momentum Principle. The Cosmological Principle has no experimental basis to prove its validity without Lambda, and in a very small region of the energy density parameter with Lambda, while the Conservation of Angular Momentum Principle has stood the test of time repeatedly everywhere.

REFERENCES

1. Irani, A. (2024) A Theoretical Analysis of the Acceleration and the Angular Momentum of the Universe. *Journal of High Energy Physics, Gravitation and Cosmology*, **10**, 101-105. doi: 10.4236/jhepgc.2024.101009.
2. Irani, A. (2021) Dark Energy, Dark Matter, and the Multiverse. Journal of High Energy Physics, Gravitation and Cosmology, 7, 172-190. https://doi.org/10.4236/jhepgc.2021.71009
3. Liddle, Andrew (2015) An Introduction to MODERN COSMOLOGY Third Edition, John Wiley & Sons, Ltd., Figure A2.4, Page 134.
4. Irani, A. (2023) The Accelerated Expansion of the Universe. *Journal of High Energy Physics, Gravitation and Cosmology*, **9**, 407-410. doi: 10.4236/jhepgc.2023.92028.
5. Liddle, Andrew (2015) An Introduction to MODERN COSMOLOGY Third Edition, John Wiley & Sons, Ltd., Selected Equations.

This page is intentionally left blank

Scan to know paper details and
author's profile

Ancient Vedic Mathematics: Rare Methods of Indian Mathematics

Dr Prof Avinash Challelwar

INTRODUCTION

Ancient Vedic Mathematics offers several techniques and principles that can be applied to geometry, particularly in the context of geometric constructions, measurements, and calculations. While it may not have a separate branch dedicated solely to geometry, many of its sutras (aphorisms) and methods can be used to solve geometric problems efficiently. Here are some key aspects of Vedic Mathematics about geometry:

Geometric Constructions: Vedic Mathematics provides techniques for geometric constructions, particularly those described in the Sulba Sutras, ancient Indian texts related to Vedic rituals and ceremonies. Techniques like Urdhva-Tiryagbhyam (Vertically and Crosswise) and Yavadunam Tavadunikritya Vargaancha Yojayet (Whatever the Deficiency, That Many Times the Deficiency) can be used to construct geometric shapes and structures with precision.

Keywords: NA

Classification: LCC Code: QA21

Language: English

Great Britain
Journals Press

LJP Copyright ID: 925622
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 11 | Compilation 1.0

Ancient Vedic Mathematics: Rare Methods of Indian Mathematics

Dr Prof Avinash Challelwar

Author: M Sc/Ph D/D Sc/Hon D Litt/D Div Mathematics, Researcher/Professor/Guide.

I. INTRODUCTION

Ancient Vedic Mathematics offers several techniques and principles that can be applied to geometry, particularly in the context of geometric constructions, measurements, and calculations. While it may not have a separate branch dedicated solely to geometry, many of its sutras (aphorisms) and methods can be used to solve geometric problems efficiently. Here are some key aspects of Vedic Mathematics about geometry:

Geometric Constructions: Vedic Mathematics provides techniques for geometric constructions, particularly those described in the Sulba Sutras, ancient Indian texts related to Vedic rituals and ceremonies. Techniques like Urdhva-Tiryagbhyam (Vertically and Crosswise) and Yavadunam Tavadunikritya Vargaancha Yojayet (Whatever the Deficiency, That Many Times the Deficiency) can be used to construct geometric shapes and structures with precision.

Measurement and Calculation: Vedic Mathematics offers methods for geometric measurement and calculation, such as finding areas, perimeters, and volumes of geometric figures. Techniques like the Paravartya Yojayet (Transpose and Apply) sutra can be applied to calculate measurements and solve geometric problems involving triangles, quadrilaterals, circles, and other shapes.

Geometric Proportions: Proportional reasoning is a key aspect of Vedic Mathematics that can be applied to geometry. Principles like Anurupyena (Proportionately) and Shesanyankena Charamena (The Last Digit from the Last) can be used to establish and solve geometric proportions in various contexts.

Geometric Patterns and Symmetry: Vedic Mathematics emphasizes the recognition of patterns and symmetry, which are essential in geometry. Techniques like Nikhilam Navatashcaramam Dashatah (All from 9 and the Last from 10) and Shunyam Saamya Samuccaye (When the Sum is the same that Sum is Zero) can be applied to identify and exploit geometric patterns and symmetries in problem-solving.

Geometric Transformations: Methods for geometric transformations, such as translations, rotations, reflections, and dilations, can be facilitated using Vedic Mathematics principles. Techniques like the Ekanyunena Purvena (One More Than the Previous One) sutra can be employed to perform transformations and manipulations on geometric figures.

Application to Three-Dimensional Geometry: Vedic Mathematics techniques can also be applied to three-dimensional geometry, including solid figures and spatial reasoning. Principles such as Gunita Samuchchaye (Factors the Sum) and Shunyam (Zero) can be used to solve problems involving volumes, surface areas, and other properties of three-dimensional shapes. By leveraging pattern recognition, proportional reasoning, and simplified algorithms, Vedic Mathematics provides alternative approaches to geometry that can complement conventional methods and enhance problem-solving skills in geometric contexts. The number system in Vedic Mathematics is based on a decimal system, similar to the modern decimal system used worldwide. However, Vedic Mathematics offers unique insights and techniques for performing arithmetic operations and calculations within this number system. Here are some key aspects of the Vedic Mathematics number system.

Geometric Constructions: Vedic Mathematics techniques, such as the Urdhva-Tiryagbhyam Sutra (Vertically and Crosswise), can be applied to construct geometric shapes and structures with precision. These techniques can help in laying out foundations, determining angles, and creating symmetrical designs in architectural plans.

Measurement and Calculation: Vedic Mathematics offers methods for geometric measurement and calculation, which can be useful in construction projects. Techniques for calculating areas, perimeters, and volumes of geometric figures can aid in estimating material quantities, determining spatial requirements, and optimizing space utilization.

Proportional Reasoning: Proportional reasoning, a key aspect of Vedic Mathematics, can be applied to establish and maintain harmonious proportions in architectural design. Principles like Anurupyena (Proportionately) can guide the scaling of architectural elements and ensure visual balance and coherence in construction projects.

Geometric Patterns and Symmetry: Vedic Mathematics emphasizes the recognition of patterns and symmetry, which can enhance the aesthetic appeal and structural integrity of buildings. Techniques for identifying and exploiting geometric patterns and symmetries can inform design decisions and contribute to the artistic and functional aspects of construction projects.

Calculation of Structural Parameters: Vedic Mathematics calculations can be used to determine structural parameters such as load-bearing capacities, stress distributions, and material strengths in construction. Techniques for solving linear and quadratic equations, as well as manipulation of algebraic expressions, can aid in analysing structural elements and optimizing structural designs.

Optimization and Efficiency: By leveraging Vedic Mathematics techniques for mental calculation and rapid computation, construction professionals can streamline planning, design, and execution processes. Efficient use of resources, optimal spatial arrangements, and effective problem-solving can be facilitated by applying Vedic Mathematics principles to construction projects. Integrating Vedic Mathematics calculations with modern construction practices can foster creativity, innovation, and precision in building projects.

Vedic Mathematics can be applied in various engineering disciplines due to its efficient problem solving techniques, mental calculation methods, and emphasis on pattern recognition. While it may not replace conventional engineering methodologies, it can complement them and offer alternative approaches to problem-solving. Here are some ways Vedic Mathematics can be useful in engineering:

Quick Calculations: Vedic Mathematics offers mental calculation techniques that enable engineers to perform arithmetic operations rapidly without relying on calculators or computers. Engineers can use Vedic Mathematics methods for quick estimations, feasibility studies, and initial design calculations, saving time and effort.

Optimization Problems: Vedic Mathematics principles, such as proportionality and optimization techniques, can be applied to solve engineering optimization problems. Engineers can use Vedic Mathematics to optimize parameters such as cost, efficiency, energy consumption, and resource utilization in engineering designs and processes.

Numerical Analysis: Vedic Mathematics techniques can enhance numerical analysis methods used in engineering simulations and computational modelling. Engineers can apply Vedic Mathematics principles to improve numerical stability, convergence, and accuracy in solving differential equations, linear algebra problems, and optimization algorithms.

Structural Engineering: Vedic Mathematics calculations can aid structural engineers in analyzing and designing various structural elements such as beams, columns, and trusses. Techniques for solving linear and quadratic equations, as well as manipulation of algebraic expressions, can be applied to determine structural loads, stresses, and deformations.

Electrical Engineering: Vedic Mathematics can be useful in electrical engineering for calculations involving circuits, signals, and systems. Engineers can apply Vedic Mathematics techniques to analyze electrical networks, solve circuit equations, and optimize system performance in terms of power consumption, signal processing, and communication.

Mechanical Engineering: In mechanical engineering, Vedic Mathematics can assist in solving problems related to kinematics, dynamics, and fluid mechanics. Techniques for solving equations of motion, analysing mechanical systems, and optimizing design parameters can benefit from Vedic Mathematics principles.

Civil Engineering: Vedic Mathematics calculations can be applied in civil engineering for tasks such as surveying, transportation planning, and environmental analysis. Engineers can use Vedic Mathematics techniques to perform geometric calculations, estimate quantities of construction materials, and optimize infrastructure designs.

Innovation and Creativity: By incorporating Vedic Mathematics principles into engineering education and practice, engineers can foster innovation, creativity, and critical thinking skills. Alternative problem-solving approaches inspired by Vedic Mathematics can lead to novel solutions, improved design methodologies, and more efficient engineering practices. Vedic Mathematics can play a role in research across various fields due to its unique problem-solving techniques, mental calculation methods, and emphasis on pattern recognition. While it may not be the primary focus of research endeavours, Vedic Mathematics principles and methods can complement conventional research methodologies and offer alternative approaches to problem-solving. Here are some ways Vedic Mathematics can be applied in research.

Data Analysis: Vedic Mathematics techniques can be applied in data analysis and statistical research to perform calculations, analyze trends, and derive insights from datasets. Researchers can use Vedic Mathematics methods for quick estimations, hypothesis testing, and exploratory data analysis, particularly in fields such as economics, finance, and social sciences.

Algorithm Development: Vedic Mathematics principles can inspire development of computational algorithms and optimization techniques for solving complex problems in various domains. Researchers can explore the application of Vedic Mathematics concepts in algorithm design, machine learning, and artificial intelligence to improve efficiency and accuracy in computations.

Mathematical Modelling: In mathematical research, Vedic Mathematics can offer alternative methods for solving equations, optimizing functions, and analysing mathematical structures. Researchers can investigate the applicability of Vedic Mathematics techniques in mathematical modelling, numerical analysis, and mathematical physics to address research questions and theoretical problems.

Educational Research: Education research can explore the effectiveness of integrating Vedic Mathematics principles into educational curricula and pedagogical practices. Researchers can investigate the impact of Vedic Mathematics instruction on student learning outcomes, cognitive development, and problem-solving skills in mathematics education.

Interdisciplinary Studies: Vedic Mathematics principles can be applied in interdisciplinary research projects that require mathematical reasoning, computational skills, and analytical thinking. Researchers from different disciplines can collaborate to explore the integration of Vedic Mathematics with fields such as engineering, biology, medicine, and environmental science to address complex research challenges.

Historical and Cultural Studies: Research in history and cultural studies can examine the historical development, cultural significance, and philosophical foundations of Vedic Mathematics. Researchers can investigate the historical context of Vedic Mathematics, its role in ancient Indian civilization, and its influence on mathematical thought and education.

Innovation and Problem-Solving: Vedic Mathematics can inspire innovation and creativity in research by offering alternative problem-solving approaches and mathematical techniques. Researchers can explore the application of Vedic Mathematics principles in addressing real-world problems, fostering interdisciplinary collaborations, and advancing knowledge in diverse research fields. Integrating Vedic Mathematics into research endeavours can broaden perspectives, stimulate interdisciplinary thinking, and contribute to advancements in scientific knowledge and scholarship.

The history of Vedic Mathematics traces back to ancient India, where mathematical concepts and techniques were documented in various ancient texts known as the Vedas. Here's an overview of the past and historical context of Vedic Mathematics.

Origins in Vedic Literature: Vedic Mathematics finds its roots in the Vedas, the oldest sacred texts of Hinduism, composed in ancient India between 1500 BCE and 500 BCE. Mathematical concepts and techniques are mentioned in several Vedas, including the Rigveda, Samaveda, Yajurveda, and Atharvaveda, reflecting the significance of mathematics in Vedic culture.

Sulba Sutras: The Sulba Sutras, a collection of ancient Indian texts dating from around 800 BCE to 500 BCE, contain mathematical and geometric principles related to ritualistic and architectural practices. These texts provide instructions for constructing altars and fire pits with precise geometric proportions, showcasing advanced mathematical knowledge and techniques of ancient Indian mathematicians.

Ancient Indian Mathematicians: Ancient Indian mathematicians, known as "Rishis" or sages, made significant contributions to the development of mathematical knowledge and techniques. Scholars such as Baudhayana, Apastamba, Katyayana, and others authored mathematical texts containing geometric, algebraic, and arithmetic principles used in various practical applications.

Mathematical Treatises: Mathematical treatises & texts from ancient India, such as "Brahmasphutasiddhanta" by Brahmagupta & "Lilavati" by Bhaskaracharya, further expanded on mathematical concepts & techniques. These texts covered topics such as arithmetic operations, algebraic equations, geometry, trigonometry, and numerical calculations, demonstrating the depth of mathematical knowledge in ancient India.

Transmission and Preservation: Mathematical knowledge in ancient India was transmitted orally and through written texts, ensuring its preservation and continuity over generations. Gurukuls, traditional schools of learning, played a crucial role in disseminating mathematical knowledge to students through direct instruction from gurus.

Cultural and Religious Context: Mathematics in ancient India was intertwined with religious, cultural, and practical aspects of daily life, influencing ritualistic practices, architectural designs, astronomical observations, and trade activities. The application of mathematical principles in various domains reflected the holistic worldview and intellectual pursuits of ancient Indian society. The past of Vedic Mathematics is deeply rooted in the intellectual and cultural heritage of ancient India, where mathematical knowledge flourished as an integral part of Vedic literature, religious rituals, and practical applications. Through the contributions of ancient Indian mathematicians and scholars, Vedic Mathematics laid the foundation for the development of mathematical sciences and continues to inspire inquiry, exploration, and appreciation in the modern world. In the present day, Vedic Mathematics continues to be relevant and influential, impacting various aspects of education, research, and practical applications. Here's a glimpse into the present state of Vedic Mathematics.

Education: Vedic Mathematics is taught in schools, educational institutions, and through online platforms worldwide, offering alternative approaches to learning mathematics. Educators integrate Vedic Mathematics principles into curricula, textbooks & teaching methodologies to enhance students' mathematical proficiency, problem-solving skills, and cognitive abilities.

Research: Scholars and researchers explore the mathematical concepts and techniques found in Vedic texts, studying their historical context, mathematical rigor, and practical applications. Interdisciplinary research combines insights from Vedic Mathematics with modern mathematical theories, computational methods, and scientific inquiry, leading to discoveries and innovations.

Practical Applications: Vedic Mathematics principles find applications in various fields such as engineering, computer science, finance, architecture, and decision-making. Algorithms inspired by Vedic Mathematics techniques are developed for optimization, cryptography, data analysis, artificial intelligence, and other computational tasks, contributing to advancements in technology and innovation.

Educational Outreach: Workshops, seminars, and online courses on Vedic Mathematics are conducted to raise awareness, promote learning, and foster interest in mathematical traditions and cultural heritage. Educational initiatives focus on making Vedic Mathematics accessible to diverse audiences, including students, teachers, parents & enthusiasts, through outreach programs and community engagement.

Cultural Revival: Efforts are made to preserve and revive ancient mathematical traditions and cultural heritage associated with Vedic Mathematics. Cultural organizations, institutions, and scholars promote the study and appreciation of Vedic Mathematics as part of India's rich intellectual legacy and global heritage.

Cross-Cultural Exchange: Vedic Mathematics transcends cultural and geographical boundaries, attracting interest & participation from individuals & communities worldwide. Cross-cultural exchange programs, collaborations & academic exchanges facilitate the sharing of knowledge, experiences, and insights related to Vedic Mathematics across different cultures & societies.

Innovation and Entrepreneurship: Entrepreneurs and innovators develop products, services, and applications based on Vedic Mathematics principles, catering to diverse market needs and consumer preferences. Start-ups and businesses leverage Vedic Mathematics techniques for problem-solving, decision-making, and optimization, driving economic growth and social impact. In the present era, Vedic Mathematics continues to thrive as a source of inspiration, exploration, and learning, shaping educational practices, fostering interdisciplinary research, and contributing to practical solutions and innovations in various fields. The future of Vedic Mathematics holds promise in several areas, driven by advancements in education, technology, and interdisciplinary research. Here are some potential directions for Vedic Mathematics in the future.

Integration into Educational Systems: Vedic Mathematics can be integrated into mainstream educational systems worldwide, offering alternative approaches to teaching and learning mathematics. Educators may incorporate Vedic Mathematics principles into school curricula, textbooks, and teaching methodologies, catering to diverse learning styles and fostering mathematical proficiency among students.

Technological Applications: Vedic Mathematics principles can inspire the development of algorithms and computational techniques in various technological domains. Researchers may explore applications of Vedic Mathematics in artificial intelligence, machine learning, optimization algorithms, and other computational fields, leading to innovative solutions and advancements in technology.

Cross-Disciplinary Collaboration: Vedic Mathematics can serve as a bridge between different academic disciplines, fostering interdisciplinary collaboration and research. Mathematicians, scientists, engineers, educators, and practitioners from diverse fields may collaborate to explore the intersections between Vedic Mathematics principles and their respective domains, leading to new insights, methodologies, and applications.

Cognitive Enhancement: Vedic Mathematics techniques can be leveraged for cognitive enhancement and mental agility, benefiting individuals of all ages. Programs and workshops focusing on Vedic Mathematics may be developed to promote cognitive skills, problem-solving abilities, and lifelong learning, contributing to personal development and professional success.

Cultural Preservation and Revival: Vedic Mathematics can play a role in preserving and reviving ancient mathematical traditions and cultural heritage. Efforts to study, document, and disseminate Vedic Mathematics teachings may be undertaken to preserve India's mathematical legacy and promote cross-cultural understanding and appreciation.

Global Outreach and Awareness: Vedic Mathematics can reach a wider audience through global outreach initiatives, educational platforms, and digital media.

Innovation and Entrepreneurship: Vedic Mathematics principles can inspire innovation and entrepreneurship in various sectors, including education, technology, finance, and healthcare. Entrepreneurs and innovators may develop products, services, and applications based on Vedic Mathematics principles, addressing societal challenges and creating new opportunities for economic growth and social impact. The future of Vedic Mathematics holds immense potential for education, technology, interdisciplinary collaboration, cognitive enhancement, cultural preservation, global outreach, and innovation. By embracing and exploring the rich heritage of Vedic Mathematics, individuals and communities can unlock new avenues for intellectual inquiry, creativity, and progress in the years to come. Vedic mathematics is a system of mathematical techniques that originated in ancient India, primarily found in ancient Hindu scriptures called the Vedas. These techniques cover a wide range of mathematical operations and concepts, including arithmetic, algebra, geometry & calculus. The direct application of Vedic mathematics to the golden ratio isn't explicitly discussed in classical Vedic texts.

The golden ratio, often denoted by the Greek letter phi (φ) is an irrational number approximately equal to 1.6180339887749895. It has unique mathematical properties such as being the solution to the equation $^{1+\sqrt{5}}\,_{2}$and having a significant presence in various natural phenomena and art forms due to its aesthetic appeal. While Vedic mathematics provides numerous shortcuts and techniques for performing calculations efficiently, it doesn't offer specific methods for directly dealing with the golden ratio. However, one can certainly use Vedic mathematics techniques in conjunction with principles related to the golden ratio in mathematical problem-solving or exploration. Vedic multiplication techniques could be applied to calculate products involving the golden ratio or its powers more efficiently. Additionally, Vedic square techniques might be utilized in geometric constructions or manipulations involving shapes related to the golden ratio.

This page is intentionally left blank

Development of the Industrial Complex of Kryvoryzhya: Economic Benefits, Technogenic Consequences and Environmental Problems

Nazaruk M.M. & Ostroushko M.V

National University of Lviv

ABSTRACT

The rapid economic development of Kryvyi Rih and large-scale geospatial changes in the territory are associated with the development of the iron ore basin and the development of the mining and industrial complex and ferrous metallurgy enterprises of the city.

The study aims to highlight the positive economic factors of industrial development in the region and to study the whole complex of geospatial changes in the territory. The task of the research is also to understand the negative environmental consequences and ways to solve the problems of environmental pollution.

As a result of studying historical sources and cartographic materials in the study it was possible to understand the patterns of spatial development of the city and the scale of geospatial changes in Kryvyi Rih. In the course of the work, objects of anthropogenic landscapes, water bodies and territories of industrial enterprises were studied and plotted on the city map. This made it possible to understand the peculiarities of the location, the scale of the transformation of the territory and man-made danger.

Keywords: man-made danger, mining industry, anthropogenic landscapes, quarries, stockpiles, karst landscapes, ecological condition.

Classification: LCC Code: QA21

Language: English

Great Britain
Journals Press

LJP Copyright ID: 925623
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 10 | Compilation 1.0

Development of the Industrial Complex of Kryvoryzhya: Economic Benefits, Technogenic Consequences and Environmental Problems

Nazaruk M.M.[α] & Ostroushko M.V[σ].

RESUME

The rapid economic development of Kryvyi Rih and large-scale geospatial changes in the territory are associated with the development of the iron ore basin and the development of the mining and industrial complex and ferrous metallurgy enterprises of the city.

The study aims to highlight the positive economic factors of industrial development in the region and to study the whole complex of geospatial changes in the territory. The task of the research is also to understand the negative environmental consequences and ways to solve the problems of environmental pollution.

As a result of studying historical sources and cartographic materials in the study it was possible to understand the patterns of spatial development of the city and the scale of geospatial changes in Kryvyi Rih. In the course of the work, objects of anthropogenic landscapes, water bodies and territories of industrial enterprises were studied and plotted on the city map. This made it possible to understand the peculiarities of the location, the scale of the transformation of the territory and man-made danger.

The city's enterprises have a significant impact on Ukraine's economy. The share of Kryvyi Rih in the total gross domestic product of Ukraine is 9%, national exports - 8%, total industrial production of Dnipropetrovsk region - 42.3%. More than 80% of iron ore is extracted here and 20% of Ukraine's metal is produced. [9]

As a result of open-cast iron ore mining, anthropogenic landscapes have emerged in the city, as a result of mining and quarrying, storage of waste rock and waste processing and beneficiation of minerals, the formation of underground cavities in mines, followed by their redemption and displacement of blocks of the earth's crust. Industrial landscapes occupy huge areas that can be compared with the areas of many large cities in Ukraine.

Also, the development of the industrial complex and the growing population of the city required large reserves of fresh water. And since the territory does not have large natural sources of water supply, to solve this problem, a number of reservoirs were built on the existing river network and the Dnieper-Kryvyi Rih canal was built.

Unfortunately, the development of industry in addition to the clear economic benefits brought the city a number of environmental problems and man-made hazards such as:

- *Concentration of potentially dangerous objects in the city (mines, quarries, dumps, sludge storages, waste cavities, etc.), which require annual discharge of excess return water;*
- *Formation of abysmal landscapes, which is associated with underground mining of iron ores and the displacement of adjacent blocks of native rocks;*

- *The presence of waste from the extractive industry, which is presented in the form of dumps, sludge storages, heaps and landfills, forming zones of man-made desertification, the area of which by the end of the XX century. amounted to about 8% of the total territory of Ukraine;*
- *Emissions of pollutants into the atmosphere by the enterprises of the complex, which annually amount to more than 1.5 million tons, or almost 32% of total emissions in the country;*
- *Soil pollution as a result of industrial enterprises;*
- *Water pollution by heavy metals, which occurs due to discharges of insufficiently treated water by enterprises of the mining, metallurgical and metalworking industries directly into the rivers of the region.*

Keywords: man-made danger, mining industry, anthropogenic landscapes, quarries, stockpiles, karst landscapes, ecological condition.

Author α: Doctor of Geographical Sciences, Professor Ivan Franko National University of Lviv.
σ: Master’sIvan Franko National University of Lviv.

I. INTRODUCTION

The beginning of iron ore mining on an industrial scale in Kryvyi Rih almost 150 years ago became the impetus for the rapid industrial development of the region. As a result, only during the period from the 30s to the 90s of the 20th century, Kryvyi Rih turned from a small town into an industrial giant. The Kryvyi Rih region experienced rapid economic development, but at the same time, the industrial complex fundamentally changed the landscape and led to extremely serious environmental problems and man-made hazards. Therefore, it is important to study and research the geospatial changes of the territory, environmental hazards and search for solutions to the problems.

The purpose of this study is to comprehensively highlight the positive economic factors of the development of the industrial complex of Kryvyi Rih and to study the geospatial changes of the territory as a consequence of the development of the mining and industrial complex.

The task of the research is to highlight man-made and ecological problems and the environmental impact of the industrial complex in the city of Kryvyi Rih, associated with the rapid development of the mining and industrial complex of the region.

II. THEORETICAL AND METHODOLOGICAL FOUNDATIONS OF RESEARCH

In the last decade, the interest of scientists in the study of anthropogenic changes in the territory of Kryvyi Rih and the study of mining landscapes has increased. Thus, in the article by Kazakov V.L. "On the way to a complete study of mining landscapes of Kryvbas" presents a database of the studied spatio-temporal structure of mining landscapes of the city and region. The researcher determined the objective of the work to justify the schemes of optimization of mining landscapes and their inclusion in regional eco-networks, taking into account their structure in the development of the general plan of the city of Kryvyi Rih, for the development of various directions of industrial tourism. [2]

Many scientific studies are devoted to the ecological problems of the city, in particular E.V. In the article "Environmental problems of Kryvyi Rih - state and prospects", Chasova highlighted the real state and severity of environmental hazards in the industrial city of Kryvyi Rih. [2, 3, 8]

III. RESEARCH METHODS AND DATA

In the process of this research, a number of methods were used that helped to investigate geospatial changes and the consequences of anthropogenic impact on the environment in the region. Thus, the study of historical cartographic materials and the use of modern satellite images helped to solve one of the main issues of this study - the mapping of territories with anthropogenic landscapes on the city map. In the course of field research, observations were made of a number of industrial facilities: the quarry and museum of the Southern Mining and Processing Plant, the Burshchytsky dump, the quarry dump of the Novokryvorizkiy Iron Ore Enrichment Works, the sinkhole of the mines named after Ordzhonikidze and Ternivska, mine named after Shilman, flooded quarries: № 2 Novokryvorizkiy Iron Ore Enrichment Works, Karachuniv granite quarry, Central Iron Ore Enrichment Works quarry, Hannivskiy quarry. Such observations made it possible to understand the patterns of organization and features of the spatial development of the city's industrial complex.

An important method in the study was the systematic analysis of all economic and ecological aspects of the city's industrial complex, as interconnected systems of factors affecting the territory and the ecosystem as a whole.

Comparative analysis in this study was used to compare the interaction of natural and anthropogenic factors of influence on geospatial changes of the city territory.

The principle of comprehensiveness of research is important for conducting research, which allows to develop recommendations in compliance with the requirement "not to worsen the ecological situation", to investigate the entire system, to identify its problems and to form perspectives for further research.

Mathematical methods make it possible to carry out calculations, forecasting, generalizations, and conclusions in research that cannot be obtained without a mathematical component. In research, these methods, thanks to their objectivity, allow you to compare certain objects with each other, highlight the main thing among a large amount of information, and evaluate the participation of each factor in the total amount of influences.

The method of literary sources was used in the process of collecting reference and historical material. The statistical method is the main one in the process of processing statistical materials of various information resources of the city of Kryvyi Rih and industrial enterprises. It made it possible to compile all data on the current state of the city's industrial complex and all changes in the development process.

IV. RESEARCH RESULTS

The beginning of industrial development of iron ores in 1880 was connected with the organization "Joint-Stock Company of Kryvorizki Iron Ores". Mining operations began in 1881 at the Saksahanskiy mine. In the same year, the construction of the Catherine railway began, which connected the city with the industrial regions of Dnieper and Donbas. She played a huge role in accelerating the development of industry in the region.

At the end of the 19th century the territory around the city of that time was developed extremely intensively. One by one, mines are opened, near which settlements for workers are built. In 1897, Kryvyi Rih iron ore basin took first place in ore mining in the Russian Empire, overtaking the Ural Basin. The first mine in the basin began to operate in 1886. Since then, underground mining of iron ore has continued at an increasing pace. In 1890, there were already 79 mines operating in Kryvyi Rih, and by the end of the 19th century, 266 industrial enterprises.

On June 16, 1931, Hryhoriy Ordzhonikidze, head of the Supreme Soviet of the USSR, signed an order on the construction of the Kryvorizkiy Metallurgical Plant. On August 4, 1934, the first blast furnace was launched. This day is considered the birthday of the Kryvorizhstal plant. In 1936, the construction of the Kryvyi Rih Coke Chemical Plant was completed.

In the post-war period, there was a rapid development of the industrial complex: in 1952, the Kryvyi Rih Cement Plant was created; in 1955, the first stage of the Southern Iron Ore Enrichment Works was put into operation; In 1959, factory № 1 of the Novokryvorizkiy Iron Ore Enrichment Works was put into operation; In 1961, the first stage of the Central Iron Ore Enrichment Works was built; In 1962, blast furnace № 7 (BF №7), equipped with electronic computing equipment, industrial television, was put into operation; In 1964, the first stage of the Northern Iron Ore Enrichment Works was launched; In 1965, 573 enterprises operated in the city. During the years 1960-1985, the industrial potential of the city continued to grow: in 1966, the Inhulets Iron Ore Enrichment Works was created on the basis of the Inhulets deposit of iron quartzite; In 1969, a wagon repair depot was opened; In 1970, the unique "Artem-2" mine complex was launched; after the launch of the blast furnace -8, the blast furnace shop of the Kryvyi Rih Metallurgical Plant became the largest in Europe; 1974 — the launch of the world's largest Blast Furnace-9 took place; In 1975, the “Remgormash” plant was established.

At the end of the 1960s, the city's population exceeded 500,000. The unification of workers' villages in Kryvyi Rih was facilitated by the completion of the construction of a 100-kilometer asphalt highway in 1958, which connected the city with the northern and southern mines and the settlements near them. Also, the city of Inhulets became part of Kryvyi Rih after 1963, and Terny in 1969.

As it becomes clear from the historical excursion, the city experienced rapid development with the growth of the mining industry in the 20th century.

Modern Kryvyi Rih is a large industrial city, the center of the Kryvyi Rih iron ore basin, the most important raw material base of metallurgy in Ukraine. [4]

The Kryvyi Rih industrial region plays a leading role in the economy of Ukraine and is the main raw material base for the development of ferrous metallurgy, is of strategic importance for the economic independence and security of the state. In the total gross domestic product of Ukraine, the share of Kryvyi Rih is 9%, of national exports - 8%, of the total volume of industrial production of Dnipropetrovsk region - 42.3%. [9]

More than 70 million tons of iron ore and concentrates are produced every year by metal ore mining and beneficiation enterprises. Two mines are managed by the “Evraz Sukha Balka” company, four by the Kryvyi Rih iron ore plant. More than 6.0 million tons of steel, as well as more than 5 million tons of cast iron and 5.5 million tons of rolled steel are produced annually at metallurgy and metal processing enterprises.

The construction complex is represented by organizations of various specializations: a cement-mining plant, plants for the production of reinforced concrete, local building materials, and others. The city is one of the three bases of the industrial giant “HeidelbergCement” in Ukraine.

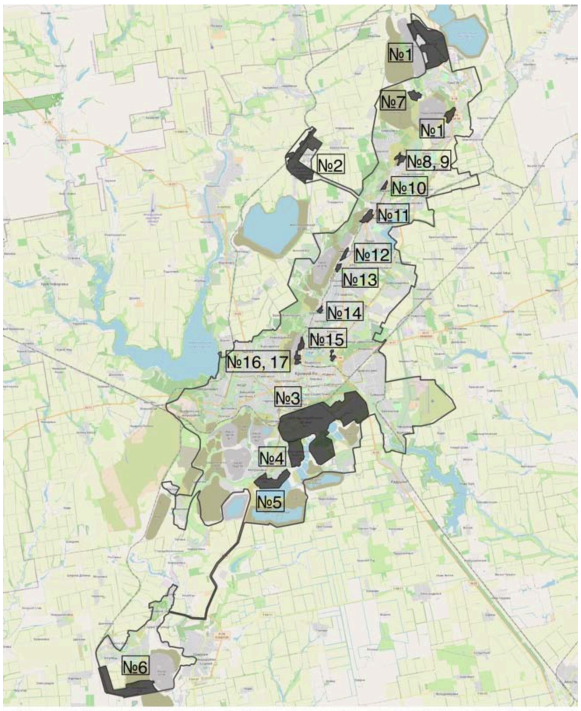
8 out of 11 Ukrainian iron ore mining and processing enterprises, as well as main production service enterprises, are located in the Kryvyi Rih Basin. Therefore, the main city-forming industry that steadily determines the city's profile in the territorial division of labor is ferrous metallurgy.

The Kryvyi Rih iron ore basin is one of the oldest and largest basins in our country. More than 80% of iron ore raw materials are mined here and 20% of Ukraine's metal is produced. Iron ore deposits of Kryvyi Rih are complex in their composition, each of them is composed of two or three types of iron ores and accompanying non-metallic minerals. The specific gravity of the mining and metallurgical complex is 86% of the total volume of industrial production in the city.

Kryvyi Rih is home to one of the world's largest metallurgical plants - "ArcelorMittal Kryvyi Rih", five mining plants - Northern, Southern, Central, Novokryvorizkiy, Inhuletsky with ten quarries with a depth of more than 300 m for open mining, three ore processing plants and other.

Preferred nomenclature: iron ore, concentrate, agglomerate, coils, cast iron, steel, ready-rolled products. The only one in the country, the Kryvyi Rih Surik Factory produces iron surik, which is in demand in Ukraine and beyond. The Kryvorizkiy Mining Equipment Plant and Kryvbasvybuhprom (enterprises engaged in explosive works) also operate in the city. [9]

(See Fig. 1)



1)Northern Iron Ore Enrichment Works; 2)Central Iron Ore Enrichment Works; 3)"ArcelorMittal Kryvyi Rih"; BF - 9; Kryvyi Rih Surik Factory; Kryvyi Rih Cement Plant; Kryvyi Rih Coke Chemical Plant; 4)Novokryvorizkiy Iron Ore Enrichment Works; 5)Southern Iron Ore Enrichment Works; 6)Inhulets Iron Ore Enrichment Works; 7)Pershotravneva Mine Management ("Pershotravneva" Mine); 8)Central Iron Ore Enrichment Works mine named after Ordzhonikidze; 9)Kryvyi Rih Iron Ore Plant mine "Ternivska"; 10)Kryvyi Rih Iron Ore Plant mine "Gvardiyska"; 11)"Evraz Sukha Balka" mine "Yuvileina"; 12)"Evraz Sukha Balka" mine named after M.V. Frunze; 13)Kryvyi Rih Iron Ore Plant mine "Oktyabrska"; 14)Kryvyi Rih Iron Ore Plant mine "Rodina"; 15)"ArcelorMittal Kryvyi Rih" N°1 named after Artema; 16)Kryvyi Rih Iron Ore Plant mine "Saksahan"; 17)Central Iron Ore Enrichment Works mine "Hihant-Hlyboka".

Fig. 1: Map of territories occupied by enterprises.

The city received an impetus for development not only because of its resource potential, but also because of its favorable geographical location. Because it is located in the very center of Ukraine and has approximately the same distance to all economically important regions of the country. This makes it possible to deliver rental cars to Donbas enterprises and ready-made products to Black Sea ports with relatively low costs. That makes it possible to reduce logistics costs in the delivery of industrial goods to the final consumer. Therefore, the city was one of the first in the Russian Empire to receive a railway connection and today has one of the most extensive networks of both passenger and industrial railway infrastructure in Ukraine. The Kryvyi Rih Directorate of Railway Transportation "Ukrzaliznytsia" is located in the city, which serves five directions and annually provides up to 17% of the national volume of all rail freight transportation. In general, the daily volume of cargo transportation is about 200,000 tons.

The city's enterprises have a significant impact on the economy of Ukraine. Thus, ArcelorMittal Kryvyi Rih is the largest exporter, 85% of finished products go abroad. The enterprise employs more than 20,000 workers according to 2019 data. The Southern Iron Ore Enrichment Works produces an average of 34 million tons of ore per year and has the largest open industrial quarry in the country and

Europe (currently the most popular object of industrial tourism in Ukraine), the enterprise employs 7,600 workers. The Novokryvorizkiy Iron Ore Enrichment Works of the deposit produces an average of 15.2 million tons of ore per year. At the Central Iron Ore Enrichment Works, mining is carried out by open-pit and mine methods, the enterprise employs a total of 4,643 workers. The Northern Iron Ore Enrichment Works is the largest mining enterprise in Europe with a complete cycle of blast furnace raw material preparation — iron ore concentrate and coils — where the deposits are mined by the open method and 5,965 workers work. The Inhulets Iron Ore Enrichment Works produces 70 million tons of ore mass annually and produces 14 million tons of iron ore concentrate, and the company also employs 4,931 workers. The Kryvyi Rih Cement Plant specializes in the production of slag types of cement and uses slag and other waste from the metallurgical industry of the Kryvyi Rih region. Sukha Balka (mine) is an enterprise specializing in underground mining of iron ore, the reserves of which have been explored to a depth of 2,060 m in the Yuvileyna mine field and to a depth of 1,500 m in the mine field named after Frunze (both mines have underground bunker-crushing complexes and surface crushing-sorting factories), the enterprise employs 3,000 workers. [9]

Since the Kryvyi Rih region is noted for its industrial component, it becomes obvious that mining activity could not pass without a trace for almost 150 years. Due to the development of open-pit mining of iron ores, today we can see the consequences of this activity in the form of quarries, dumps and sludge storages, which occupy huge areas that can be compared with the areas of many large cities of Ukraine.

In this way, anthropogenic landscapes arise as a result of open-pit and extractive mining operations, storage of empty rock and waste from mineral processing and beneficiation, the formation of underground cavities in mines with their subsequent extinguishment and displacement of forged blocks of the earth's crust. [7]

Because of this, a significant ecological and man-made problem arises in Kryvyi Rih, since the technology for processing spent sludge and waste rock is not implemented in Ukraine today. Therefore, the only way for now is to accumulate these rocks in already existing sludge storages, dumps and occupy more and more new territories with them.

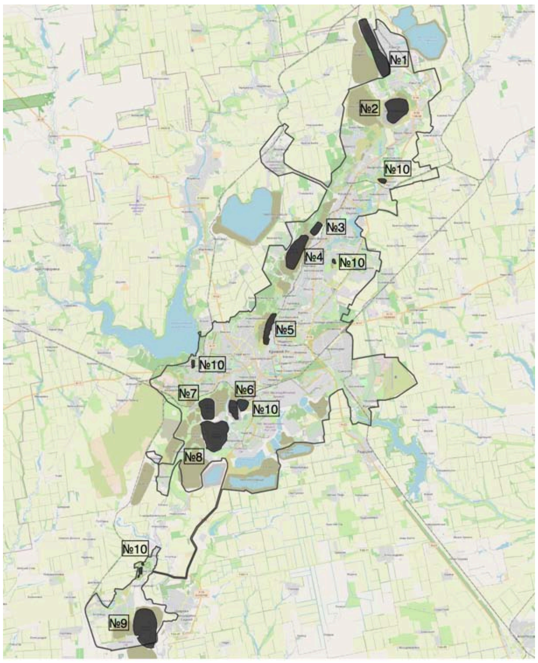
Quarries are a negative form of relief of man-made origin, within which open mining of minerals takes place. There are only 54 quarries (working and decommissioned, with re-operation) on the territory of Kryvyi Rih: 41 iron ore, 4 granite, 6 sand, 3 clay. The main condition for laying quarries is the shallow occurrence of the mineral deposit and the overlap with a small thickness of sedimentary deposits.
(See Fig. 2)

Dump mining landscapes are formed on the basis of man-made formations such as dump. Dumps are one of the main forms of anthropogenic relief, which is formed as a result of the storage of overburden on the earth's surface and the storage on the earth's surface of the by-products of mineral enrichment - slurries in the process of quarrying. Dumps are formed from "empty" and "poor" rocks that cannot be enriched. In turn, sludge occurs as a by-product of ore processing after the selection of the magnetic fraction on magnetic separators, which occurs during ore enrichment at mining and beneficiation plants. After this procedure, the sludge is pumped to sludge storage facilities where it is stored. Landfills are divided by type into sludge storage (hydraulic landfills), loose (loamy, sandy), rocky and mixed. In total, there are 104 landfills in the territory of Kryvyi Rih, ranging from low (up to 20 meters high) to very high (almost all sludge repositories with a height of 110-130 m). Landfills also vary in size from very small (up to 50 hectares) to large ones, where the area is more than 300 hectares (the area of the largest sludge storage facility of the Northern Iron Ore Enrichment Works is 1,840 hectares or 18.4 km^2). *(See Fig. 3)*

After quarries and dumps, failed landscapes represent the third group of mining anthropogenic landscapes, the emergence of which is associated with underground mining of iron ores and displacement of adjacent blocks of native rocks. There are two types of fault landscapes on the territory of Kryvyi Rih: displacement zones and fault zones (zones of the formation of troughs and depressions). There are a total of 26 such zones. *(See Fig. 4)*

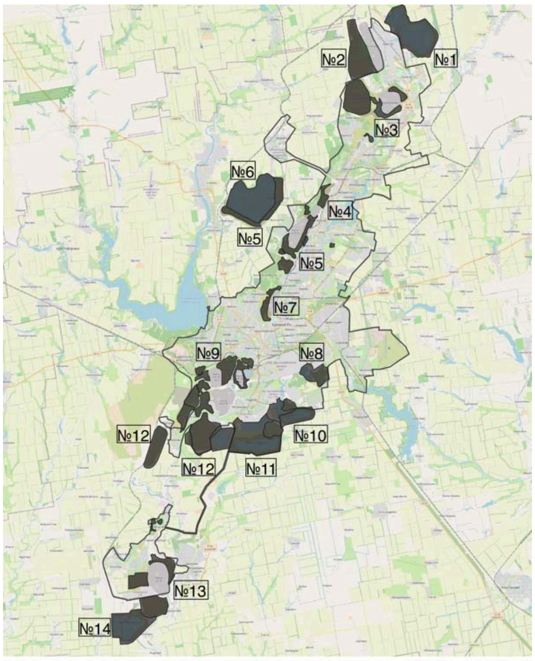
Today, the total area of mining landscapes of Kryvyi Rih is 201 km² (which can be compared with the area of the city of Lviv, which is 149 km², and the city of Odesa - 162.4 km²).

The structure of the city's mining landscapes is as follows: the area of quarries is more than 42 km²; the area of the dumps is 70 km²; sludge storage area - 55 km²; the area of mine failures and displacement zones is 34 km². The given figures are constantly changing, due to the unceasing continuation and growth of mining operations and dumping. [2, 3] *(See Fig. 5)*



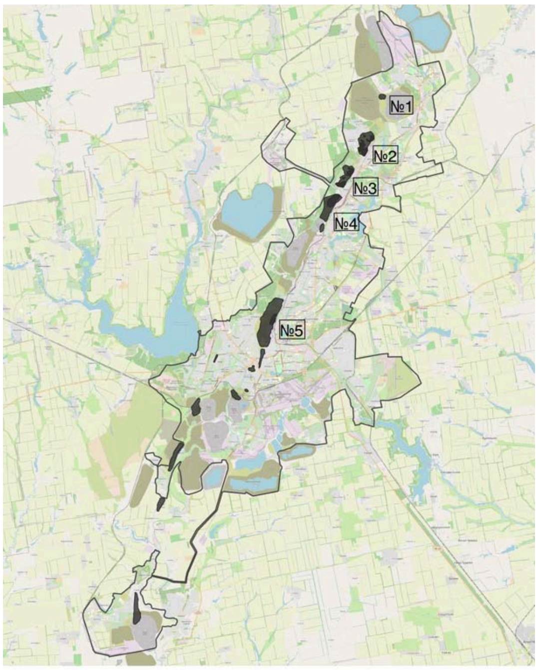
1)Hannivskiy quarry; 2)Pershotravneviy quarry; 3)Novokryvorizkiy Iron Ore Enrichment Works quarry; 4)Hleyvatskiy quarry; 5)Southern and Northern quarries; 6)№ 2 Novokryvorizkiy Iron Ore Enrichment Works quarry; 7)№ 3 Novokryvorizkiy Iron Ore Enrichment Works quarry; 8)Southern Iron Ore Enrichment Works quarry; 9)Inhulets Iron Ore Enrichment Works quarry; 10)Flooded granite quarries.

Fig. 2: Map of quarries.



1)Northern sludge storage; 2)Dump of the Hannivskiy quarry; 3)Dump of the Pershotravneviy quarry; 4) Dump of the Central Iron Ore Enrichment Works quarry; 5)Dump of the Hleyvatskiy quarry; 6)Central Iron Ore Enrichment Works sludge storage; 7)Dump of the Southern and Northern quarries; 8)Kryvyi Rih Cement Plant sludge storage; 9)Dump of the Nº2, Nº3 Novokryvorizkiy Iron Ore Enrichment Works quarries; 10)Novokryvorizkiy Iron Ore Enrichment Works sludge storage; 11)Southern Iron Ore Enrichment Works sludge storage; 12)Dump of the Southern Iron Ore Enrichment Works quarry; 13)Dump of the Inhulets Iron Ore Enrichment Works quarry; 14)Inhulets Iron Ore Enrichment Works sludge storage.

Fig. 3: Map of industrial dumps.



1)"Pershotravneva" mine displacement zone; 2)The displacement zone of the mine named after Ordzhonikidze and the "Ternivska" mine; 3)"Gvardiyska" mine displacement zone; 4)The displacement zone of the "Yuvileina" mine and the mine named after M.V. Frunze; 5)The displacement zone of the "Saksahan" mine and the "Hihant-Hlyboka" mine.

Fig. 4: Map of failed landscapes.

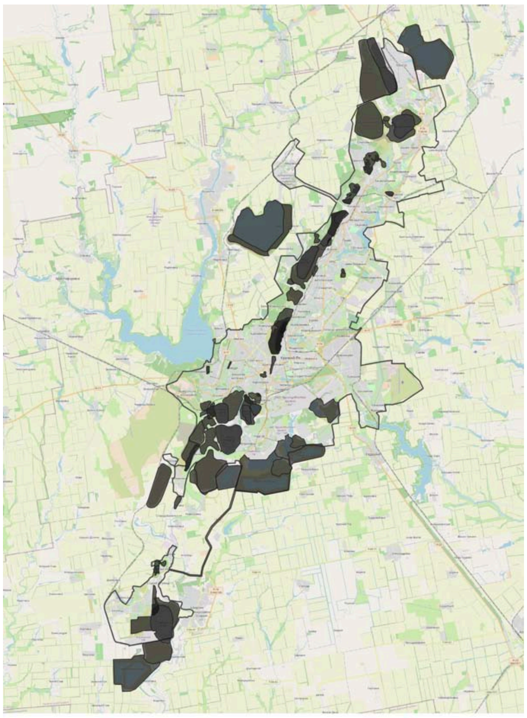


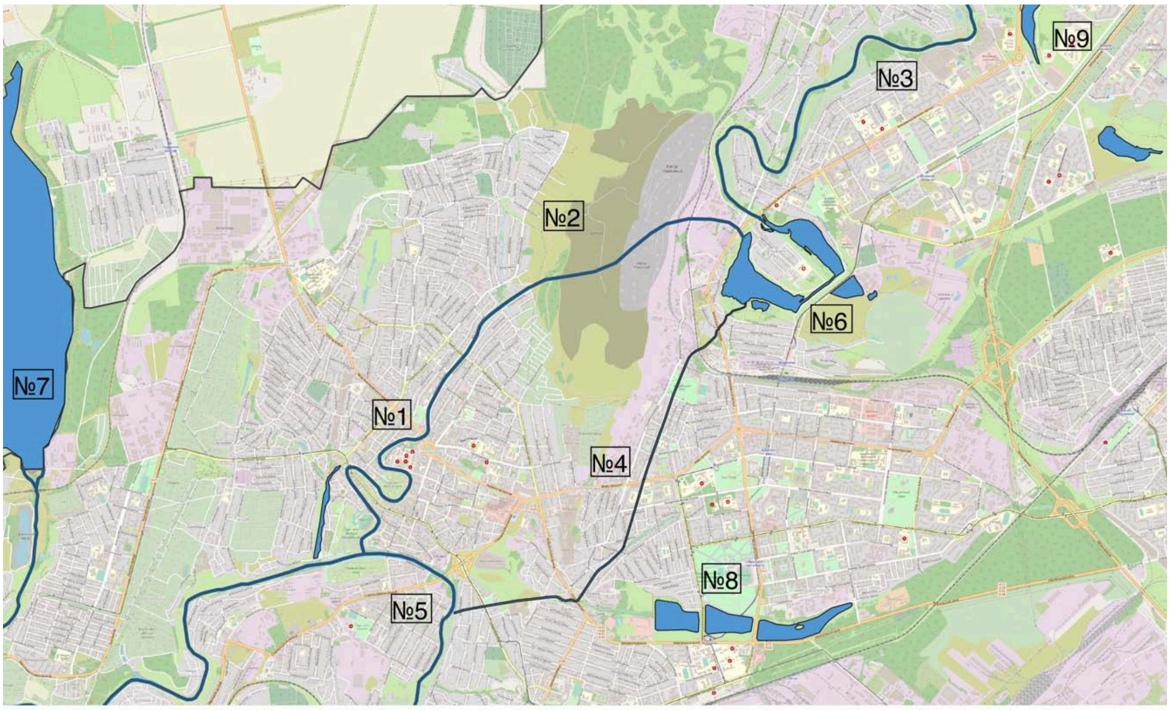
Fig. 5: Map of mining landscapes.

In order to understand the entire complex of geospatial changes of the territory of the city and the region, the issue of geographical features of Kryvyi Rih is important. The territory is located in the steppe zone and does not have large natural sources of water supply. And the development of the city's industrial complex was directly related to the creation of the necessary reserves of high-quality fresh water. This task was solved by the construction of a number of reservoirs on the existing river network and the construction of the Dnipro - Kryvyi Rih canal with a length of 41.3 km. Large-scale construction made it possible to ensure the supply of huge volumes of water for the needs of industry and the city's population.

Water supply to the city and the Kryvyi Rih region is carried out from two main sources: the Karachuniv reservoir and the Southern reservoir. There are a total of 5 reservoirs near the city, which perform different functions:

- The Karachuniv reservoir (area reaches over 36 km²) on the Inhulets river (the largest and oldest - 90 years) is used as a source of water intake, a recreation area, for fish farming, land irrigation and flood water level regulation. It was laid in 1930 in connection with the construction of the Kryvyi Rih Metallurgical Plant (now ArcelorMittal Kryvyi Rih).
- The southern reservoir was artificially created in the Taranova and Chebanka streams (the basin of the Kamianka river). It was built in 1961 to store Dnipro water, which is supplied to it by the Dnipro-Kryvyi Rih canal and is intended for drinking and domestic purposes, irrigation of agricultural land.
- The Iskriv reservoir was built in 1958. Length 35 km, width up to 1.7 km. The reservoir was built for the technical water supply of the Kryvyi Rih basin and the city of Yellow Waters, as well as for irrigation.
- The Kresiv reservoir was created on the Saksahan river at the beginning of the 20th century for a hydroelectric power plant. Water can be used only for technical purposes.
- Makortov reservoir on the Saksahan river 25 km from the town of Zhovti Vody, created in 1958. The reservoir is the first of the cascades of Saksahan reservoirs and accumulates Saksahan river runoff.

The water is used for industrial water supply of the Kryvyi Rih iron ore basin, irrigation of agricultural lands. [5]. *(See Fig. 6)*



1)The old channel of the Saksahan river; 2)Path of the Saksahan river before the construction of the South and North quarries; 3)Saksahan river; 4)Saksahansky derivation tunnel; 5)Inhulets river; 6)Saksahan reservoir; 7)Karachuniv reservoir; 8)"ArcelorMittal Kryvyi Rih" settling ponds; 9)Ponds of "Sonyachny" and "Hirnytskyi" microdistricts.

[Fig. 6]

The Saksahansky derivation tunnel was built in 1957, simultaneously with the Saksahansky reservoir. The construction of the tunnel was due to the availability of rich iron ores in the Saksahan river valley, after the diversion of the river, iron ore mining began in the newly established "Pivdenniy" quarry, located in the mine field of the mine Kirova.

The tunnel, 5.3 km long, at depths from the day surface of 24-65 m, from the Saksahan reservoir to the exit portal on the Inhulets river. The exit portal, i.e. the present-day mouth of the Saksahan river, is located 1.5 km downstream of the Inhulets river than the historical mouth.

Unfortunately, the industrial development of the region, in addition to economic and social benefits and geospatial changes of the territory, led to serious environmental consequences. Kryvyi Rih is one of the most ecologically dangerous cities in Ukraine. Mining and processing enterprises, to which the city owes its development, are also its biggest problem. The volume of products produced at the enterprises of the complex reaches 33% of the total volume of production in Ukraine, and emissions of pollutants into the air by the enterprises of the complex, according to unofficial data, annually amount to more than 1.5 million tons, or almost 32% of the total emissions in the country. From these data, it becomes clear what an extraordinary environmental load the 600,000-strong population of the industrial city and the environment receives.

Atmospheric air experiences the greatest negative impact from the activities of enterprises in Kryvyi Rih. The main pollutants are carbon monoxide (73%), dust (15%), sulfur dioxide (3%) and other harmful substances (hydrogen sulfide, ammonia, phenol, formaldehyde and others). Although official statistics emphasize the annual reduction of emissions into the atmosphere and the improvement of cleaning technologies at the enterprises of the region, in reality, public activists and independent environmentalists record repeated unauthorized emissions of harmful substances into the atmosphere and significantly higher emission rates. [8]

In July 2019, the government created the "Office of Control of Emissions into the Atmosphere" in Kryvyi Rih. The main task of this inspection is to control emissions of polluting enterprises. After all, the network of control points is located in the system of the enterprises themselves, so the real state of emissions and even the access of independent ecologists to the enterprises is extremely complicated.

The low level of efficiency in the use of subsoil and raw materials with significant volumes of its extraction led to large losses of minerals in the subsoil and the accumulation of a large amount of production waste in the form of dumps and sludges.

One of the problems is soil pollution as a result of the activities of industrial enterprises. Polluting substances enter the atmospheric air, and then settle on the ground and are washed away by precipitation within a radius of up to 5 km from a stationary source of emissions.

One of the objects of the environment, the most important for humans and at the same time the most susceptible to the influence of heavy metals, is natural water. Their contamination with heavy metals occurs due to the discharge of insufficiently purified water by enterprises of the mining, metallurgical and metalworking industries directly into the rivers of the region. Approximately half of city wastewater is discharged into water bodies insufficiently treated, of which about 15% - without treatment at all. Up to 70% of industrial wastewater is discharged without any treatment.

The Inhulets river should be noted among the most polluted rivers. The Saksahan river also suffered an irreversible negative impact. The natural regime of the river has been greatly changed by the regulatory influence of dams, the discharge of mine and industrial waters, as well as the withdrawal of water for technical needs. Also, the transfer of a large section of the river into a derivation channel led to waterlogging of the old part of the channel. Attempts to artificially feed the old channel with a pipeline from the Karachuniv reservoir did not give the desired result. Therefore, a large section of the river on the territory of the city is actually gradually becoming swampy.

A significant concentration of potentially dangerous objects on the territory of the city (mines, quarries, landfills, sludge storage facilities, spent voids, etc.), which, if groundwater pumping is stopped or reservoirs overflow, will inevitably become a source of emergency situations and man-made disasters. The lack of a real alternative to the full use or disposal of excess return water dictates the need for annual measures to discharge excess return water from Kryvyi Rih mining and ore enterprises.

The disposal of industrial and household waste is a big problem in the cities of Ukraine. The complexity of the problem is proportional to the population and industrial potential of the city. In metallurgy and thermal energy, up to 40% of the enterprise's territory is used for waste storage. As a result, unique anthropogenic landscapes are formed in close proximity to human habitation. They are due to the presence of waste from the mining industry, which is presented in the form of dumps, sludge storages, terricones and landfills, which form zones of man-made desertification, the area of which by the end of the 20th century. was about 8% of the total territory of Ukraine. Even according to official statistics, emissions of harmful substances amount to more than 395,000 tons - 590 kg per person. But independent experts talk about exceeding these data several times. Also, almost 9 billion tons of industrial waste have accumulated at the enterprises of the region, which causes the clogging of huge areas of fertile land.

In the process of production activities of Kryvyi Rih enterprises, more than 169 million m3 of industrial waste is generated annually, which is taken to landfills and sludge storage facilities, where more than 2.5 billion m3 of enrichment waste is already stored; they cover an area of about 16,000 hectares. This means that huge areas of fertile land are lost forever, and the area of these objects will increase every year. It should be noted that these objects also have a negative impact on the environment, as they pollute huge areas of agricultural land and residential areas. [8]

The main polluting enterprises are located in the immediate vicinity of residential areas, since historically urban residential buildings were formed for the needs of each enterprise.

Mining of ore in the subsoil, pumping of underground water, a huge amount of artificial sediments created by man - cause changes in the geological structure, which cause an increase in the man-made crisis.

The city's environmental program provides for industrial enterprises to modernize existing production facilities and dust and gas treatment plants, build new efficient dust and gas collection systems, as well as a set of dust suppression measures at landfills, sludge storage facilities, product warehouses, industrial sites, highways, streets of residential areas in the area of industrial activity including the use of binders, as well as cooperation with specialized scientific organizations on the development, review and implementation of new technologies for dust suppression, including "green technologies". But all the measures envisaged by the program require constant state control. [1].

The city experienced rapid economic development in the 20th century. from a town of 20,000 people, it grew into a large city, which at the beginning of independence reached almost a million people. Industrial development became the impetus for the development of residential construction and the unification of many towns of Kryvyi Rih agglomeration into a large city, which is the longest in Ukraine and Europe.

During the Soviet era, all giant enterprises such as "ArcelorMittal Kryvyi Rih" and 5 Iron Ore Enrichment Works emerged, which became the largest mining and metallurgical enterprises of Ukraine. This led to the development of railways, road and air routes.

What became a decisive factor for the rapid development of the city. Today, Kryvyi Rih is the "metallurgical capital of Ukraine", one of the largest cities and has great prospects for development and improvement of the standard of living. The city has one of the lowest unemployment rates.

But at the same time, the city's enterprises are among the biggest air polluters in Ukraine, which have a negative impact on the air, rivers and fertile soils of the region. Due to the unsatisfactory condition of the components of the natural environment, the incidence of lung diseases and cancer in Kryvyi Rih residents is very high.

The industrial landscapes formed as a result of iron ore mining and processing carry a potential man-made danger and require a constant search for solutions for their reclamation, conservation and disposal of production waste.

Although dust and gas capture systems have been used in recent decades, and the rates of extraction and processing have decreased, thereby reducing the impact on the environment, the ecological situation in the city is very complex and requires constant monitoring by state environmental inspections and the public.

REFERENCES

1. Environmental passport of the city of Kryvyi Rih, 2017, pp. 32-35;
2. Kazakov V.L. Anthropogenic landscapes of Kryvbas // Diversity of landscape complexes of Ukraine and ways of their rational use and conservation: methodological and applied aspects. Coll. of science works of sciences conf. - Kyiv, 2000. - p. 41-46;
3. Kazakov V.L., Gerasimchuk O.O. Underground mining landscapes of the Kryvbas mine as an object of study of anthropogenic landscape science: statement of the problem // Geographical studies of Kryvbas. Vol. 3. - Kryvyi Rih: KDPU, 2008. - p. 6-13;
4. Ostroushko M.V. To the history of the formation of water supply and drainage systems in Kryvyi Rih // XVI All-Ukrainian scientific Taliiv readings - Kharkiv - 2020 - p. 99;
5. Ostroushko M.V. Surface water as a factor in the formation of geospace in the city of Kryvyi Rih // City development strategy: youth and the future (innovation elevator): materials of the International Scientific and Practical Conference - Kharkiv - p. 355;
6. Smetana M.G., Provozhenko T.A. To the classification of anthropogenic landscapes of Kryvbas // Environmental protection: ecological, medical, educational aspects. Mater. 2nd All-Ukrainian conf. - Kryvyi Rih, 1997. - p. 3-5;
7. Tobacconist Yu.G. Identification, structure and classification of landscapes of urbanized territories // Geogr. and nature resource. - 1991. - No. 3. - p. 22-28;
8. E.V. Temporarily. Ph.D. chemical of Science, Assoc., V.V. IVCHUK, senior lecturer of Kryvyi Rih National University, Environmental problems of Kryvbass - state and prospects.
9. https://ig.krmisto.gov.ua/ua/citycard/econ.html.

Scan to know paper details and
author's profile

Role of Arbuscular Mycorrhizal Fungi in Plant Tolerance to Sub and Supra-Optimal Temperature Stress

Parashuram Bhantana, Muhammad Shoaib Rana, Sujan Pathak, Shree Prasad Vista, Rajesh

Huazhong Agricultural University

ABSTRACT

Plant fitness, development, and survival are significantly influenced by different environmental factors including extreme temperature regimes. The roots of the majority of terrestrial plant species can establish mutually beneficial with arbuscular mycorrhizal fungi (AMF), and AMF symbiosis can lessen the harmful effects of sub- and supra-optimal temperature stress on plants. AMF plants produce more biomass under heat stress than their untreated counterpart. Plants colonized with AMF have improved vigor, productivity, and fruit quality under heat stress. Temperature stress causes physiological disorders and excessive production of reactive oxygen species (ROS) that disturb the delicate equilibrium between the production of ROS and plants' antioxidative capacity to remove ROS, leading to detrimental oxidative reactions such as protein oxidation and membrane lipid peroxidation. Symbiotic relationships between plants and AMF can enrich the ROS-antioxidant shield pathway, which eventually enhances plant stress tolerance. In this chapter, we summarize the role of AMF in plant tolerance to sub- and supra-optimal temperature stress. We focus on underlying molecular mechanisms and propose that further molecular knowledge of the precise kinetics of ROS metabolism in plant-mycorrhizal interactions is essential to increase plant production under challenging thermal environments.

Keywords: AMF, colonization, *Rhizophagus intraredices,* heat stress, cold stress, climate change, *Piriformospora indica.*

Classification: FOR Code: 060704

Language: English

Great Britain
Journals Press

LJP Copyright ID: 925624
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 11 | Compilation 1.0

Role of Arbuscular Mycorrhizal Fungi in Plant Tolerance to Sub and Supra-Optimal Temperature Stress

Parashuram Bhantana[1,4, 6,7*], Muhammad Shoaib Rana[2,6,7], Sujan Pathak[3] Shree Prasad Vista[4], Rajesh Jha[5] & Chengxiao Hu[6,7*]

ABSTRACT

Plant fitness, development, and survival are significantly influenced by different environmental factors including extreme temperature regimes. The roots of the majority of terrestrial plant species can establish mutually beneficial with arbuscular mycorrhizal fungi (AMF), and AMF symbiosis can lessen the harmful effects of sub- and supra-optimal temperature stress on plants. AMF plants produce more biomass under heat stress than their untreated counterpart. Plants colonized with AMF have improved vigor, productivity, and fruit quality under heat stress. Temperature stress causes physiological disorders and excessive production of reactive oxygen species (ROS) that disturb the delicate equilibrium between the production of ROS and plants' antioxidative capacity to remove ROS, leading to detrimental oxidative reactions such as protein oxidation and membrane lipid peroxidation. Symbiotic relationships between plants and AMF can enrich the ROS-antioxidant shield pathway, which eventually enhances plant stress tolerance. In this chapter, we summarize the role of AMF in plant tolerance to sub- and supra-optimal temperature stress. We focus on underlying molecular mechanisms and propose that further molecular knowledge of the precise kinetics of ROS metabolism in plant-mycorrhizal interactions is essential to increase plant production under challenging thermal environments.

Keywords: AMF, colonization, *Rhizophagus intraredices,* heat stress, cold stress, climate change, *Piriformospora indica.*

Corresponding Author 1: Agricultural Research Station, Nepal Agricultural Research Council, Pakhribas, Dhankuta, Nepal. *emails: hailstormsea@gmail.com/hucx@mail.hzau.edu.cn*
2. Corteva Agriscience Pakistan.
3. National Key Laboratory for Germplasm Innovation & Utilization of Horticultural Crops, College of Horticulture and Forestry Sciences, Huazhong Agricultural University, Wuhan 430070, People's Republic of China.
4. National Soil Science Research Center, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal.
5. Faculty of Agriculture, Farwestern University, Tikapur Kailali, Nepal.
6. Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River), Ministry of Agriculture and Micro-elements Research Center, College of Resource and Environment, Huazhog Agricultural University, Wuhan, Hubei Province 430070, People's Republic of China.
7. Hubei Provincial, Engineering Laboratory for new fertilizers, Huazhong Agricultural University, Wuhan, Hubei Province 430070, People's Republic of China.

.

I. INTRODUCTION

Plant growth environments significantly stimulate plant fitness, development, and survival. Symbiotic microorganisms, like arbuscular mycorrhizal fungi (AMF), colonize plant parts in various habitats, enhancing mineral and water availability and environmental tolerance in plant-dwelling species.Additionally, AMF symbiosis changes the connection between plants and water in both drought-stressed and well-watered environments and AMF can even increase the productivity of colonized plants under sub and supra optimal temperature stress (Duc et al., 2018). A number of machineries were displayed to be and by AM to water deficits in AMF plants, including improved stomatal conductance, enhanced water use efficiency, and lower oxidative damage due to higher enzymatic antioxidant activities and non-enzymatic antioxidant levels. Additionally, AMF change the levels of phytohormones such as abscisic acid and jasmonic acid (JA) as well as the proline content in the host plants.

There are still few studies on AMF plants in the context of high temperatures, in contrast to the many reports of AMF plants that are stressed by drought. Several studies have found that AMF colonization can lessen the detrimental effects of temperature stress on plants like rice, wheat and maize(M adouh and Quorreshi, 2023). It was also observed that AMF plants produced higher biomass when under heat stress in comparison to untreated counterpart (Duc et al., 2018).Mycorrhizal plant diversity, intensity and proportion of colonized roots all increase with soil temperature (Heinemeyer and Fitter, 2004). The inoculum potential of Montana AMF is higher in cold soils than that of Syrian AMF. Harmal, a cultivar chosen from the Syrian barley land races, showed the highest mycorrhizal fungal colonization among the cultivars tested Inoculation of AMF to barley increased yield in increasing soil temperature Based on the proportion of mycorrhizal roots and the sum of mycorrhizal plants, barley genotypes were distinguished in a warm soil. From the viewpoint of showing germplasm for mycorrhizae, however, a bigger amount of plants can be judged for the occurrence of a characteristic arbuscule than for the percentage of mycorrhizal roots in a specific time period (Grey, 1991). AMF native communities and isolates from cold climates, in particular the external mycelium, have been demonstrated to exhibit severe growth reductions below 20ºC in studies. Earlier it is observed that local warming of the extraradical mycelium from 12ºC to 20ºC improved hyphal growth in a system where both the plant and the fungus were exposed to the warming treatment (Gavito and Azcon-Aguilar, 2012). Raising the temperature had minimal effect on the growth of one isolate of *Glomus. mosseae* outside of its stimulating effect on the host plant (Gavito and Azcon-Aguilar, 2012). *G. proliferum*, however, exhibited three phases of growth: no enlargement at 6°C or 12°C; a rise between 12°C and 24°C; and a drop between 24°C and 30°C. Up to 30°C, *G. intraradices* extraradical mycelium mass continuously grew. Effects on root length were highly related to how temperature affected the growth of AMF isolates (Gavito et al., 2005). Also the advance of the fungus *G. intraradices* is in three phases low at 6°C and 12°C, peaking between 18°C and 24°C, declining at 30°C (Gavito et al., 2005). However, to the date, studies about how AMF starts to develop and function when soil temperatures are either low (10ºC) or high (>30ºC) for prolonged periods of time during the growth season are scant. It is significant to note that there is currently little work has been done on the study of mycorrhizal plants under sub and supra optimal temperature stress. So this study is designed to extrapolate how plant, AMF and growth environment for instance temperature interact each other and help successfully tolerate the sub and supra optimal temperature situations.

How the consequences of climate change will change mycorrhizal plant-fungal interactions is a significant problem for mycorrhizal research in the new millennium. The physiology of mycorrhizal fungi as well as the species mix of these underground communities may be impacted by global temperature change, either directly or indirectly (such as hyphal development, sporulation, and nutrient uptake). Soil moisture and temperature are unquestionably two of the most crucial factors, even if other factors comprising plant nutrients, light intensity, and plant community composition have also been suggested to affect the growth of AMF and the establishment of mycorrhizae. It has been demonstrated that rising soil temperatures encourage the expansion of extraradical mycorrhizal hyphae, the length of mycorrhizal roots, and fungal structures in both soil and plant roots. Modifications in precipitation and soil moistness can also affect the composition of the litter and the quantity of fungi. The competitive dynamics among diverse AMF species and the composition of AMF communities may be affected by global warming and accompanying changes in precipitation patterns because different fungal species may need different temperatures and amounts of moisture for optimal growth (Feng et al., 2013). There will be obvious changes as a result of localized climate change, but it is not yet apparent how these changes will affect the argument and storage of carbon in terrestrial ecosystems. A healthy carbon cycle depends on plant communal and plant throughput composition, but soil and soil microbe responses to climate change might also be very important. Because dirt are expected to store roughly 1500 Pg of organic carbon in the upper layer, more than double what plants produce, even a very insignificant adjustment in the fraction of stored soil carbon can have a significant effect. It has been proposed that over the past 25 years, soil carbon losses may have significantly exceeded any native sinks in the temperate ecosystems (Hawkes et al., 2008).

Under more sustainable agricultural management practices, AMF are anticipated to play a larger role in the operation of biomes and the cycling of nutrients (Barrett et al., 2011). AMF are important symbionts of various plant species because they facilitate root access to soil derived nutrients. There are many factors that influence how AMF symbioses with plants are established. A particular AMF species can settle a wide-ranging range of plant species, although the intra- and extra-radical hyphal density and the number of spores produced can differ significantly depending on the kind of plant. The occurrence of AMF may also directly or indirectly have an effect on the larger soil microbial community by impacting nutrient availability and by influencing root characteristics like water uptake and rhizosphere carbon flux. For instance, the generalist AMF's potential for colonization is significantly influenced by the identity of the host plant (Arruda et al., 2021). Knowing soil affect studues working of mycorrhiza under climate change may have a greater influenc on study studies on has been done on the impact of elevated CO_2 than the impact of temperature on AMF performance. However, it is difficult to predict AMF to colonize the roots due to insufficient root zone temperatures, mycorrhizal benefits may still be essential for phosphorus acquisition (Carvalho et al., 2015). By growing increasing the activity of antioxidant enzymes in the leaves and roots, both fungal symbionts *Septoglomus constrictum* and *S. deserticola* were able to lessen oxidative stress. However, similar benefits in plants that also contained *S. deserticola* were not immediately apparent (Duc et al., 2018). The inoculation of AM fungus also boosted the activity of the enzymes superoxide dismutase (SOD), ascorbate peroxidase, and ascorbic acid in the leaves of heat-stressed cyclamen plants, according to investigations (Matsubara et al., 2014; Maya and Matsubara, 2013). The quantities of the antioxidant enzymes peroxidase (POD),SOD, and catalase (CAT), as well as the concentrations of the soluble sugars in the roots and leaf proline, varied in maize AM plants during temperature stress. Recent research under heat stress showed that AMF wheat produced more grains, modified the way nutrients were distributed, and altered the nutrient makeup compositions of the tiller (Duc et al., 2018). Earlier findings verified that mycorrhizal inoculations did not affect the physiological characteristics in non-stress environments. Yet, by decreasing lipid peroxidation level and H_2O_2 accumulation and improving the effectiveness of reactive oxygen species (ROS) scavengers, immunization treatment with *S. deserticola* and *S. constrictum* could the defense of plants against oxidative stressors (higher POD, SOD, and CAT activities in roots and leaves, as well). *S. constrictum* inoculated plants were more resistant to oxidative stressors. Heat stress was the primary stressor for this study, and mycorrhizal plant reactions to heat stress and drought were equivalent to those under heat. The host plants' stomatal conductance, water status (higher leaf water potential and relative water content), maximum PSII efficiency (raised Fv/Fm), and biomass production increased as a result of mycorrhization by *S. constrictum*, but these improvements were less pronounced in plants inoculated with *S. deserticola* (Duc et al., 2018).

It is uncertain how temperature impacts the carbon cycle, AMF, and plant performance. Yet, the factor of environmental change that may have the biggest direct effect on these fungus is temperature. In this crucial and increasingly relevant environment, it has become necessary to examine and appreciate the potential stimulations or constraints that the rapidly shifting temperatures may impose on these symbiotic fungi. The majority of other species are generally thought to have evolved to grow and function under the local climatic conditions or to persist by only developing sometimes when specific favorable conditions occur. It is unknown which sort of organisms make up the common of AMF species or ecotypes, or both. But it is largely accepted that AMF have evolved to grow in the majority of global ecosystems and can function in a wide range of temperatures since they are so prevalent (Gavito and Azcon-Aguilar, 2012).Here, we have looked at how soil temperature affects the carbon cycle as it is facilitated by plants and AMF. The questions we precisely addressed were whether the effects of soil temperature on AM fungi happened independently of effects on the plant, how soil temperature affected intra- and extraradical AMF structures, and how it affected the rate and extent of carbon movement through roots and AMF. To this goal, we looked at the carbon pools and fluxes for roots and fungi combined and fungi alone. Root-free compartments were retained both close to and far from the root system in order to understand how temperature affects the growth and size of the extraradical hyphal network. In order to isolate the effects of soil temperature, we adjusted the temperature below ground but not above it, and we maintained a consistent soil moisture level across all temperature treatments (Hawkes et al., 2008).

1.1 Arbuscular Mycorrhizal Fungi And Plant Tolerance To Sub -Optimal Temperature Stress

A fundamental temperature below which no physiological action occurs must be taken into consideration. The host plant species, however, may or may not be taken into consideration when establishing the base temperature for colonization development. It follows that the plant controls how temperature affects the fungus's ability to grow as the base temperature varies depending on the type of plant. However, the root zone temperature affects AM initiation rather than the fungus (Carvalho et al., 2015). Three different isolates of *Funneliformis mosseae* collected from Finland, Denmark and Spain displayed reduced development, and in particular, very little external mycelium growth between 6 and 12ºC, regardless of the temperatures they generally experienced in their natural environments. Also, they all had a similar pattern of growth with rising soil temperature. These results suggest that AMF have a little window of opportunity to thrive in cold areas when temperatures are frequently below 15ºC. This window should be fully utilized, especially in agroecosystems where management is concentrated on improving crop yield and soil quality. If mycorrhizal development and benefit are properly managed in cold regions and temperatures rise, they may also increase (Gavito and Azcon-Aguilar, 2012). The Gavio Azcon Agquilar thory suggest that C mobility was involved in AMF's response to temperature changes was supported by the variations seen in root-C uptake and C translocation in the fungus. Low temperatures did not appear to have an adverse effect on the transportation of other nutrients, as evidenced by the fact that temperature had an effect on C movement to the fungus but not on root P uptake or P translocation. Another study's findings in that temperature range support the notion that there are no temperature-related effects on P absorption, translocation, or transfer between 10 and 25°C (Gavito et al., 2005).

The effect of freezing soil temperatures on mycorrhiza growth has practical implications when assessing the potential benefits of the symbiosis within agricultural systems. Since they may adversely affect the colonization of roots by AMF. Because only roughly one third of the Earth's land surface is covered by soils with mean annual temperatures above 15°C, it is crucial to comprehend the effects of suboptimal root-zone *temperatures*. Several host plant species have reported a range of minimal temperatures that preclude AMF colonization, including 5ºC for wheat and barley, 10 to 12ºC for subterranean clover and 15ºC for soybean. AMF colonization may still take place, even if the soil temperature never rises over 5°C. Contrastingly, a deleterious relationship was detected between soil temperature and AMF, when the soil temperature was between 4 and 16°C. The levels of colonization in natural ecosystems can be significant throughout the winter. The AMF's biological variability, the presence of mycorrhiza in many ecoregions, and the capability of spores to sprout in cool settings all strongly imply that the smallest temperature for foundation It is widely known that strigolactones and flavonoids contained in plant root exudates are essential for plant communication and mycorrhizal establishment. Maize's root shape was more influenced by inadequate root temperatures than wheat. Hence wheat was less affected by chilly temperatures. Here cool temperatures may mark root exudates by changing both plant activity and the structure of the root system (Carvalho et al., 2015). The extraradical mycelium was found to be more sensitive to low temperatures than the intraradical mycelium, contrary to the common belief that the intraradical and extraradical mycelium develop in proportion. The latter developed significantly below 5°C, but the former was typically unable to develop below 15°C. It is important to continue researching this distinct reaction since it could have significant effects on how to understand the AM symbiosis (Gavito et al., 2005). The properties of low temperatures on C uptake by modified roots have not been examined, despite the fact that many plants are known to absorb less ions and water at low temperatures. This information was deemed unnecessary in the vast majority of earlier research that used this system (Gavito et al., 2005). The capacity of sink organs to absorb nutrients and the capacity of source organs to supply nutrients both work to limit yield. Therefore, any modification to the source-sink relationship, such as a change in how nutrients are delivered from source to sink or how carbon (C) is partitioned, will have an effect on the final yield. Reduced carbon (C) absorption and altered nitrogen (N) redistribution and partitioning during heat stress can affect source-sink relationships. Additionally, it has been observed that the C sink strength of the AM symbiosis increases the photosynthetic rates. In order to offset the costs of the symbiosis, the improved C fixation improves "photosynthetic nutrient utilization efficiency," modifies source-sink interactions in the plant, and inspirations subsequent invention (Cobral et al., 2016). Mycorrhizal roots may hold more solvauble sugar and starch than non-mycorrhizal roots even when respiration is high because the host plant's photosynthetically secure carbon was moved to the AM fungus. These improved levels of carbohydrates are employed by both the respiration of the roots and the transfer to AMF for the nutrition interchange between the two symbiotic sides. Soluble sugar and starch, which are the main carbohydrates produced during photosynthesis, are important substrates for respiration (Liu et al., 2014a).

1.2 Role of arbuscular mycorrhizal fungi in plant tolerance to sub -optimal temperature stress

Cold stress, a significant abiotic contrain, has a detrimental influence on the productivity and development of many agricultural products crops on a global scale. During cold stress plant metabolism is impaired, cell membranes become hard and lose their ability to function, proteins and solutes leak out, sugar metabolism is reduced, and reproductive ability is lost. So it is necessary to create methods that can assist plants withstand harsh weather without reducing their productivity. There has been a lot of interest in this area on the use of AMF for minimizing cold stress in plants (Devi et al., 2019). Most studies revealed that intraradical mycorrhizal colonization increased as temperature rose between 5ºC and 37ºC. Although some early studies suggested that native AMF isolates would be able to adapt to withstand extreme temperatures in their environment. Symbiotic efficacy, extraradical hyphae development, and root colonization were all hampered by low temperatures (5ºC–15ºC). Unfortunately, the fact that few of those studies looked at how both the intraradical and extraradical phases developed limits our understanding of the mycorrhizal mycelium's temperature dependence (Gavito and Azcon-Aguilar, 2012). The results provided conclusive evidence that the AMF isolates had not developed any tolerance to cold soil temperatures. Nonetheless of the temperatures they typically practiced in their new territories, these three isolates of the same AMF species displayed low ability to develop an external mycelium at temperatures below 12ºC, as previously reported for individual AMF Danish isolates and native communities as well as outcomes from in vitro cultures with isolates from different regions of the world (Gavito and Azcon-Aguilar, 2012). The influences of CO_2 on the host plant would have less of an impact on AMF advance and nutrient application than would soil temperature. Using a lonely isolate of *Glomus caledonium* or AMF from field soil, pea plants were grown in factorial combinations at current (350 ppm) or elevated (700 ppm) atmospheric CO_2 and the corresponding current (10°C) or elevated (15°C) soil temperatures (Gavito et al., 2003). The optimum temperatures for root growth in *G. intraradices* and *G. proliferum* cultures were 18°C and 24°C, respectively. Both the overall root length and the colonized root length in *G. intraradices* were significantly influenced by temperature. The total root length increased between 6 and 18°C and dropped between 18 and 30°C, whereas the colonized root length enlarged linearly from 6 to 30°C. The growth of extra-radical hyphae was affected by temperature treatments in cultures containing all three AMF isolates. The extraradical mycelium did not extend past the inoculum stopper at either 6°C or 12°C. However, the total root length of *G. proliferum* developed similarly to that of *G. intraradices*.

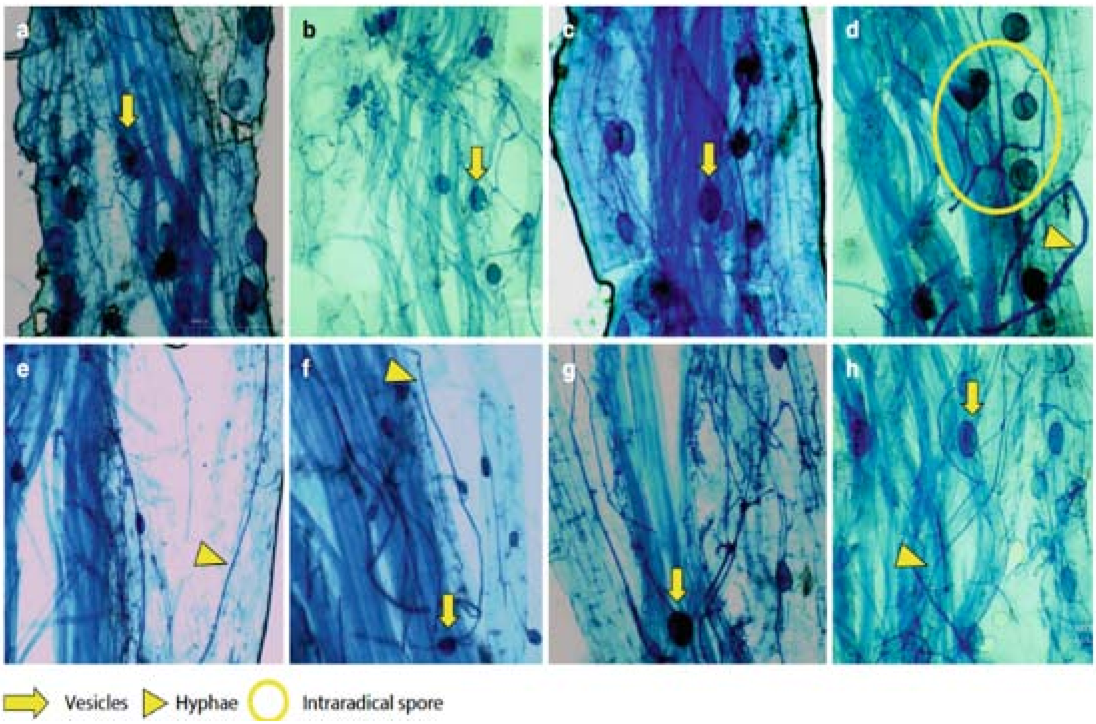


Fig. 1: Mycorrhizal root colonization of pearl millet lines by *Funneliformis mosseae* (a, b, c, e, f, g) and *Rhizophagus aggregatus* (d, h) under control and high temperature treatments in culture chamber. a L253 at 32–28 °C (day-night temperature), b L220 at 32–28 °C, c L132 at 32–28 °C, d L3 at 32–28 °C, e L253 at 37–32 °C, f L220 at 37–32 °C, g L132 at 37–32 °C, h L3 at 37–32 °C. Arrow: vesicles; triangle: hyphae; circle: intraradical spore (Ndeko et al., 2021).

Low temperatures affect rice productivity in addition to grain excellence and even existence due to the physiological development of crops and the insurgence of plant uptake. Low temperatures change the equilibrium of absorbed carbon, influencing the amount of carbohydrates in the leaf and root and, accordingly, respiration. Small temperatures also reduce leaf exports of carbohydrates and sink activity. Low temperatures have also been connected to changes in the pathways that regulate respiration in addition to reducing the production of adenosine triphosphate (ATP) and respiration rate (R) (Liu et al., 2014a). Pyruvate application and the relative expression of genes related to pyruvate breakdown were measured. Intriguingly, pyruvate concentration was lesser in the roots of mycorrhizal rice than non-mycorrhizal rice at truncated temperatures. The expression levels of pyruvate kinase and pyruvate dehydrogenase (PDHEα) in mycorrhizal rice roots were found to be greater than those of nonmycorrhizal rice under low-temperature conditions. Mycorrhizal rice may have lower pyruvate concentrations than non-mycorrhizal rice because it expresses PDHEα at comparatively higher levels for pyruvate metabolism. However, because non mycorrhizal rice has a relatively lower level of PDHEα than mycorrhizal rice, it might be more vulnerable to pyruvate accumulation under low-temperature stress (Liu et al., 2014a). As a result, it may be assumed that under low-temperature stress, AMF may initially pick up the host's "cry for help" signal and then promote greater host photosynthesis, which increases the availability of substrates for respiration (Liu et al., 2014a). There is proof that the symbiotic relationship between plant roots and AMF encourages plant growth as well as increases plants' resistance to biotic and abiotic stresses, such as cold temperatures. The use of AMF to control how plants respond to cold stress has garnered a lot of attention, in particular, over the past ten years. After receiving mycorrhizal inoculation, bean plants under cooling stress responded by exhibiting enhanced leaf water potential. AMF colonization in plant roots may increase plants' resistance to cold temperatures by lowering membrane lipid peroxidation and plasma membrane permeability as well as boosting osmolyte accumulation, antioxidant enzyme activities, photosynthesis, and secondary metabolism (Liu et al., 2014a).

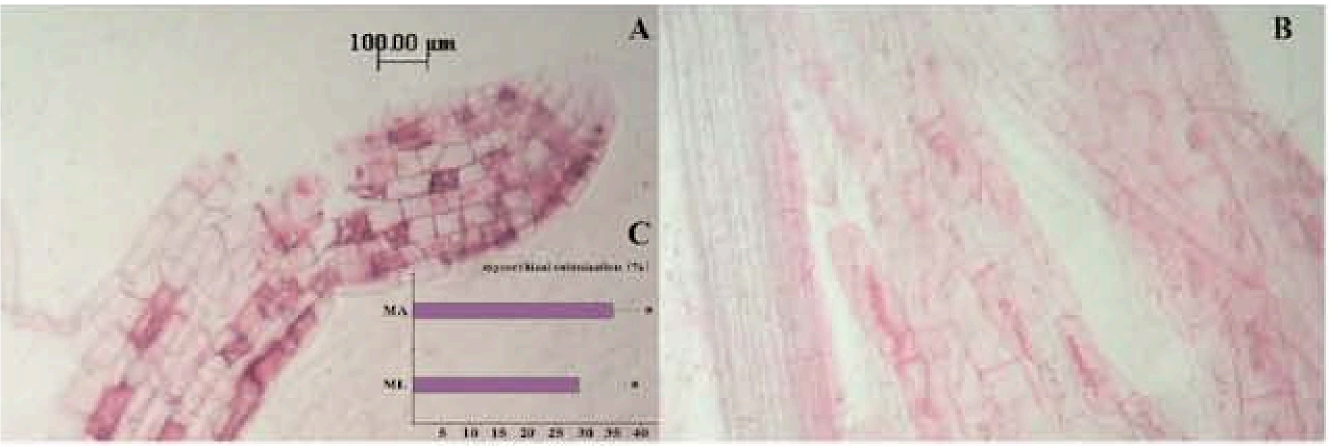


Fig. 2: Root colonization of maize seedlings inoculated with *Rhizophagus irregularis*. (A) Mycorrhizal colonization under ambient temperature. (B) Mycorrhizal colonization under low temperature (C) Mycorrhizal colonization of under ambient temperature and low temperature. Error bar indicates the standard deviation of three technical replicates (Source: Li et al., 2020).

Low temperature stress is one of the main abiotic factors that limits plant growth and natural dissemination. Likewise, chilling is one of the most severe abiotic stresses that limits crop growth and yield globally. Most plants will adjust their physiological functions, including photosynthesis and hydration status, when exposed to cold temperatures. Plant water interactions are worsened by reduced hydraulic conductivity and a lack of stomatal control brought on by low temperature. Low temperatures also hinder the production of chloroplasts, change the color of pigments, and decrease chlorophyll fluorescence, all of which decrease the capacity and effectiveness of photosynthesis (Latef and Chaoxing, 2011). The main site of cold stress hurt, is the cell membrane, which is affected by rise in permeability, electrolyte leakage, and significant changes in structure and lipid content. These improvements result in the addition of ROS, which affects cellular lipids, proteins, DNA, and other macromolecules. One of the defense mechanisms that plants have evolved to counteract excessive ROS is the synthesis of antioxidant metabolites, such as proline and soluble carbohydrates, and antioxidant enzymes, such as SOD), CAT, and APX (Pasbani et al., 2020). In the lack of cold stress, the AMF colonization led to a large rise in the H_2O_2 level notwithstanding a contemporaneous rise in the activity of the foraging enzymes (CAT and APX). Hydrogen peroxide is a nodding molecule that activates downstream processes, comprising plant stress defense. The higher H_2O_2 concentration, which was seen here despite the absence of cold stress, may prepare mycorrhizal eggplants for diverse environmental challenges. According to the previous findings, H_2O_2 plays a vital regulatory role in mycorrhizal symbiosis, and AMF inoculation has a priming effect that raises tolerance to a variety of biotic and abiotic stresses. When compared to the control temperature (25 °C), the H_2O_2 and free phenolics content at 5 °C was much lower in the + AMF plants than the -AMF plants, which was associated with elevated CAT and APX activities. According to the findings, under cold stress conditions, the + AMF plants were able to adequately scavenge ROS because of their improved ROS scavenging ability (Pasbani et al., 2020).

Low temperatures increased AMF aquaporin (GintAQPF) manifestation levels, and rice aquaporin (OsPIPs) expression levels were observed as compared to rice that is not mycorrhizal. The enhanced trehalose biosynthesis gene transcripts, such as OsTPS1, OsTPS2, and OsTPP1, in mycorrhizal rice roots generated more trehalose than non-mycorrhizal rice at either normal or low temperature. Exogenous trehalose was used to demonstrate how trehalose could regulate AMF and rice water absorption and enhance plant development conditions by inducing the expression of GintAQPF and a number of OsPIPs. Therefore, we suggested that AMF-enhanced trehalose accumulation was one of the methods by which AMF strengthened plant resistance to low temperature. AMF and host plant aquaporin expression may be induced as a result, which would improve water relationships in mycorrhizal plants at low temperature (Liu et al., 2014b). As a result of AMF colonization, stress also induces a discernible increase in the trehalose pool in the mycorrhizal roots (Liu et al., 2014b). Hence, studies into the accumulation of trehalose in mycorrhizal roots may provide a key insight into how AMF responds to challenging circumstances (Liu et al., 2014b).

When AMF is generated, plants are thought to perform more effectively under normal and traumatic conditions. Low temperatures (15°C) typically prevent AMF from colonizing roots, although research has shown that mycorrhizal plants are more resilient to frozen stress. Symbiotic idea of plant roots with AMF increases cold patience through the drop of lipid peroxidation and salvation of skin truthfulness, the growth of antioxidative potential, the optimization of osmolytes intensification and instruction of root hydraulic conductance, the expansion of photosynthetic bustle and respiration rate, and assimilated transcriptional guideline of cold-receptive genes (Devi et al., 2019). Terrestrial shrub species have changed to favor mycorrhizal symbiosis. This symbiotic message has, and probably will continue to play, an important role in decreasing the detrimental effects on plants caused by numerous abiotic stresses, particularly cold stress. Since the beginning of time, AM symbiosis has been renowned to exist and is essential to the control of terrestrial ecosystems. AMF immunization has the capacity to lessen the cold stress that plants knowledge, as has been adequately established. Future agriculture will benefit from the association since it offers a better way for plants to adjust the demanding environmental conditions (Devi et al., 2019). AMF symbiosis increases host plant osmotic adjustment during cold stress and increases roots' capacity to gather soil water and maintain open stomata in leaves through the addition of soluble sugar and proline. According to reports, AMF under cold stress collected with water relations increases the host plants' leaf chlorophyll concentration, photosynthesis, and antioxidant enzyme bustle. The AMF inoculation-induced increase in phenolic metabolism may be necessary for the AMF-mediated enhancement of cold stress (Chen et al. 2013). Although low temperatures restrict plant growth, a process known as cold acclimation regular exposure to low but not freezing temperatures increases the survivability of plants after a freeze-thaw cycle. The accumulation of suitable solutes like carbohydrates and amino acids, changes in the make-up of membrane lipids, and the creation of certain proteins that prevent ice from recrystallizing are all associated with cold acclimation (Chen et al., 2013).

Increased cell membrane permeability is the first sign of low temperature stress in plants. Additionally, a number of ROS, comprising as hydroxyl radicals, superoxide anion radicals, and H_2O_2 are generated. Membrane lipid peroxidation is caused by an imbalance between manufacture and foraging in the cell or organism. In order to avoid oxidative damage, plants adjust their osmotic potential and activate antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbaperoxidase (APX), and glutathione reductase (GR), in addition to some non-enzymatic antioxidants like ascorbic acid, a-tocopherols, phenolic compounds, and others (Latef and Chaoxing, 2011). Cold stress, which encompasses chilling (5°C-15°C) and freezing (<0°C) temperatures, is one of the most frequent environmental stressors that crop plants encounter on a global scale. The effects of cold stress on plant yield and survival are quite detrimental. Due to altered pigment composition, poor chloroplastic development, decreased root hydraulic conductivity, and loss of stomatal control, cold stress lowers the capacity and efficiency of photosynthesis. Plants that are subjected to cold stress first experience impacts on their cell membrane, which results in a loss of fluidity, certain modifications to the lipid content, and membrane damage. A rise in electrolyte leakage and lipid peroxidation then follow these consequences (Hajiboland et al., 2019).

Low-temperature stress, is a chief environmental factor that significantly hinders plant respiration, can be reduced by AMF. In the present study, a pot experiment was carried out to control changes in the metabolic capacity of mycorrhizal rice (*Oryza sativa*) during low-temperature stress. The results confirmed that low temperature may speed the construction of strigolactone in mycorrhizal rice roots by stimulating strigolactone synthesis gene expression, which acted as a host stress response signal. AMF also induced the host tricarboxylic acid (TCA) cycle by enhancing pyruvate metabolism, up-regulating the expression of TCA cycle genes under low-temperature stress, and affecting the electron transport chain (Liu et al., 2014a). While the alternative oxidase pathway may be the main electron transport mechanism in stressed non-mycorrhizal rice, the cytochrome c oxidase (COX) pathway may predominate in AMF mycorrhizal symbiosis. Adenosine triphosphate synthesis was increased in mycorrhizal rice in order to maintain the usual condition of respiration while under stress. Better root growth condition and lessened low-temperature stress resulted from this (Liu et al., 2014a).

Chiling injury could cause a variety of harm, including acute mechanical stress, changes in macromolecule activity, a drop in osmotic potential in the cellular setting, an increase in H_2O_2 buildup, and significant plasma membrane alteration. Freezing injury happens when the temperature drops from 1to 0°C. Low temperatures during the winter and spring in the subtropical areas frequently endanger crop production, especially seedling growth (Chen et al., 2013). In particular, over the past ten years, the use of AMF for controlling plant responses to cold stress has attracted a lot of attention. The leaf water potential of chilling-stressed plants increased in response to mycorrhizal inoculation. By reducing membrane lipid peroxidation and plasma membrane permeability, as well as by boosting osmolyte addition, antioxidant enzyme activities, and photosynthesis, AMF colonization in plant roots may improve plants' ability to withstand cold temperatures (Chen et al., 2013).

While changed AMF caused diverse root colonization, low temperature dramatically inhibited AM colonization. Low temperatures significantly lowered plant height and total dry weight while increasing root dry weight and the root-to-shoot ratio. Compared to non-AM plants, AM plants have a greater proline content. The maize plants inoculated with *Glomus etunicatum* and *G. intraradices* showed higher amounts of malondialdehyde and decipherable sugar when the temperature was low. The catalase (CAT) and peroxidase activities of AM-infected maize was higher than those of non-AM maize when exposed to low temperature. The chilly temperature dramatically lowered CAT's activity levels (Chen et al., 2014). It is well known that both temperature and AM symbiosis affect plant growth. Despite the fact that low temperatures significantly harmed plant growth as measured by plant height, total dry weight, and root-to-shoot ratio, no positive plant growth responses to AM colonization were seen (Chen et al., 2014). The short duration of the experiment and the paucity of AMF to deliver P and other types of nutrients to the plants may be to blame for this effect of AMF, which was also noted in earlier pot studies.

It is commonly known that low temperatures cause leaf tissue to deteriorate, which slows plant growth. Damage to the membranes, which increases permeability, is the principal effect of chilling stress. Although it is influenced by the age of the plant, the leaves, and their position on the plant, electrolyte leakage (EL) is a useful indicator for determining cell membrane damage. Consequently, measurements were done using the upper fully grown tomato leaves at the same seedling age (40 days after planting) (Caradonia., et al., 2019). Only the initial tests revealed a significant difference between the treatments using microorganisms. The seedlings' variable agronomic performance may help to explain this. Actually, seedlings with more development are more resistant to environmental stresses. Therefore, it is hypothesized that the higher tolerance of seedlings may have muffled or hidden the varied effects of the treatments along the course of recovery. The non-treated control's lower EL values in the second experiment compared to the first trial further supported this theory (Caradonia., et al., 2019).

The investigation's findings showed how the examined microorganisms behaved in a protective manner toward cell membranes. Environmental stresses impede plant growth and yield, which results in substantial losses. Crop growth and yield, in particular, are affected by chilling in subtropical regions (Caradonia., 2019). Cold stress results from physical and chemical changes in biological molecules brought on by low temperatures. Conditions of freezing (0 °C) and chilling (10-15 °C) severely restrict the growth of plants. Low temperatures affect plant ecophysiological function, which affects crop yield loss globally as well as the fitness and dispersion of wild species. Prior studies have focused on the functional mechanisms that enable plants to withstand cold stress through a variety of morphological, physiological, biochemical, genetic, and epigenetic aspects (Acuna-Rodriguez et al., 2020). After the chilling stress in both trials, *Funneliformis mosseae* primarily reduced the cell membrane damage in terms of electrolytic leakage and photosystem II efficiency. On the other hand, an application of *F. mosseae* increased photosystem II efficiency while enhancing seedling regeneration. Modern genotypes that had been infected with microorganisms also demonstrated greater seedling regeneration (Caradonia., 2019). Making use of beneficial AMF could be a long-term way to decrease the demand for outside resources and boost resilience to biotic and abiotic problems.

When it came to reducing the effects of low temperature stress on barley cultivars, *G. versiforme* frequently outperformed *Rhizophagus irregularis*, although *R. irregularis* performed better when it came to boosting survival. This finding implies that successful application of AMF under freezing conditions depends on selecting the proper fungus type and host-plant cultivar (Hajiboland et al.,2019). While earlier research suggested that the use of AMF could reduce the effects of chilling stress, this research tended to focus on primary metabolism, such as plant growth, dietary intake, chlorophyll parameters, and antioxidant enzymes. Recent results suggest a relationship between changes in secondary metabolism and stress responses. According to reports, flavonoids have an impact on spore germination, hyphal growth, and AMF root colonization. Many theories claim that secondary metabolites including lignin, flavonoids, and phytoalexins are produced as part of defense systems (Chen et al., 2013). Future research subjects into plant-microbial symbioses in chilled and frozen circumstances are suggested, as well as whether temperature impacts how plants respond to symbiotic microbes. Without symbionts, it is evident that studies examining how plants respond to cold and subzero temperatures are most likely artifacts. Future study should routinely incorporate symbiotic microbes in their experimental designs to appropriately assess how plants respond to chilling and freezing temperatures in the natural environment (Acuna-Rodriguez et al., 2020).

2.2 However, compared to the room temperature, superoxide dismutase and peroxidase activity were significantly elevated in the AMF group below low temperature stress. The combination application of AMF dramatically improved catalase bustle and proline contented while lowering malondialdehyde levels in the plant leaves under low-temperature stress. As a result, AMF accelerated the growth of *Lolium perenne* plants and improved their resistance to salt water soil stress and low temperatures (Yan et al., 2021). Temperature had a significant effect on the AM hyphal network, which went from having more vesicles (storage) in cooler soils to having larger extraradical hyphal networks (growth) in warmer soils. Also, it has been discovered that as soil temperature rose, there was an intensification in the rate of plant photosynthate transfer to and respiration by roots and AMF as well as an increase in the amount of carbon respired per unit hyphal length. Neither plant size nor photosynthetic rates were significantly correlated with these differences. In a warmer future, we would consequently anticipate higher atmospheric carbon losses through AMF respiration, which are unlikely to be countered by higher AMF hyphae formation (Hawkes et al., 2008). Despite the fact that the photosynthetic rates of the cooled treatment were only slightly (<10%) higher than those of the control group during the light intensities used for pulse-labeling, the observed increase in throughput was not likely caused by a shift in photosynthetic rates. Soil temperature may also have an effect on how much carbon is transferred from the plant to the fungus, either directly or by affecting how effective the fungal sink is. According to the $^{13}CO_2$ content of the soil air in the AMF slot, rising soil temperatures increased the transfer of carbon from plants to mycorrhizal fungus. This may be partially explained by variations in the size and investment of the extraradical mycelium (Hawkes et al., 2008). At low temperatures, the two cultivars both showed equivalent decreases in the leaf concentrations of soluble sugars, phosphate (P), and potassium (K). However, equivalent increases were seen in the levels of malondialdehyde (MDA), H_2O_2, superoxide anion radical (O_2), and proline. The activities of superoxide dismutase, ascorbate peroxidase, guaiacol peroxidase, ascorbate, and glutathione as well as the amounts of O_2, MDA, and H_2O_2 in the leaves of the blueberry cultivars were all increased by AM inoculation. AMF caused more notable changes in leaf composition. In comparison to non-inoculated plants, plants from the blueberry cultivars "Britewell" and "Misty" that had been infected with AMF showed higher amounts of soluble sugar, proline, P, and K (Liu et al., 2016). So it is advisable that the application of AMF provides plant resistance to cold temperatures. Low temperature decreased soluble sugar concentration in leaves, and increased leaf proline concentration. Inoculation with AM enhanced soluble sugar and proline concentrations in the leaves of two blueberry cultivars. Conversely, under the low temperature, leaf soluble sugar concentrations of AM-inoculated 'Britewell' and 'Misty' blueberry plants increased by 15.71% and 12.21%, respectively, in comparison with non-mycorrhizal plants. Under the normal temperature, they increased by 20.63 % and 14.88 %, respectively. Proline concentration was higher in 'Britewell' leaves than in 'Misty' leaves (Liu et al., 2017). Blueberry plants inoculated with AM displayed higher levels of leaf SOD, APX, GPX, ASA, and GSH in response to low-temperature stress than non-AM-inoculated plants, but lower levels of leaf O_2, H_2O_2, and MDA, indicating that the ASC-GSH cycle would function well in AM plants. It is thought that reducing H_2O_2 levels is one of the ways AM fungus protects plants from numerous stresses (Liu et al., 2017). It is common knowledge that one of the key elements of freezing tolerance mechanisms is osmotic adjustment. Sugars can serve a number of purposes, such as providing osmoprotection, energy for basic metabolism, and the production of new molecules that respond to stress. Proline, which serves as an energy sink to control redox potentials and as a hydroxyl radical scavenger, is the most significant amino acid involved in organic osmotic adjustment. It is reported that AM-inoculated The possible of arbuscular mycorrhizal fungus to increase the host plants' resistance to cold temperatures is well documented. Although the popular of lessons have outlined the favorable impact of AMF on host respiration and there are ample data describing variations in plant breathing under low-temperature conditions in both mycorrhizal and non-mycorrhizal plants, the more fundamental mechanisms remain unclear (Liu et al., 2014a). The opening contamination and subsequent colonization of barley by mycorrhizal fungi were both influenced by temperature. Although mycorrhizae can develop in a range of temperatures from 11 to 26°C, warm temperature are when the majority of colonized roots occur. While *Glomus hoi*, the predominant AMF fungus from Syria, was further accepting of sincere soils at 24 to 26°C, *G. macrocarpum*, the predominant AMF fungus from Montana, was more tolerant of cool soils at 11 to 14°C. *Glomus* species have different ideal growing temperatures for mycorrhizae, which has also been observed in wheat (Grey, 1991). Winter wheat was most effectively infected with *G. epigaeum* at a temperature of 25°C, but not at 10°C. The vast choice of temperatures suggests that various *Glomus* species have varying thresholds for heat (Grey, 1991).

Temperature stress causes physiological problems and the production of ROS in plants. The buildup of ROS disturbs the delicate equilibrium between the production of ROS and plants' capacity to hunt for them by causing destructive oxidative processes, such as membrane lipid peroxidation and protein oxidation. Malondialdehyde (MDA) is commonly used as a marker for the degree of membrane lipid peroxidation and as its final product. So the MDA content in tomato plant leaves was assessed below low temperature stress. Low temperature stress led to a rise in leaf MDA concentrations in non-mycorrhizal plants. However, the MDA content in mycorrhizal plants persisted lower than that in non-mycorrhizal plants, suggesting that the presence of the AM fungus may have a preventative impact against membrane lipid peroxidation. Through AM symbiosis, the concentration of MDA in leaves was decreased under cold stress (Latef and Chaoxing, 2011). Notably, H_2O_2 and malondialdehyde buildup significantly decreased following AMF inoculation, indicating that it significantly reduced the oxidative stress brought on by chilling. While AMF injection significantly decreased this leakage, watermelon seedlings grown in cold circumstances showed an increase in leaf electrolyte leakage (Bidabadi and Mehralian, 2020). Compared to non-mycorrhizal plants, mycorrhizal plants have more soluble protein, carbohydrates, and photosynthetic pigments in their leaves, but a decreased concentration of proline. The colonization of AM increased the activity of the enzymes SOD, catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX) in leaves. The results show that by reducing membrane lipid peroxidation and increasing photosynthetic pigments, osmotic adjustment chemical accumulation, and antioxidant enzyme activity, the AM fungus can shield tomato plants from the harm brought on by low temperature stress. As a result, the development of AMF, which increased host biomass and speed up plant growth, considerably boosted the tomato plant's capacity to endure cold circumstances (Latef and Chaoxing, 2011). Earlier reports demonstrated that under low temperature stress, carotenoids increased while chlorophyll content (chl a, chl b, and chl a+b) dropped. This suggests that there are connections between the plant physiological make-up and stress tolerance to the plant. Similarly, the amount of chlorophyll content in plant leaves showed that there were lower rates of chlorophyll synthesis and higher rates of chlorophyll breakdown under low temperature stress (Latef and Chaoxing, 2011). AMF and low temperatures change the protein makeup of tomatoes. Low temperature stress can result in substantial accumulations of proline. According to the recent findings, plants that are inoculated with AMF have less proline in their leaves than plants that are not (Latef and Chaoxing, 2011).

As a result, it is possible that AMF colonization could lessen ROS damage, protect plants from oxidation damage, and ultimately improve the plants' resistance to temperature extreme. So it is possible that some antioxidant enzymes are more active as a result of how plants generally defend themselves from low temperature stress. The AMF symbiosis may affect the production of antioxidants, osmotic regulation, membrane lipid peroxidation, and reactive oxygen metabolism in plant tissues, however this is yet unknown. Therefore, more study is needed to fully understand the mechanism by which AM symbiosis affects oxygen metabolism, membrane lipid peroxidation, and antioxidant production in plants. The changes in leaf proline show that the injuries to mycorrhizal plants were less severe, necessitating the synthesis of less proline to provide osmotic adjustment protection. There are observable changes in the relative permeability of the leaf and root membranes to high- and low-temperature stressors between mycorrhizal and non-mycorrhizal plants (Zhu et al., 2010a). How the AM symbiosis affects the generation of antioxidants, osmotic regulation, membrane lipid peroxidation, and reactive oxygen metabolism in plant leaves and roots is still unresolved. Furthermore, mycorrhizal plants exhibit lower relative membrane permeability than non-mycorrhizal plants. At low temperatures, the two cultivars both showed equivalent decreases in the leaf concentrations of soluble sugars, phosphate (P), and potassium (K). However, equivalent increases were seen in the levels of malondialdehyde (MDA), H_2O_2, superoxide anion radical (O_2), and proline. The activities of superoxide dismutase, ascorbate peroxidase, guaiacol peroxidase, ascorbate, and glutathione as well as the amounts of O_2, MDA, and H_2O_2 in the leaves of the blueberry cultivars were all increased by AM inoculation. AMF caused more notable changes in leaf composition. In comparison to non-inoculated plants, plants from the blueberry cultivars "Britewell" and "Misty" that had been infected with AM showed higher amounts of soluble sugar, proline, P, and K (Liu et al., 2016). So it is advisable that the application of AMF provides plant resistance to cold temperatures. Low temperature decreased soluble sugar concentration in leaves, and increased leaf proline concentration. Inoculation with AM enhanced soluble sugar and proline concentrations in the leaves of two blueberry cultivars. Conversely, under the low temperature, leaf soluble sugar concentrations of AM-inoculated 'Britewell' and 'Misty' blueberry plants increased by 15.71% and 12.21%, respectively, in comparison with non-mycorrhizal plants. Under the standard temperature, they improved by 20.63 % and 14.88 %, respectively. Proline absorption was higher in 'Britewell' leaves than in 'Misty' leaves (Liu et al., 2017). Blueberry plants inoculated with AM displayed higher levels of leaf SOD, APX, GPX, ASA, and GSH in response to low-temperature stress than non-AM-inoculated plants, but lower levels of leaf O_2, H_2O_2, and MDA, indicating that the ASC-GSH cycle would function well in AM plants. It is thought that reducing H_2O_2 levels is one of the ways AM fungus protects plants from numerous stresses (Liu et al., 2017). It is common knowledge that one of the key elements of freezing tolerance mechanisms is osmotic adjustment. Sugars can serve a number of purposes, such as providing osmoprotection, energy for basic metabolism, and the production of new molecules that respond to stress. Proline, which serves as an energy sink to control redox potentials and as a hydroxyl radical scavenger, is the most significant amino acid involved in organic osmotic adjustment. It is reported that AM-inoculated plants, especially "Britewell," had higher levels of leaf proline and soluble sugar than non-AM-inoculated plants, demonstrating that AM fungi can alter cell osmotic potential to protect the activities of enzyme systems by promoting the accumulation of osmoregulation compounds, minimizing the harm caused by membrane lipid peroxidation, and ultimately increasing the resistance of blueberry plants to chilling stress (Liu et al., 2017).While rice mycorrhizal showed higher levels of aquaporin (OsPIPs) expression than non-mycorrhizal rice. But more investigation is necessary to identify the underlying mechanisms (Liu et al., 2014b). AMF are recognized to be actual in enhancing host plants' tolerance to low-temperature stress by growing nutrient application and water immersion and inducing biochemical changes like the accumulation of proline, polyamines, antioxidants, and carbohydrates. Low temperatures seriously impair plants' ability to absorb water. There is a ton of information describing how trehalose accumulation changes in both mycorrhizal and non-mycorrhizal plants under stressful conditions, and it also shows how crucial trehalose is to AMF's improvement of plant stress tolerance (Liu et al., 2014b).

By regulating both their own aquaporin activity and the countenance of plant aquaporin genes, AMF may mend water delivery to the plant. This experiment's findings were consistent, when OsPIP1;1, OsPIP1;3, OsPIP2;1, and OsPIP2;5 expression was more highly expressed in AMF-colonized rice roots than in non-mycorrhizal rice roots. In addition, compared to non-mycorrhizal rice, low-temperature stress elevated the expression of the mycorrhizal rice genes OsPIP1;1, OsPIP1;3, OsPIP2;1, and OsPIP2;5 (Liu et al., 2014b). Therefore, trehalose's concentration in mycorrhizal roots and its biosynthesis may have a big impact on how the fungus responds to pressure. In order to comprehend the role of trehalose metabolism in mycorrhizal roots at low temperatures, the manifestation of significant genes involved in trehalose production was discovered. Rice that had been colonized with AMF had higher levels of the transcripts OsTPS1, OsTPS2, and OsTPP1 than rice that had not been colonized with AMF. In addition, in response to low-temperature stress, both mycorrhizal and non-mycorrhizal roots expressed OsTPS1, OsTPS2, and OsTPP1. Increased trehalose biosynthesis could lead to an increase in OsTPS1, OsTPS2, and OsTPP1 transcript levels, which would increase trehalose concentration (Liu et al., 2014b). The concentration of trehalose in mycorrhizal rice roots was knowingly higher than that in non-mycorrhizal roots, which was compatible with the pattern of gene expression for trehalose production. When compared to the control, the H_2O_2 accumulation in the roots treated with AMF under low temperature was decreased by 42.44%. H_2O_2 typically builds up on the cell walls of apoplast, and is rarely detectable in the cytoplasm or organelles of roots. Once more, AMF inoculation under low temperature significantly decreased NADPH oxidase activity involved in the production of H_2O_2. AMF inoculation significantly increased the P-type H^+-ATPase, P-$Ca2^+$-ATPase, V-type H^+-ATPase, total ATPase activity, ATP concentration, and plasma membrane protein content in the roots under low temperature (Liu et al., 2016). Additionally, plasma membrane ATPase gene expression and ATP levels were increased by AMF inoculation. By mediating AMF-mediated tolerance to chilling stress, these results imply that NADPH oxidase and ATPase may be essential in maintaining a reduced H_2O_2 accumulation in cucumber roots (Liu et al., 2014). Root colonization, plant height, and biomass of AM all decreased as a result of the cold. N, P, K, Ca, Mg, Zn, NO_3^-N, and NH_4^+N concentrations in the shoot and N, P, K, Ca, Al, Zn, and Cu concentrations in the root were both decreased by low temperature stress. Under low temperatures, mycorrhizal plants had higher concentrations of N, P, K, and Cu in the shoot and N, P, Ca, and Zn in the root compared to non mycorrhizal plants. Low temperatures also increased NR activity, which was higher in mycorrhizal plants than in non-mycorrhizal plants. Hence AMF inoculation improves maize plants' nutritional status and enhances their capacity to function in cold climates (Liu et al., 2016). Despite the fact that low temperatures impede the growth and physiological functions of AM plants, it has been shown that AMF applications have a positive influence on the host plants' progress and enlargement (Liu et al., 2016). Mycorrhizal plants showed enhanced water station than equivalent non-mycorrhizal plants regardless of temperature treatments, and significant differences in water conservation (WC) and water usage efficiency (WUE) were found. With the invasion of AM, the levels of chlorophyll a, b, and a + b increased. AM plants outperformed non-AM plants in terms of maximal fluorescence (Fm), maximum quantum efficiency of primary PSII photochemistry (Fv/Fm), and prospective photochemical efficiency (Fv/Fo), while primary fluorescence was lower in AM plants (Fo) (Zhu et al., 2010b). AM inoculation considerably increased the net photosynthetic rate (Pn) and transpiration rate (E) of maize plants. The distinction between mycorrhizal and non-mycorrhizal plants only reached statistical significance at 5°C. Mycorrhizal plants showed lower intercellular CO_2 concentrations (Ci) than non-mycorrhizal plants under stumpy temperature stress. The outcomes show that AM relationship improves maize plants' photosynthetic efficiency and hydration condition, enabling maize plants to withstand low temperature stress (Zhu et al., 2010b).

Under normal conditions, inoculation promoted cucumber development, but under cold stress, it only significantly enhanced root biomass. Mycorrhizal plants have more phosphorus than non-mycorrhizal plants, which proved that AMF delivered phosphorus to the host plant while it was under cold stress and at ambient temperatures. Therefore, even though the advantage of mycorrhiza was smaller than it would have been in ambient conditions, it nevertheless benefited the cold-stressed cucumber seedlings. As a result, at room temperature and to a lesser extent under cold stress, mycorrhiza strongly activated Pi transporter gene from the Pht1 gene family. In mycorrhizal plants that had undergone cold stress, the expression levels of the other three Pi transporters tested, which belonged to different families, were greatest. This suggests a complex interplay between mycorrhiza and cold stress on internal P cycling in cucumber plants (Ma et al., 2015). In ERM, symbiotic P uptake and transfer have been linked to the high-affinity Pi transporter GintPT, but in IRM, its expression was considered to be linked to the reabsorption of P from the periarbuscular region and control of P release to the plant. Alkaline phosphatase (ALP) genes, which have also been described in AMF, are associated with P metabolism. It is hypothesized that because ALP genes were shown to express under symbiotic conditions, notably in IRM, they may be involved in nutrient exchange with the host plant (Ma et al., 2015). When the mycorrhizal pathway of Pi uptake is activated with AMF colonization, numerous H^+ symporters of the Pht1 family are up- or downregulated, which influences these two Pi transporter pathways. Some Pht1 genes even only express in mycorrhizal roots, indicating that they are mycorrhiza-specific. The expression of the several Pht1 homologues maintains the equilibrium between the fungal and root epidermis absorption routes (Ma et al., 2015). Expression of mycorrhiza-specific Pi transporters, such as MtPT4 from *Medicago truncatula*, are signs of a healthy relationship. Other plant Pi transporters are also in charge of internal Pi cycling in the plant and delivery to subcellular compartments and organelles, including those in the Pht2, mitochondrial phosphate transporter (MPT) and PHO1 gene families (Ma et al., 2015). In contrast to the Pht1 gene family, little is known about how these additional Pi transporter genes respond to AMF (Ma et al., 2015). In order to understand how AM and cold stress combine to affect cucumber development and P absorption, it is crucial to identify Pi transporters in the mycorrhizal route that have not yet been identified in this species (Ma et al., 2015). Low temperatures can cause a range of injuries in plants, including immediate mechanical constraints, activity changes of macromolecules, reduced osmotic potential in the protoplasm, increased hydrogen peroxide accumulation, and alternation of plasma membranes. Association with AMF has been also shown to enhance plant tolerance to low temperature despite the fact that root colonisation by AMF is often restrained at low temperatures below 15°C. AMF were shown to alleviate the damage caused by low temperature stress by reducing membrane lipid peroxidation and increasing the amount of photosynthetic pigments, by the accumulation of osmotic adjustment compounds and by increasing photosynthesis (Ma et al., 2015). Increased resistance of mycorrhizal cucumber seedlings to low temperature stress may depend on the maintenance of lower H_2O_2 accumulation in the roots of mycorrhizal plants. AMF were specifically suggested to play a key role in maximizing growth in cucumber by stimulating the synthesis of secondary phytomedicinal metabolites at low temperatures. Despite these results, the effects of cold stress on the P delivery of AMF to their host plants have not yet been completely investigated by research. In contrast to earlier findings that P uptake by ERM decreased at low temperatures, with an investigation of P supply to plants under cold stress found no differences in P uptake by the plants (Ma et al., 2015).

Gene expression study revealed that low-temperature stress significantly upregulated the AMF aquaporins GintAQPF1 and GintAQPF2, with GintAQPF2 having a higher transcript level than GintAQPF1. Owing to the potential for AMF to control aquaporin expression and activity in both rice and the fungi, mycorrhizal rice was able to maintain a comparatively greater root relative water content (RWC) and root length at low temperatures, improving rice's ability to withstand cold. Mycorrhizal rice therefore seems to have a more effective water strategy than nonmycorrhizal rice . As expected, cold stress decreased chlorophyll content, net photosynthetic rate, and metrics related to photochemical quenching while increasing nonphotochemical quenching and sugar concentrations in leaves. Contrarily, AM boosted the cucumber seedlings' photosynthetic efficiency under both cold stress and at the control ambient temperature, having the opposite effect on the majority of the metrics that were examined. Stronger carbon sinks were a crucial factor in maintaining increased photosynthetic efficiency in mycorrhizal cucumber seedlings under cold stress, as we also noticed a significant reduction in the influence of cold stress on the sugar content of leaves (Ma et al., 2019). Understanding how mycorrhiza influences numerous aspects of plant physiology at low temperatures is critical. To examine the interplay between mycorrhiza and cold stress on cucumber photosynthesis, conducted an experiment in which mycorrhizal and non-mycorrhizal plants were subjected to cold stress in a full-factorial design. An analysis of several gas exchange and Chl fluorescence measurement-related parameters to estimate CO_2 assimilation and the effectiveness of the photosynthetic apparatus, respectively. Also, simultaneous tests of soluble sugar and sucrose concentrations were conducted to determine the metabolism of carbohydrates in cucumber leaves. Whether arbuscular mycorrhiza's advantageous effects on plant photosynthesis are maintained at low temperatures was our primary study question. Although mycorrhiza boosted both ambient and low temperatures equally, the net photosynthetic rate clearly reduced at low temperatures. Reduced CO_2 assimilation may be caused by stomatal restrictions or nonstomatal factors. Gs is the primary factor limiting CO_2 assimilation if gs and Ci are also dropping. On the other hand, if gs decreases while Ci does not change or increases, the decrease in CO_2 assimilation should be attributed to nonstomatal factors. This is consistent with past research showing that non-stomatal factors (Ma et al., 2019). As cold stress prevented both mycorrhizal root colonization and mycorrhizal growth response, mycorrhizal plants' gs may have decreased under cold stress to the same level as non-mycorrhizal plants (Ma et al., 2019).

Arbuscular mycorrhizal fungi and plant tolerance to supra-optimal temperature stress: It is widely known that AMF can alter the host response to temperature with altered carbon concentration in the below ground and above ground plant communities (Barrett et al., 2014). The *Glomus hoi* hyphal length density was only five times higher at room temperature (about 24° C) than it was when it was refrigerated (around 11° C) (105 d after patch addition). In another trial, which was carried out 86 days after patch installation, there was no effect of patch compartment temperature on AMF hyphal development. These differences between tests are most likely the result of the substantial variety in the ERM produced by the different ways the organic patch was applied to duplicates. The amount of plant biomass and phosphate concentration varied depending on the temperature at which the hyphae of the two AMF species formed (Barrett et al., 2014). When the AMF were grown at about 18 °C as opposed to about 11 °C, plant biomass increased, but it stayed the same at around 21° C (Barrett et al., 2014). It has been shown that the external hyphae of AMF can directly affect the related host plant growth in response to temperature fluctuations. The location and quantity of nutrients delivered, however, varied significantly between the two AMF that were compared. Global climate change is causing temperatures to rise, which has a huge effect on all biological relationships. Ecosystems of plants and soil are suffering in this new condition, especially in semi-arid areas with limited water resources. The quantity and quality of fruit are affected negatively by rapidly rising temperatures for agricultural crops, prompting the creation of sustainable solutions to deal with these novel situations. Plants inoculated with AMF have better under heat stress because of their improved vigor, productivity, and fruit quality. In this study some ways of optimism and points to more environmentally friendly production methods that are suitable for the real scenario of global climate change have been achieved (Reva et al., 2021). In addition to impairing photosynthesis, oxidative stress, and increasing the risk of drought, high temperatures can also have negative effects that are exacerbated in semi-arid and tropical locations. Heat stress (HS) events, which are the results of brief exposure to extremely high temperatures, are of special concern. Even if they only last a few hours, temperature peaks can have a major impact on agricultural yield (Reva et al., 2021). We have not yet looked into the potential effects of heat stress on these alterations brought on by AM symbiosis (Cobral et al., 2016). Despite the recent awareness of the favorable benefits of endophytic microorganisms on plant survival, there is accumulating evidence that fungal and bacterial symbionts exhibit similar effects on a number of plant species by triggering distinct metabolic and physiological changes. Various compounds are produced by stressed microorganisms and released into the tissues of the host plant. These chemicals are subsequently incorporated into the plant's internal cell and cytosolic stress response pathways (Acuna-Rodriguez et al., 2020). Numerous research has shown that the AMF symbiosis increases carbon use efficiency, but nothing is known about how it affects light use efficiency at high temperatures.

For the most part, AM production increases plant biomass, which lessens leaf browning, and has superior HS, relative water content, and water usage efficiency. Due to improved plasma membrane preservation in AM plant cells, which protects vegetal tissues from HS, a surge in the production of osmotic-active compounds like proline, trehalose, and glomalin as well as antioxidative enzymes like superoxide dismutase, catalase, and ascorbate peroxidase occurs. AM plants exposed to HS have equally markedly increased photosynthetic rates, stomatal conductivity, leaf transpiration, photosystem II efficiency, concentrations of chlorophyll (a and b), carotenoids, and photochemical potential. In addition to higher amounts of soluble sugars, higher rates of catabolism, gene expression, enhanced P uptake, assimilation, and utilization, and improved metabolism. AM plants being best able to endure HS and combat its negative effects since they are the richest in N (nitrate, ammonium, and amino acids). Additionally, new research has demonstrated how to lessen the negative effects of both the drought and HS. The most exciting questions for any producer remain, to our knowledge, unreported: how can AM symbiosis effect fruit yield and quality in extreme HS conditions? (Reva et al., 2021).

Current research results clearly show that the application of the ultra-pure AM inoculant mycogel under agronomic conditions boosted plant resistance to severe HS in three agriculturally significant crops. Nearly all of the measures examined demonstrated beneficial benefits, and the treated plants outperformed the control plants in terms of fitness and shoot and root development. The majority of AM research that has been published to date for a variety of plants, soils, and environmental conditions is consistent with these findings, which included higher plant biomass and water content as well as fewer effects on AM plants from HS occurrences. Our research, however, also demonstrates that utilizing the proper AM inoculant increases fruit yield and quality, which are likely the two aspects that both growers and the plant (in terms of reproduction) value the most (in terms of income). If we consider that AM encouraged all these benefits as a part of more considerate management of the soil, land, and ecosystem, we can conclude that AM inoculation in agriculture, with the proper inoculum source, is one of the keystones to building our next defense wall against climate change. (Reva et al., 2021).

Mycorrhizal seedlings greatly outgrew non-mycorrhizal seedlings in terms of growth parameters at both optimum and high temperatures, but at low temperatures, the advantages were almost entirely lost. Mycorrhizal seedlings often showed noticeably higher root characteristics than non-mycorrhizal trifoliate orange seedlings, regardless of temperature (projected area, surface area, number of forks, and volume). Mycorrhizal colonization significantly increased the amount of soluble protein and the SOD and CAT activities at high temperatures. Only SOD activity increased at ideal temperatures, but only the amount of soluble protein decreased at low temperatures. It suggests that trifoliate orange seedlings had mycorrhizal decrease of temperature stress at high temperatures, but that it was obviously lowered at low temperatures (Wu, 2011). Non-AM lettuce produced at 35°C had poorer thylakoid structure, a bigger buildup of starch granules, lower chlorophyll levels, and a worse net photosynthetic rate when compared to lettuce grown at 25°C. The chlorophyll a, chlorophyll b, net photosynthetic rate, and transpiration rate of lettuce infected with *F. mosseae* increased by 4.5%, 4.5%, 7.7%, and 5.9%, respectively, in comparison to lettuce generated without the AM fungus when it was cultivated in high temperatures (Yan et al., 2021b). The chlorophyll fluorescence transient of a non-AM lettuce was demonstrated to decrease while dramatically growing under high temperatures. The maximum fluorescence (Fm) of non-AM lettuce reduced by 8.6% when the temperature was raised from 25°C to 35°C, but there were no discernible differences in Fm between AM lettuce grown at 35°C and non-AM lettuce grown at 25°C. Absorption energy flow, dissipation energy flux, and trapping energy flux per reaction center all rose as lettuce was grown at a high temperature, although quantum yield for electron transport (Eo) and performance index for energy conservation fell (Yan et al., 2021b). On the other hand, lettuce infected with *F. mosseae* in hot weather displayed the opposite effects. AM injection significantly boosted lettuce's endurance to high temperatures by enhancing photochemistry and shielding the PSII system from heat damage (Yan et al., 2021b). Heat stress will decrease uptake even though research on the impact of heat stress on asparagus nutrient uptake has not been done. We looked into the effects of AMF, *G. intraradices*, on the development of asparagus, nutrient uptake, responses to heat stress, and antioxidative activities (*Asparagus officinalis* L.). With or without AMF inoculation, we raised asparagus plants in sand culture for 14 weeks at 20 to 25 °C. The plants were then exposed to control (20 °C/25 °C night/day), mild heating (30 °C/35 °C night/day), and severe heating (37 °C/42 °C night/day) temperatures in growth chambers. Plants were compared in terms of morphological and physiological growth parameters with and without AMF inoculation (Yeasmin et al., 2019). The mycorrhizal symbiosis greatly boosted biomass production when compared to plants that had not received an AMF inoculation and negatively impacted plant reactions to heat stress. Plants grown without AMF inoculation showed a high incidence of leaf browning (80% to 100%) during heat stress, whereas mycorrhizal plants showed a low frequency of leaf browning. The results showed that mycorrhizal fungal inoculated plants had greater levels of antioxidant enzymes such ascorbate peroxidase and superoxide dismutase. The 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity also responded more favorably in mycorrhizal plants than in control plants under each temperature range. By an increase in antioxidant activity, application of AMF enhanced plant nutrition and growth while minimizing the impacts of heat stress damage. The mycorrhizal association significantly improved asparagus' resistance to heat stress (Yeasmin et al., 2019). Malondial-dehyde levels and relative membrane permeability were both decreased by AM symbiosis in leaves and roots under low temperature. Compared to nonmycorrhizal plants, mycorrhizal plants' roots had larger concentrations of proline and soluble sugars, whereas leaf proline content was lower. AM colonization increased the activity of superoxide dismutase, catalase, and peroxidase in the leaves and roots. The results show that by reducing membrane permeability and lipid peroxidation and increasing the accumulation of osmotic adjustment compounds and antioxidant enzyme activity, the AM fungus can shield maize plants from the damage caused by temperature stress. Hence, the development of arbuscular mycorrhiza significantly increased the maize plant's resistance to extreme temperatures, which increased the host biomass and promoted plant growth (Zhu et al., 2010). As a result, plants use osmotic adjustment and antioxidant enzyme activity to protect themselves from oxidative harm. The AM symbiosis can alter a plant's physiology to aid it in overcoming obstacles as they come up. When there is a temperature stress, it is unknown how the AM symbiosis affects the host plants' reactive oxygen metabolism. Understanding how temperature-stressed plants' lipid peroxidation and antioxidant enzyme activity are impacted by AM fungus is vital. Shoot dry weight, shoot fresh weight, root dry weight and AM colonization increased with increase in temperature up to 25ºC and decreased in 30 and 35ºC (Zhu et al., 2010). Root colonization by AM fungus typically decreases when temperatures rise beyond 30°C and temperatures above 40°C are always lethal to AM fungi. Since the MDA content of mycorrhizal plants remained lower than that of nonmycorrhizal plants, it is obvious that the AM fungus' presence may reduce the peroxidation of membrane lipids (Zhu et al., 2010). Between mycorrhizal and non-mycorrhizal plants, there are notable differences in the relative permeability of the leaf and root membranes to high- and low-temperature stresses (Zhu et al., 2010). Under low-temperature stress, AM colonization, plant height, and biomass all experienced a sharp decline. Compared to non-AM plants, AM plants displayed increased levels of total N, glutamate oxaloacetate transaminase, and glutamate pyruvate transaminase activity. The net photosynthetic rate (Pn) of AM plants was larger than that of non-AM plants, despite the fact that low temperatures decreased the Pn. AM plants had higher levels of root sucrose and fructose, leaf soluble sugars, reducing sugars, and amylase and sucrose phosphate synthase activity at low temperatures than non-AM plants did. Moreover, compared to non-mycorrhizal plants, mycorrhizal plants have decreased membrane relative permeability (Zhu et al., 2015). Moreover, AM colonization lowered the root C: N ratio while raising it in the leaves of maize plants under low temperature stress. These results suggested that the C and N metabolism of maize plants varied between the ambient and low temperature regimes. The C metabolic enzymes were altered by the AM symbiosis, resulting in an accumulation of soluble sugars that may have improved maize plants' ability to withstand low temperatures and increase Pn production (Zhu et al., 2015). An increase in the amino acids level in the root and shoot is experienced due to mycorrhizal treatments (Zhu et al., 2016).

II. ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI IN PLANT TOLERANCE TO SUPRA-OPTIMAL TEMPERATURE STRESS

It is challenging to directly research AMF responses to temperature since these fungi are obligate biotrophs and cannot be cultivated separately. The fungus is totally dependent on their host plant for their carbon supply. As a result, the host plant's contemporaneous response, which might change how carbon is dispersed underground, will also have an indirect impact on how the AMF responds physiologically to a change in temperature. The fungus symbiont's growth will be impacted by the rise in temperature (Barrett et al., 2014). The sensitivity of AMF to temperature changes may have a significant impact on our comprehension of the role of the AMF symbiosis in plant nutrition, soil aggregation and exploitation, and C-cycling in regions of the world where soil temperatures below 20°C or above 40°C are typical during the growing season. Further research examining the genetic and plastic variation among these AMF is undoubtedly needed in order to fully understand the extent to which temperature may be limiting these AMF 's growth and function in diverse settings.

Photosystem II is the component of the photosynthetic apparatus that is most susceptible to damage at high temperatures. This is because heat-induced changes to the fluidity of the thylakoid membrane hinder electron transport via PSII. In a trial using heat-stressed maize plants, AMF inoculations reduced the harm to the PSII response center (Cobral et al., 2016). The favorable plant development responses to AMF colonization are influenced by temperature, and under high temperature stress, they may even be compromised in comparison to nonmycorrhizal plants. The advantages of early root colonization in the spring, however, may help plants like grains that are normally colonized later in the growing season (Grey, 1991). To the best of our knowledge, there hasn't been any investigation into the relationship between AMF and high temperature on a variety of crop species. AMF species have been shown to vary in symbiotic efficacy, and different combinations of plant species, genotypes, and isolates may behave differently under stress. So an understanding of how plants and fungi interact is essential for the appropriate application of AMF in specific situations. The right combination of AMF species and the host plant may be able to reduce stress to some extent or completely (Hajiboland et al., 2019).

2.1 Mechanism of AMF driven plant tolerance to supra-optimal temperature stress

As a result of soil warming brought on by climate change, soils' capacity to retain carbon will probably shift due to elevated temperature. The final role that AMF play in this will depend on modifications in the structure of the AMF network and the transit of labile photosynthates from plants via the fungus. The investment and expansion of the extraradical AMF hyphal network, the rate of transfer and respiration of plant photosynthates by AMF, and the amount of carbon respired per unit of hyphal length are all affected by an increase in soil temperature, as it is mentioned (Hawkes et al., 2008). So, it is assumed that AMF would store less carbon as the temperature rises, AMF would release plant carbon more quickly into the atmosphere through respiration. Depending on changes to the environmental conditions that were controlled in this study, such as light levels and soil moisture, the direction of this finding may change. Knowing the plant-independent reactions of AMF to changed climate conditions would surely be necessary to estimate the function of AMF in a warmer world (Hawkes et al., 2008). No matter how the changing structure of the AM fungal networks influenced carbon throughput, soil temperature had an effect. Soil respiration peaked at ^{13}C, two hours earlier in warmed soils than in ambient soils. Cooled soils considerably slowed and delayed the transport of carbon through the system, with the peak of ^{13}C in soil respiration beginning 20 or more hours following warmed and ambient soils. The pulse either did not reach the AM compartment in the chilled or ambient pots during this monitoring period, or perhaps a tiny peak was missed by our sampling intervals (Hawkes et al., 2008). The development and maintenance of AMF symbiosis need intense coordination between the two parties. Based on a closely regulated chemical conversation between signaling molecules, strigolactones have become important cues in this coordination (Liu et al., 2014a). According to a recent study, the host plant can increase strigolactone production to attract AMF when nutrients are scarce. This aids in promoting the proliferation of fungus and the development of symbiotic partnerships. Strigolactones play a crucial role in the symbiotic interaction between the two species and act as the host's signal, according to research on the mechanism by which AMF decreases salt stress. Experiments using abiotic stress demonstrated strigolactone's crucial role in the AMF symbiont. However, there are currently no studies available on the role of strigolactone at low temperatures (Liu et al., 2014a). Strigolactones, a new class of plant hormones, are secreted into the soil where they act as root parasite plant germination stimulants as well as critical host-detection signals for AMF, encouraging their metabolism and hyphal branching (Liu et al., 2014a). It has been suggested that mycorrhizal plants create more strigolactone while under stress environments, which is likely to promote the growth and symbiosis of AM fungus and relieve the stress (Liu et al., 2014a). Total chlorophyll, soluble sugar, and starch concentrations were analyzed, and it was found that under low-temperature stress, mycorrhizal rice had higher concentrations of these compounds than non-mycorrhizal rice. According to this research, AMF increases host photosynthesis and fortifies the C pool for respiration. Both AMF suppression and increased temperature alone reduced the community's temporal stability, but the addition of N had no impact. The main causes of community temporal stability were increased temperature, N addition, and AMF suppression that had an impact on the stability of the dominating species. AMF suppression, high temperature, which altered AMF richness connected to community asynchrony, and N addition, which affected mycorrhizal colonization, were all significant drivers, albeit to a lower extent. AMF suppression, N addition, and high temperatures in conjunction with AMF suppression all resulted in a reduction in the number of plant species, but there was no evidence linking these modifications to changes in community temporal stability (Yang et al., 2020). Structural equation modeling (SEM) further revealed that elevated temperature, N addition, and AMF suppression controlled community temporal stability by influencing both the temporal mean and variation in community productivity. The stability of temperate meadows may be significantly impacted by changes in the global environment, according to our findings, which also highlight the significance of belowground AMF status in plant communities' reactions to temporal stability of environmental change (Yang et al., 2020). By removing the constraint of cold temperatures, elevated temperature encourages synchronous plant growth in alpine grasslands. This decreases community temporal stability, suggesting that species asynchrony may be important in determining community temporal stability under elevated temperature. Hence, a rise in temperature that impacts species asynchrony, dominant species stability, and functional productivity of communities may also alter community temporal stability (Yang et al., 2020). While the addition of fungicide reduced spore density, hyphal length density, AMF richness, mycorrhizal colonization, and AMF concentrations, the addition of N reduced AMF richness and mycorrhizal colonization. Temperature increase led to higher spore density but lower AMF richness (Yang et al., 2020). The good effect of the higher temperature on spore density, may likely due to enhanced root C allocation for AMF sporulation, or AMF may have chosen this way as a mechanism of sporulation in response to environmental stress (Yang et al., 2020). Under the circumstances of natural vegetation regeneration, AMF diversity increased in response to increasing temperatures and precipitation. When temperatures exceeded 20 °C and there was a lot of precipitation, shrubland and mature forest had higher AMF richness than agriculture did. As a result, AMF were flexible in terms of variety to climatic changes and the recovery of the vegetation. The AMF communities' compositions were influenced by temperature and vegetation type (Xiao et al., 2021). The relative abundances of AMF groupings such as *Gigaspora*, *Glomus*, and *Septoglomus* increased at temperatures higher than 18 °C. The relative abundances of the AMF genus *Glomus* and the diazotroph genus Bradyrhizobium were higher in cropland compared to farmland, shrubland, and mature forests, while the relative abundances of the AMF genus *Septoglomus* increased. With increasing temperatures and precipitation, network complexity between AMF species grew (Xiao et al., 2021). These results suggest that high hydrothermal zones enhance the interactions between AMF spp, especially the *Glomus* thereby protecting against nutritional degradation. Management to increase AMF abundance during vegetation recovery in high climatic levels may encourage nitrogen uptake and transport (Xiao et al., 2021). It was vital to comprehend how the origin of the plant or the inoculum in connection to the temperature caused symbiotic activity. Particularly, it became clear that the plant struggled to adapt to its new surroundings when the temperature and inoculum were sympatric but allopatric to it. Further research showed that the symbiotic function was inversely associated to fungal diversity in high temperature conditions. These findings demonstrate the significance of taking into account both biotic and abiotic interactions when predicting how symbionts will react to environmental change on a global scale and imply that local adaptation is a key driver in the emergence of novel plant, inoculum, and temperature combinations (Yang et al., 2017).

2.2 Arbuscular Mycorrhizal Fungi Interacted with Nutrients and Plant Tolerance to Temperature Stress

Internal colonization typically increases between 10ºC and 30ºC in temperature, and it is frequently documented that colonization is suppressed below 15ºC. Moreover, only at temperatures of 15ºC and higher did AMF colonization result in improved plant P arrest when related to non-AM plants. Similar to this, showed that at 17ºC but not at 12ºC, AMF colonization results in higher shoot N content (Barrett et al., 2014). According to numerous additional research, AM plants produce worse than non-AM plants at temperatures under 15ºC but superior at temperatures over 15ºC. This shows that the advantages of exploiting an AMF to a host plant depend on temperature. Changes in the host's carbon allocation or a direct physiologic response by the fungus may be to blame for such temperature-driven alterations in mycorrhizal benefit (Barrett et al., 2014). The growth of the extra radical mycelium (ERM) gathered when warmed by 6ºC while protecting the crowd plant at an ambient temperature of 12/23 ºC (night/day), in contrast it is observed that only temporary effects on the growth of the ERM from warming the ERM by 8ºC while the host plant stayed at about 12ºC. The extended roots of the specific host plant, they observe, suggest that the direct impacts of temperature on AMF advance can potentially take unintended effects on host plant growth (Barrett et al., 2014). Because AMF are more temperature delicate than roots, it would be expected that low soil temperature would have a substantial impact on the fungal symbiont's ability to gather nutrients (Barrett et al., 2014). Even at temperatures of 10-12ºC, *G. hoi* was found to grow and transfer nutrients to its host plant (Barrett et al., 2011). Temperatures higher than 18ºC and lower than 30ºC were necessary for the formation and development of AMFs concluded that AMF growth was substantially more penetrating to cold temperatures than root growth, which was another finding. However, the temperature treatments utilized would also have a direct impact on root growth; hence, it is conceivable that the reaction of the roots to temperature could devour an indirect effect on the development of AMF (Barrett et al., 2014). There was no discernible difference between the two temperatures (11ºC or 24ºC) in terms of plant biomass or total N content. Data demonstrates that growing the AMF at 18ºC was more advantageous for host plant development and P nutrition than growing the AMF at higher temperatures (>21ºC). Further proof for this can be found in the associations found in plants that have been colonized by *G. hoi* AMF (Barrett et al., 2014). Inoculation of AMF to barley increased yield in increasing soil temperature (Grey, 1991). Based on the proportion of mycorrhizal roots and the number of mycorrhizal plants, barley genotypes were distinguished in a warm soil. From the standpoint of showing germplasm for mycorrhizae, however, a larger number of plants can be judged for the presence of a characteristic arbuscule than for the percentage of mycorrhizal roots in a specific time period (Grey, 1991).

The outcome of the mycorrhizal symbiosis as a whole is probably a combination of these reactions, even if the plant and fungal components respond to temperature in distinct ways. In other words, optimal growth would probably take place in a temperature range where each component benefits (Gavito and Azcon-Aguilar, 2012). P uptake by extraradical AMF hyphae was investigated autonomously from root P uptake in a root exclusion compartment. Intraradical colonization advanced successfully at both soil temperatures, and from 10 to 15°C, it virtually duplicated. In the root exclusion compartment, extraradical mycelium only grew at 15 °C, making this the only temperature at which hyphal P absorption could be examined. Rising the host plants at two distinct atmospheric CO_2 levels had minimal impact despite the large differences in hyphal P absorption between inoculum types. No discernible connections between soil temperature and CO_2 were found. Knowing what happens to newly fixed carbon in soil is crucial for expecting potential carbon sequestration in terrestrial ecosystems. Latest research employing the isotope ^{13}C has demonstrated that recent photosynthesis over the past few days dominates in regulating the rate of soil respiration. Both naturally occurring ^{13}C and pulse labeling were used in these investigations.

The interaction between temperature and the availability of photosynthetic substrate may have an impact on belowground respiration (Hawkes et al., 2008). The proportion of colonized roots and extra radical mycelium length were definitely interrelated with temperature while in symbiosis with *Plantago. lanceolata*, but fluctuations in root length colonization were a purpose of plant biomass. In the roots of *Holcus lanatus*, there was very little colonization and no evident effect of temperature. In the fungal partition, increased throughout time and peaked for *Glomus mosseae*. Warming the fungal compartment considerably improved the length of extraradical mycelium while having no effect on root length colonization. Yet, it is dramatically increased the amount of roots in the plant compartment, showing that the fungus controls the dynamics of symbiotic growth. From the perspective of global climate change, the effects of these temperature responses on carbon dynamics models (Heinemeyer et al., 2004). Poorly, very little is understood about how variations in soil temperature impact on and how newly secure carbon from plants transfers to soils or how carbon is dispersed among plants and soil infectious groups.

III. ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI INTERACTED WITH NUTRIENTS AND PLANT TOLERANCE TO TEMPERATURE STRESS

Temperature, developmental stage, and plant species interacted considerably with one another in terms of their effects on root density. *Ornithopus compressus* had the shortest root system compared to the other species, and it responded less to the temperature stress. The AMF was unable to colonize maize at 10°C, however root growth was unaffected. The *Lolium rigidum*. reached its highest root density after 42 days at 20°C. Only maize had a value for the average of the three growth phases that was considerably lower at 10°C than at other soil temperatures. This indicator tracks how temperature affects the entire plant's morphology, specifically how the roots respond in comparison to the shoots (Carvalho et al., 2015). It is still acceptable a more precise measurement of the host and fungal development as well as a preliminary evaluation of the role of C nutrition in AMF's reaction to temperature changes. For instance, the partners' different temperature optimum differences and the absence of any relationship among fungal progression and root development provided compelling evidence for the direct effects of temperature on AMF development. The temperature ranges from 6–30°C were taken to produce three isolates of AMF, and growth curves and measurements of C uptake transfer translocation. A number of experiments were conducted utilizing the model fungus isolate *Glomus intraradices* to examine the effects of temperature on lipid body and ^{33}P mobility, as well as the effects of acclimation and incubation time (Gavito et al., 2005). Although in certain instances obviously independent root and AMF growth responses, the absorption and translocation of ^{13}C were also influenced within the temperature range tested. As a result, both direct and indirect effects of temperature were seen on the proliferation of AMF. Cold temperatures (18°C) prevented the fungus from absorbing C from the roots and, to a lesser extent, translocating it. The absorption and transport of ^{33}P by fungal hyphae, however, was equivalent at 10 and 25°C. We come to the conclusion that temperatures between 6 and 18°C restrict AMF growth, and that C transport to the fungus plays a role in this reaction. According to the aforementioned findings, climate change's temperature component may have a bigger influence on AMF growth and operation in the understudied system than CO_2 component (Gavito et al., 2005). Mycorrhizal fungus has a substantial impact on how below-ground terrestrial systems adapt to environmental change, which has the potential to disrupt the carbon balance. Most land plants are believed to have arbuscular mycorrhizal (AM) fungi in their roots, which serve as a sink for 3-20% of the photosynthate produced by the host plant. They are also widely dispersed in soil, where the top 10 cm of soil worldwide has an estimated 1.4 Pg of fungal biomass. Up to 15% of the soil's organic carbon content and 20–30% of its microbial population are found in extraradical mycelium, a huge network of hyphae produced by the AM fungus (Hawkes et al., 2008).

In pepper roots, temperature and AM fungal treatments had an effect on overall colonization, arbuscule and vesicle generation. With roots colonized by *G. intraradices* and the *Glomus* combination, these parameters had lower values at high temperatures than they did at low temperatures. These outcomes support a recent study discovered a negative association between increasing air temperature and the colonization of *Acacia farnesiana* roots by *G. fasciculatum* and *G. geosporum*. On the other hand, we found that Glomus AZ112, an isolate from a warmer area than the *G. intraradices* isolate, acted to be insignificantly promoted by high temperatures for overall colonization and arbuscule formation in roots. We didn't find any vesicles on the roots of the Glomus AZ112 isolate at any temperature. All of the non-AM control plants kept their mycorrhizal ties (Martin and Stutz, 2004). The capacity of pepper to absorb P can be enhanced by mycorrhizal fungus. Hence, we gave twice as much P manure to all non-AM plants in an effort to uncover non-P related AM fungal influences on plant development in order to account for a predicted AM boost of plant P uptake. Despite this endeavor at reparation, the levels of P in pepper leaves were affected by temperature and AM fungal treatments. Leaf P levels of mycorrhizal plants were almost 1.4 times higher than those of non-AM plants in conditions of moderate temperature, but were 20% lower in circumstances of high temperature. Non-AM control plants showed equal leaf P values in high and modest temperatures (Martin and Stutz, 2004). Crop failure can result from changes in precipitation, and the need for water might rise as a result of warmer temperatures. Maize inoculated with AM fungus offered higher levels of antioxidants, vitamins, and minerals, as well as better plant development, revenue, and nutrient application, to improve food quality parameters. Thus AM fungi are recognized as a significant biotechnology tool in agricultural output. In order to diminish the consequences of climate change, it is important to preserve AM fungal populations in the soil, and this review highlights their crucial role in the sustainable production of maize (Silvia et al., 2022). However, they will be less than the harms affected by climate change. The costs and benefits of mitigation technology may not be cheap or straightforward. The anticipated effects of climate change will be particularly detrimental in low- and middle-income countries, where millions of people depend on agriculture and are at danger of food insecurity. The impact on global food security, which will be connected to food supply and food quality, food access and utilization, and the stability of food security, will result in decreased per capita calorie availability, childhood malnutrition, and child mortality (Silvia et al., 2022). Certain crops' nutritional properties may be influenced by climate change. The concentrations of minerals in different crops (including wheat, rice, and soybeans) were up to 8% lower when carbon dioxide (CO_2) levels were raised. According to studies on yields (especially those of wheat, maize, rice, and soybeans) under various climate change scenarios, these yields may gradually decline significantly (Silvia et al., 2022).

3.1 Mechanism of arbuscular mycorrhizal fungi interacted with nutrients and plant tolerance to temperature stress

About to 15% of the soil's organic carbon pool and 20–30% of the soil microbial population come from extraradical mycelium, a huge network of hyphae created by the AMF outside of roots. AMF can hold recently adjusted photosynthetic carbon from lipids for at least 32 days, despite the fact that fine hyphae have rapid rates of turnover and some carbon flows through them quickly. Long-term fungal carbon pools are also likely given that AM fungal tissues contain refractory materials as chitin and glomalin. In order to predict future soil carbon stocks and fluxes, it is crucial to comprehend how AM fungi will respond to environmental change (Hawkes et al., 2008). A plant's size, photosynthetic rates, or allocation below the ground can all indirectly affect mycorrhizal fungus. For instance, a new meta-analysis of 24 research discovered that rising CO_2 amplified extraradical hyphae and the percentage of root length colonized in AM fungus in a manner that was proportional to the plant response. Also, it is possible to have a direct effect on the fungus itself (Hawkes et al., 2008). Even though different AM fungus species had varying ideal temperature ranges, higher temperatures (between 24 and 30°C) were typically associated with improved root colonization, more extraradical mycelium, and better sugar uptake. Soil warming directly influenced the development of the extraradical hyphal network. Since that the root does not provide protection, the extraradical mycelium may be more profound to temperature throughout the development phase than the intraradical mycelium. It is crucial to measure AM fungus's direct response to climatic change apart from plant roots in order to comprehend the function that fungi will play in the carbon cycle in upcoming climates (Hawkes et al., 2008).

Symbiotic microbes, in general, and AMF, in specific, have been found to offer favorable methods for stress reduction that are mindful of the environment and soil homeostasis. Due to the consequences of global warming, heat stress has recently become a significant area of distress for agricultural production. In-depth research is being conducted all around the world to develop strategies for coping with abiotic challenges, including the development of heat- and drought-tolerant cultivars, modifications to crop cycles, and resource management strategies (Maya and Matsubara, 2013). Despite the fact that most of these processes are laborious and expensive, recent research suggests that AMF may help crops cope with abiotic problems. AMF fungi have caught the attention of crop scientists due to their host plants' numerous benefits. The AMF symbiosis, which is formed between the roots of most terrestrial plants and fungi from the phylum Glomeromycota, has a number of benefits for the host plant that reduce environmental stress, including improved water and mineral nutrition absorption and tolerance to different environmental stress factors (Maya and Matsubara, 2013). Yet, some investigations have discovered that arbuscular mycorrhizal fungus has an impact on rhizospheric soil aggregation and microbial community structure. Moreover, edaphic elements like soil composition, moisture, temperature, pH, Cation Exchange Capacity (CEC), and anthropogenic stresses affect how mycorrhizal associations grow and function. The relationship between temperature and the mycorrhizal symbiosis of millet shows that how it impacts soil aggregation is poorly understood. It has been reported that a change in temperature can lead to an increase in the internal and exterior structures of AMFs (Ndeko et al., 2021). The current study investigated the effects of temperature stress and AMF treatment on mycorrhizal fungus colonization and millet line rhizospheric soil aggregation. The research showed that among millet lines, the root colonization rate with AMF was moderate and equivalent. After receiving the AMF inoculation, *Funneliformis mosseae* exhibited the highest percentage of root colonization. Several millet genotypes responded differently to the inoculations with *R. aggregatus* and *F. mosseae*. However, the AMF inoculation had no impact on the rhizospheric soil aggregation of the lines (MAS/RB). According to this study, temperature stress severely affected all growth and physiological markers and greatly slowed down mycorrhizal colonization and rhizospheric soil accumulation (Ndeko et al., 2021). AMF immunization had minimal effect on plant growth when there was no stress. AMF did, however, significantly affect plant growth, mycorrhizal colonization, and millet line mycorrhizal growth response when visible to high temperatures. In terms of millet growth, this study showed that various millet lines react to AMF colonization in various ways. L132 and L220 kept their soil accumulation levels in the control, *R. aggregatus*, and *F. mosseae* treatments due to their mycorrhizal colonization rate and a positive mycorrhizal growth response to high-temperature treatment compared to other lines.

High temperature stress is one of the most significant and harmful stress among the several abiotic stresses. High temperatures are anticipated to worsen in the coming years, with long-lasting effects. This stress negatively impacts the morphological, physiological, and biochemical growth of the plant, which eventually lowers plant output. High temperatures over a certain period of time has an adverse effect on plant growth, metabolism, and general production. Plants must be tolerant to all these negative effects of high temperature due to the frequent seasonal swings, especially in tropical areas. The temperature range that controls plant species affects plant growth, development, and metabolism. Each plant species has a variety of maximum, minimum, and ideal temperature tolerance. Practically speaking, it is well recognized that plants are more harmed by short-term temperature stress than by long-term stress. The midsummer temperature changes are believed to have the most detrimental effects on plant development and photosynthesis. Crop growth and development are the primary factors of how changing environmental circumstances affect crops. All of the major grain crops are affected by climate change and rising temperatures in terms of their development and growth (Mathur et al., 2018).

The hostile effects of rising high temperatures on plant growth (HT) are currently shown in plants. Previous research has shown that AMF have a protective effect under stressful conditions, especially affecting physiological restrictions. To ascertain the protective role of AMF under high-temperature stress, physiological traits with typical phospholipid fatty acids (PLFA) of soil microbial communities, including AMF, have not been investigated. In this study, we investigate how below-ground traits and photosynthetic properties are affected by high-temperature stress in maize plants with and without AMF. Among the photosynthetic traits that improved in AMF + HT plants but decreased in HT-exposed plants were quantum yields of PSI and PSII, electron transport, and fractions of open reaction centers. Photosynthesis is one of the processes that plants are most susceptible to heat. The photosynthetic process starts to suffer as the temperature reaches 38 °C or higher. Both light-dependent processes involving the photosystem II (PSII) and dark-dependent reactions involving the rubisco activase contain thermo-sensitive components of the photosynthetic apparatus. Heat stress lowers oxygen evolution by impairing the function of the oxidizing side of PS II as well as photosynthetic electron transport (Mathur et al., 2021). AMF + HT plants displayed significantly higher levels of AM-signature 16:1ω5cis neutral lipid fatty acid (NLFA), spore density in the soil, and root settlement with lower levels of lipid peroxidation than non-mycorrhizal HT plants. Improved plants were more efficient at photosynthesizing when heated because they had more living biomass that was alive. This work contributes to the empathetic of how AM-mediated plants may endure high temperatures while sustaining the firmness of their photosynthetic system. We may be able to better understand how stress affects plants and the rhizosphere thanks to this work's innovative integration of above- and below-ground elements (Mathur et al., 2021). Research examining the role of AMF on the physiological characteristics of plants is frequently used to lessen the effects of high temperatures on plants. Yet, the microbial populations in the soil play an important part in controlling plant performance and may provide key insights into AMF-mediated stress relief. The lipid reporting of signature markers, such as 16:1ω5cis phospholipid fatty acid (PLFA) and neutral lipid fatty acids

(NLFA) in soil and roots, is used as a stress indicator and offers a detailed description of the alteration in the microbial community as a result of the stress brought on by increased temperature (Mathur et al., 2021). PLFA stress markers that elucidate temperature impacts include cyclopropyl to monoenoic fatty acid ratios and gram-positive to gram-negative bacteria ratios. The trans/cis stress ratio and the Gram-negative stress ratio are two physiological stress indicators. The gram-positive to gram-negative ratio is an indicator of energy restriction (Mathur et al., 2021). The presence of active hyphal biomass in AM-enriched plants contributes to the plants' increased capacity to absorb water and nutrients, improves photosynthetic efficiency, and shields the plants from oxidative damage when exposed to high temperatures. To test if plants exposed to high temperatures displayed any changes, AMF growth (root colonization, spore density, and lipid biomarkers), plant photosynthetic metrics, and variations in soil PLFA bacteria populations were also evaluated (Mathur et al., 2021). We provide data to support the hypothesis that high photosynthetic capacity can be promoted by arbuscular mycorrhizal fungi symbiosis (AMF enrichment) while protecting the photosynthetic apparatus. PSI and PSII were not adversely affected by high-temperature stress thanks to the enrichment of arbuscular mycorrhizal fungus. AMF + HT plants showed recovery for maize plants exposed to high temperatures for all of the parameters looked at. According to the physiological parameters, the abundance of NLFA in AMF + HT over control and high temperature exposed plants alone shows the arbuscular mycorrhizal mediated stress mitigation approach to defend itself and live under high temperature exposure (apparent from fluorescence results). Also, according to our view, one of the possible indicators that arbuscular mycorrhizal fungus helped the plants reduce high-temperature stress could be higher levels of NLFA and a higher ratio of Gram-positive to Gram-negative bacteria in stressed plants. Taking everything into account, our research demonstrates that AMF help plants maintain PSI and PSII stability, mitigate the negative impacts of high temperature disclosure, and enhance photosynthesis, soil quality, and crop growth, all of which lead to a rise in yield. In order to better understand how plants reply to stress, this work is the first to link PLFA (belowground) features with physiological plant qualities. factors delivering unique insight into plant improvement under stress situations (Mathur et al., 2021).

Mycorrhizal symbiosis dramatically boosted biomass output and HS^+ answers in plants when related to controls. Control plants displayed a significant rate of leaf burning (80-100%), in contrast to mycorrhizal plants, which under HS^+ conditions displayed the slightest rate of leaf burning. In the mycorrhizal plants, there was a rise in the antioxidative enzymes superoxide dismutase and ascorbate peroxidase, ascorbic acid content, and polyphenol content. The 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity also responded more favorably in mycorrhizal plants than in control plants at each temperature setting. The results demonstrate that AM fungal colonization decreased heat stress damage in cyclamen plants by enhancing antioxidative activity, and that mycorrhizal symbiosis considerably improved temperature stress tolerance, which promoted plant growth and increased the host biomass under heat stress (Maya and Matsubara, 2013). A temperature increase that surpasses a threshold and lasts long enough to permanently impair plant growth and development is referred to as heat stress. Heat stress is typically understood as a momentary increase of temperatue between 10 and 15°C over the ambient temperature. However, effects could be complicated depending on the magnitude, persistence, and rate of temperature increase. The lethal ROS that are generated in plant cells as a result of heat stress are one of the primary reasons hurting plants (Maya and Matsubara, 2013). The increased activity of enzymatic antioxidants and higher production of nonenzymatic antioxidant molecules imply that the AM symbiosis can protect plants from oxidative stress, lessen ROS damage, and improve their capacity to endure heat stress during plant growth. To completely understand how AM contributes to the production of antioxidants and the metabolism of ROS during heat stress, more research is necessary. It's possible that plants' broad defensive systems in reaction to heat stress are what's causing some antioxidants to be more active than usual. Nonetheless, the inclusive enhancement in plant progress and tolerance to heat stress in AM plants point to potential advantages of AM fungal inoculation for the production of Cyclamen under difficult climatic conditions (Maya and Matsubara, 2013). Second, while the four millet lines were growing in two separate growth chambers, they received two distinct temperature treatments: a control treatment at 32/28 °C for daytime temperatures and a temperature stress treatment at 37/32 °C. Several physiological, mycorrhizal, and soil parameters were assessed together with plant growth and mycorrhization rate. The findings demonstrated that millet lines' mycorrhization rates were moderate and did not significantly differ from one another. *Rhizophagus aggregatus* (22.79%) and the control (9.79%) had less root colonization than *Funneliformis mosseae* (31.39%). For all of the investigated lines, the temperature stress decreased soil aggregation, shoot and root biomass, and mycorrhizal colonization rate. During the control and high-temperature treatments, L220 and L132 had higher MC rates and MGR than the other lines (Ndeko et al., 2021). The MGR significantly outperformed the control when exposed to temperature stress conditions. Inoculation with *R. aggregatus* and *F. mosseae* improved chlorophyll content, root dry weight, and shoot dry weight in comparison to non-inoculated plants. AMF inoculation, particularly with *F. mosseae*, positively impacted millet lines' tolerance to temperature stress. Because AMF in this study demonstrates how these four millet lines significantly respond to temperature stress. As a result, AMF is essential in assisting crops in Sub-Saharan Africa to adapt to climatic changes (Ndeko et al., 2021).

Plant morphological, physiological, and biochemical processes are negatively impacted by high temperatures, which ultimately lowers plant output (Jumrani et al., 2022). AMF may play a crucial role in deciding how the plant community will respond to rising soil temperatures brought on by global climate change. According to increased host plant provision to AMF, a lack of evidence for temperature adaptation by AMF, and variable host responses to AMF. High temperature stress affects plants globally, and elevated soil temperatures have been noted in alpine, tropical, and desert habitats burned-out forested areas. Given that it is estimated that global air temperatures will rise by around 3°C over the next century, it is vital to appreciate how plants answer to rising soil temperatures. Plant roots especially vary in shape, pace of development, and longevity in response to elevated soil temperatures. Reduced root surface area, soil volume explored, and shorter root lifespan may be the results of these alterations, which may lead to decreased root function. Arbuscular mycorrhizae can reduce the host plant's vulnerability to environmental stress because they create symbiotic associations between the roots of most terrestrial plants and fungus from the phylum Glomeromycota. AMF could increase host plants' access to water and nutrients by extending the growth of extraradical hyphae (ERH) into soils where high temperatures prevent root growth, thereby expanding the plants' available habitat. This would be the case if fungi are more tolerant of heat than plant roots, as has been proposed in agricultural systems. However, the advantages to the host plant of discovering new soil habitats may offset the carbon cost of increased fungal respiration at high temperatures. In reality, as temperatures rise, plants allocate more carbon to AMF. The host plant's cost-benefit ratio in response to AMF is dynamic and is influenced by the plant's life stage, species, fungus species and abiotic stresses (Bunn et al., 2009). In light of these findings, the major objective of this work was to look at how the mycorrhizal symbiosis was generally affected by high soil temperatures, taking into account how both plant and fungus symbionts responded to the heat. Increasing soil temperatures increases extraradical hyphae but decreased the root length (Bunn et al., 2009).

It is observed that AMF amelioration can support high photosynthetic capacity and guard against harm to photosynthetic equipment when showing to high temperatures. The results of this investigation may be helpful for dangerously calculating the potential role of AMF in attenuating the harmful properties of high-temperature stress. In the framework of sustainable agriculture, farmers are drawn to helpful microbes like AM fungus. This data suggested that AMF inoculation might be effective in enhancing plant development under difficult environmental conditions. By raising the amount of chlorophyll, the rate of photosynthetic activity, the stomatal conductance, the WUE, the linear electron transfer, and the seed production in soybean plants, the current study indicates the effect of AMF in enhancing their capacity to endure high temperatures (Jumrani et al., 2022).

While AMF had no result on the faces of the plants that were assessed, the biomass of the facultative thermal plants *Agrostis scabra* and *Mimulus guttatus* decreased by 50% in soils with high soil temperatures. The obligate thermal plant *Dichanthelium lanuginosum*, however, only grew in mycorrhizal, biomass, and total root length at higher soil temperatures. With rising soil temperature, mycorrhizal colonization levels and extraradical hyphae (ERH) increased in all host species. The source of the AMF inoculum had no impact on colonization level, ERH length, host plant biomass, or blooming for any host species in either temperature condition, showing that AMF from thermal soils are not well suited to higher temperatures (Bunn et al., 2009). In situ depth distributions of the roots and ERH of *D. lanuginosum* were identified as the AMF species that were active in the plants growing in hot soils, we collected soil cores in the field. While ERH was only found in the hottest soils as examined, with an average temperature of 35°C, roots were restricted to soils with an average temperature of 30 °C. The populations of thermal AMF had both specialized and probably distinct fungus species, according to root molecular studies. Increased host plant allocation to AMF, a lack of apparent temperature adaptation by AMF, and a range of hosts all point to the possibility that AMF may play a key role in determining how the plant community reacts to higher soil temperatures. When grown at high temperatures, both plants exhibit lower respiration rates and greater total carbohydrate stores when isolated from high-temperature soils than equivalent plants from ambient soils (Bunn et al., 2009).

The effects of AMF can differ depending on the plant's tolerance to heat, as evidenced by the fact that the plant that exclusively thrives in thermal soils profited from it at higher soil temperatures, but those that prefer to avoid high temperatures did not. However, plants that showed lower growth committed more carbon to fungal structures even in high-temperature soils, and AMF displayed an rise in ERH and root migration. AMF are thought to be extra heat-accepting than plant roots, according to the field distributions of hyphal and roots. The nonthermal and thermal AMF responded similarly in the greenhouse experiment, demonstrating their excellent temperature tolerance (Bunn et al., 2009). In this work, pot experiments were used to determine how 44°C of extreme temperature stress affected maize plants both with and without AMF. Several factors representing photosynthetic commotion were measured in order to determine the photosynthetic efficiency in maize plants. The quantum competence of photosystem II (PSII), linear electron transport, excitation energy trapping, performance index, and net photosynthetic rate were all observed to increase in AMF (+) plants at 44°C 0.2°C. The main photochemical reaction's efficiency (represented as Fv/Fo) was higher in AMF (+) plants compared to AMF (-) plants. AMF seems to have protected the water-splitting complex under high temperatures before enhancing the basic photochemistry of PSII. Then PSII's primary photochemistry at higher heat conditions follows (Mathur et al., 2018). Basic morphological traits like leaf width, plant height, and cob number increased in AMF (+) plants when compared to AMF (-) plants. AMF (+) plants grew more quickly than AMF (-) plants because they had larger root systems. Chl concentration increased in AMF (+) maize plants compared to AMF (-) maize plants. The increase in Mg absorption brought on by AMF hyphae led to an increase in the overall chlorophyll content in AMF (+) maize plants. Hence, the output of photosynthate and biomass increased. AMF (+) plants therefore outperformed AMF (-) maize plants in terms of photosynthesis when subjected to the stress of high temperatures (Mathur et al., 2018). In a study, Gavito et al. (2005) that temperature directly affects AM fungus growth regardless of the plant host by using cultures of the organisms with altered carrot roots.

IV. CONCLUSIONS AND FUTURE RECOMMENDATIONS

Appropriate agricultural management practices can increase output, reduce erosion, improve soil fertility, and increase the ability of the land to hold onto water. Farmers generally choose to accept the agricultural systems that they are already accustomed to and that are backed by current research and industry rather than searching for critical solutions. Because they don't account for the differences in agroecological zones, cultures, and resource limitations, many of these strategies typically fail in the majority of the places where they are utilized. The fertility of the land must be improved. Thus, biologically based solutions must be used for soil fertility restoration initiatives. AMF inoculation can boost productivity under temperature extreme and this effect strongly supports the use of AMF as a biofertilizer. AMF inoculation can mitigate the detrimental effects of high-temperature stress on crop growth and productivity. Without fact, many plants can grow much more quickly if their mycorrhizal systems are in good shape. Previous studies concluded that N addition had no effect, but temperature rise and AMF suppression had a negative impact on community temporal stability in temperate meadows. AMF richness, dominant species stability, and mycorrhizal colonization were also commonly impacted by these treatments, which suggests the importance of belowground AMF in preserving aboveground plant community temporal stability in the face of climatic change. The aforementioned findings demonstrate the need of monitoring microbial activity in response to impending environmental changes as well as their role in maintaining the structure and functions of the aboveground plant community.

It is crucially necessary to comprehend this mechanism and develop a suitable plant-AMF combination for better utilization of natural resources. Future study should therefore concentrate on holistic approaches incorporating multidisciplinary sciences, such as plant and fungal physiology, soil, and molecular biology, in order to better understand the processes in the plant-AMF-soil continuum. It is safe to conclude that AMF colonization reduced the negative impacts of temperature extreme on the design structure and functionality of the photosynthetic system. Sound agricultural management practices can increase productivity, reduce erosion, enhance soil fertility, and enhance the land's capacity to hold onto water. Farmers frequently find it simpler to embrace the agricultural methods that they are already familiar to and that are supported by current research and businesses rather than seeking out the essential alternatives. Because they do not account for the differences in agroecological zones, cultures, and resource constraints, several of these strategies frequently fail in the majority of the places where they are applied. Increasing soil fertility is crucial. Soil fertility restoration programs must consequently include biologically based systems. It is advised that the effects of temperature on crop production with emphasis on AMF can be taken into considerably larger account in future studies.

ACKNOWLEDGEMENTS

My mother is the source of my inspiration, I express my heartfelt gratitude to my mother Nanimaya Bhantana, my father Rudra Prasad Bhantana and lots of love to my daughter Alaka Bhantana and son Alak Bhantana for their restlessness support in the preparation of this manuscript. Also, the intuition from my wife in divorce Mrs. Sita Paneru Bhantana help me a lot in writing up, designing and assembling this manuscript. I am recently divorced this August.

REFERENCES

1. Abdel Latef AA, Chaoxing H. Arbuscular mycorrhizal influence on growth, photosynthetic pigments, osmotic adjustment and oxidative stress in tomato plants subjected to low temperature stress. Acta Physiologiae Plantarum. 2011 Jul;33:1217-25.

2. Acuña‐Rodríguez IS, Newsham KK, Gundel PE, Torres‐Díaz C, Molina‐Montenegro MA. Functional roles of microbial symbionts in plant cold tolerance. Ecology Letters. 2020, Jun;23(6):1034-48.
3. Arruda B, George PB, Robin A, de LC Mescolotti D, Herrera WF, Jones DL, Andreote FD. Manipulation of the soil microbiome regulates the colonization of plants by arbuscular mycorrhizal fungi. Mycorrhiza. 2021 Oct;31(5):545-58.
4. Barrett G, Campbell CD, Fitter AH, Hodge A. The arbuscular mycorrhizal fungus *Glomus hoi* can capture and transfer nitrogen from organic patches to its associated host plant at low temperature. Applied Soil Ecology. 2011 May 1;48(1):102-5.
5. Barrett G, Campbell CD, Hodge A. The direct response of the external mycelium of arbuscular mycorrhizal fungi to temperature and the implications for nutrient transfer. Soil Biology and Biochemistry. 2014 Nov 1;78:109-17.
6. Bhantana P, Rana MS, Hu CX, Vista SP, Malla R, Joshi BD, Timsina GP. Role of Mycorrhizal Pathways in Plant Phosphorous and Zinc Uptake. Biomedical Journal of Scientific & TechnicalResearch. 2021;36(2):28397-411.Bidabadi, S. S., Mehralian, M., 2020. Arbuscular mycorrhizal fungi inoculation to enhance chilling stress tolerance of water melon. Gesunde Pflanzen, 72:171-179.
7. Bunn R, Lekberg Y, Zabinski C. Arbuscular mycorrhizal fungi ameliorate temperature stress in thermophilic plants. Ecology. 2009 May;90(5):1378-88.
8. Cabral C, Ravnskov S, Tringovska I, Wollenweber B. Arbuscular mycorrhizal fungi modify nutrient allocation and composition in wheat (Triticum aestivum L.) subjected to heat-stress. Plant and Soil. 2016 Nov;408:385-99.
9. Caradonia F, Francia E, Morcia C, Ghizzoni R, Moulin L, Terzi V, Ronga D. Arbuscular mycorrhiza fungi and plant growth promoting rhizobacteria avoid processing tomato leaf damage during chilling stress. Agronomy. 2019 Jun 10;9(6):299.
10. Carvalho M, Brito I, Alho L, Goss MJ. Assessing the progress of colonization by arbuscular mycorrhiza of four plant species under different temperature regimes. Journal of Plant Nutrition and Soil Science. 2015 Jun;178(3):515-22.
11. Chen S, Jin W, Liu A, Zhang S, Liu D, Wang F, Lin X, He C. Arbuscular mycorrhizal fungi (AMF)increase growth and secondary metabolism in cucumber subjected to low temperature stress. Scientia Horticulturae. 2013, Aug 27;160:222-9.
12. Chen X, Song F, Liu F, Tian C, Liu S, Xu H, Zhu X. Effect of different arbuscular mycorrhizal fungi on growth and physiology of maize at ambient and low temperature regimes. The Scientific World Journal. 2014 Jan 1;2014.
13. Devi TS, Gupta S, Kapoor R. Arbuscular mycorrhizal fungi in alleviation of cold stress in plants.Advancing Frontiers in Mycology & Mycotechnology: Basic and Applied Aspects of Fungi. 2019:435-55.
14. Duc NH, Csintalan Z, Posta K. Arbuscular mycorrhizal fungi mitigate negative effects of combined drought and heat stress on tomato plants. Plant Physiology and Biochemistry. 2018 Nov,1;132:297-307.
15. Feng, Sun X, Su Y, Zhang Y, Wu M, Zhang Z, Pei K, Sun L, Wan S, Liang Y. Diversity of arbuscular mycorrhizal fungal spore communities and its relations to plants under increased temperature and precipitation in a natural grassland. Chinese Science Bulletin. 2013 Nov;58:4109-19.
16. Gavito ME, Azcón–Aguilar C. Temperature stress in arbuscular mycorrhizal fungi: a test for adaptation to soil temperature in three isolates of Funneliformis mosseae from different climates. Agricultural and Food Science. 2012 Mar 12;21(1):2-11.
17. Gavito ME, Olsson PA, Rouhier H, Medina‐Peñafiel A, Jakobsen I, Bago A, Azcón‐Aguilar C. Temperature constraints on the growth and functioning of root organ cultures with arbuscular mycorrhizal fungi. New Phytologist. 2005 Oct;168(1):179-88.

18. Gavito ME, Schweiger P, Jakobsen I. P uptake by arbuscular mycorrhizal hyphae: effect of soiltemperature and atmospheric CO_2 enrichment. Global Change Biology;2003 Jan;9(1):106-16.
19. Grey WE. Influence of temperature on colonization of spring barleys by vesicular arbuscular mycorrhizal fungi. Plant and Soil. 1991 Nov;137:181-90.
20. Hajiboland R, Joudmand A, Aliasgharzad N, Tolrá R, Poschenrieder C. Arbuscular mycorrhizal fungi alleviate low-temperature stress and increase freezing resistance as a substitute for acclimation treatment in barley. Crop and Pasture Science. 2019 Mar 4;70(3):218-33.
21. Hawkes CV, Hartley IP, Ineson PH, Fitter AH. Soil temperature affects carbon allocation within arbuscular mycorrhizal networks and carbon transport from plant to fungus. Global Change Biology. 2008 May;14(5):1181-90.
22. Heinemeyer A, Fitter AH. Impact of temperature on the arbuscular mycorrhizal (AM) symbiosis: growth responses of the host plant and its AM fungal partner. Journal of Experimental Botany. 2004 Feb1;55(396):525-34.
23. Jumrani K, Bhatia VS, Kataria S, Alamri SA, Siddiqui MH, Rastogi A. Inoculation with arbuscular mycorrhizal fungi alleviates the adverse effects of high temperature in soybean. Plants. 2022 Aug 25;11(17):2210.
24. Li, S., Yang, W., Guo, J., Li, X., Lin, J. and Zhu, X., 2020. Changes in photosynthesis and respiratory metabolism of maize seedlings growing under low temperature stress may be regulated by arbuscular mycorrhizal fungi. *Plant Physiology and Biochemistry*, *154*, pp.1-10.
25. Heinemeyer A, Fitter AH. Impact of temperature on the arbuscular mycorrhizal (AM) symbiosis: growth responses of the host plant and its AM fungal partner. Journal of Experimental Botany. 2004 Feb 1;55(396):525-34.
26. Madouh TA, Quoreshi AM. The function of arbuscular mycorrhizal fungi associated with drought stress resistance in native plants of arid desert ecosystems: A review. Diversity. 2023 Mar 8;15(3):391.ssc
27. Liu A, Chen S, Chang R, Liu D, Chen H, Ahammed GJ, Lin X, He C. Arbuscular mycorrhizae improve low temperature tolerance in cucumber via alterations in H 2 O 2 accumulation and ATPase activity. Journal of plant research. 2014 Nov;127:775-85.
28. Liu N, Chen X, Song F, Liu F, Liu S, Zhu X. Effects of arbuscular mycorrhiza on growth and nutrition of maize plants under low temperature stress. Philippine Agricultural Scientist. 2016 Sep, 1;99(3):246-52.
29. Liu XM, Xu QL, Li QQ, Zhang H, Xiao JX. Physiological responses of the two blueberry cultivars to inoculation with an arbuscular mycorrhizal fungus under low-temperature stress. Journal of Plant Nutrition. 2017 Nov 8;40(18):2562-70.
30. Liu Z, Li Y, Wang J, He X, Tian C. Different respiration metabolism between mycorrhizal and non-mycorrhizal rice under low-temperature stress: a cry for help from the host. The Journal of Agricultural Science. 2014a May;153(4):602-14.
31. Liu Z, Ma L, He X, Tian C. Water strategy of mycorrhizal rice at low temperature through the regulation of PIP aquaporins with the involvement of trehalose. Applied soil ecology. 2014 Dec 1;84:185-91.
32. Ma J, Janoušková M, Li Y, Yu X, Yan Y, Zou Z, He C. Impact of arbuscular mycorrhizal fungi (AMF) on cucumber growth and phosphorus uptake under cold stress. Functional Plant Biology. 2015 Nov 4;42(12):1158-67.
33. Ma J, Janouskova M, Ye L, Bai LQ, Dong R, Yan Y, Yu X, Zou Z, Li Y, He C. Role of arbuscular mycorrhiza in alleviating the effect of cold on the photosynthesis of cucumber seedlings. Photosynthetica. 2019 Jan 30;57(1):86-95.
34. Martin CA, Stutz JC. Interactive effects of temperature and arbuscular mycorrhizal fungi on growth, P uptake and root respiration of Capsicum annuum L. Mycorrhiza. 2004 Aug;14:241-4.

35. Mathur S, Agnihotri R, Sharma MP, Reddy VR, Jajoo A. Effect of high-temperature stress on plant physiological traits and mycorrhizal symbiosis in maize plants. Journal of Fungi. 2021 Oct 16;7(10):867.
36. Mathur S, Sharma MP, Jajoo A. Improved photosynthetic efficacy of maize (Zea mays) plants with arbuscular mycorrhizal fungi (AMF) under high temperature stress. Journal of Photochemistry and Photobiology B: Biology. 2018 Mar 1;180:149-54.
37. Matsubara, Y., Ishioka, C., Maya, M.A., Liu, J., Takami, Y., 2014. Bioregulation potential of arbuscular mycorrhizal fungi on heat stress and anthracnose tolerance in cyclamen. Acta Hortic. 1037, 813–818.
38. Maya, M. A., Matsubara, Y., 2013. Influence of arbuscular mycorrhiza on the growth and antioxidative activity in cyclamen under heat stress. Mycorrhiza 23, 381–390. http://doi.org/10.1007/s00572- 013-0477-z.
39. Nath M, Bhatt D, Prasad R, Gill SS, Anjum NA, Tuteja N. Reactive oxygen species generation-scavenging and signaling during plant-arbuscular mycorrhizal and *Piriformospora indica* interaction under stress condition. Frontiers in plant science. 2016 Oct 21;7:1574.
40. Ndeko AB, Founoune-Mboup H, Kane A, Cournac L. Arbuscular mycorrhizal fungi alleviate the negative effect of temperature stress in millet lines with contrasting soil aggregation potential. Gesunde Pflanz. 2022 Mar 1;74:53-67.
41. Pasbani B, Salimi A, Aliasgharzad N, Hajiboland R. Colonization with arbuscular mycorrhizal fungi mitigates cold stress through improvement of antioxidant defense and accumulation of protecting molecules in eggplants. Scientia Horticulturae. 2020 Oct 15;272:109575.
42. Reva M, Cano C, Herrera MA, Bago A. Arbuscular mycorrhizal inoculation enhances endurance to severe heat stress in three horticultural crops. HortScience. 2021 Apr 1;56(4):396-406.
43. Silvia, N. D., Sitoe, M., Dames, J. F., 2022. Mitigating climate change: the influence of arbuscular mycorrhizal fungi on maize production and food security. DOI: http://dx.doi.org/10.5772/intechopen.107128.
44. Suzuki N, Mittler R. Reactive oxygen species and temperature stresses: a delicate balance between signaling and destruction. Physiologia plantarum. 2006 Jan;126(1):45-51.
45. Szechyńska-Hebda M, Ghalami RZ, Kamran M, Van Breusegem F, Karpiński S. To Be or Not to Be? Are Reactive Oxygen Species, Antioxidants, and Stress Signalling Universal Determinants of Life or Death?. Cells. 2022 Jan;11(24):4105.
46. Wu QS. Mycorrhizal efficacy of trifoliate orange seedlings on alleviating temperature stress. Plant, Soil and Environment. 2011 Oct 12;57(10):459-64.
47. Xiao D, Chen Y, He X, Xu Z, Bai SH, Zhang W, Cheng M, Hu P, Wang K. Temperature and precipitation significantly influence the interactions between arbuscular mycorrhizal fungi and diazotrophs in karst ecosystems. Forest Ecology and Management. 2021 Oct 1;497:119464.
48. Yan P, Li G, Sun H, Zhang Z, Yang R, Sun J. Can arbuscular mycorrhizal fungi and biochar enhance plant resistance to low‐temperature stress?. Agronomy Journal. 2021a Mar;113(2):1457-66.
49. Yan Z, Ma T, Guo S, Liu R, Li M. Leaf anatomy, photosynthesis and chlorophyll fluorescence of lettuce as influenced by arbuscular mycorrhizal fungi under high temperature stress. Scientia Horticulturae. 2021b Apr 5;280:109933.
50. Yang X, Mariotte P, Guo J, Hautier Y, Zhang T. Suppression of arbuscular mycorrhizal fungi decreases the temporal stability of community productivity under elevated temperature and nitrogen addition in a temperate meadow. Science of the Total Environment. 2021 Mar 25;762:143137.
51. Yeasmin R, Bonser SP, Motoki S, Nishihara E. Arbuscular mycorrhiza influences growth and nutrient uptake of asparagus (Asparagus officinalis L.) under heat stress. HortScience. 2019 May 1;54(5):846-50.
52. Zhu X, Song F, Liu F. Altered amino acid profile of arbuscular mycorrhizal maize plants under low temperature stress. Journal of Plant Nutrition and Soil Science. 2016 Apr;179(2):186-9.

53. Zhu X, Song F, Xu H. Influence of arbuscular mycorrhiza on lipid peroxidation and antioxidant enzyme, activity of maize plants under temperature stress. Mycorrhiza. 2010 Jun;20:325-32.
54. Zhu XC, Song FB, Liu FL, Liu SQ, Tian CJ. Carbon and nitrogen metabolism in arbuscular mycorrhizal maize plants under low-temperature stress. Crop and Pasture Science. 2015 Jan 9;66(1):62-70.
55. Zhu XC, Song FB, Xu HW. Arbuscular mycorrhizae improves low temperature stress in maize via alterations in host water status and photosynthesis. Plant and Soil. 2010 Jun;331:129-37.

This page is intentionally left blank

Contradiction to Neutralization Reactions

Manoj V. Gokhale

Mumbai University

ABSTRACT

This article contradicts Neutralization reactions by considering the real-life examples of the three most common Neutralization Reactions

Keywords: neutralization reactions, gases, unbalanced equations, contradiction.

Classification: LCC Code:QD476

Language: English

Great Britain
Journals Press

LJP Copyright ID: 925625
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural & Formal

Volume 24 | Issue 11 | Compilation 1.0

Contradiction to Neutralization Reactions

Manoj V. Gokhale

ABSTRACT

This article contradicts Neutralization reactions by considering the real-life examples of the three most common Neutralization Reactions.

Keywords: neutralization reactions, gases, unbalanced equations, contradiction.

Author: Electronics Department, Victoria Jubilee Technical Institute, Mumbai, 400098, India. (Mumbai University).

I. INTRODUCTION

Neutralization reactions are defined as “when an acid reacts with an alkali it results in Salt and Water” today. This research article contradicts the Neutralization equations by stating that the result of the reaction of an acid with an alkali not only results in salt and water but also gas. So the general Neutralization reaction is not.

$$\text{Acid} + \text{Akali} \rightarrow \text{Salt} + \text{Water}$$

But in the corrected form it should be

$$\text{Acid} + \text{Akali} \rightarrow \text{Salt} + \text{Water} + \text{Gas}$$

And this is a contradiction to the current Neutralization reactions.

II. MAIN METHODS, RESULTS, AND DISCUSSION

Let us consider the three most common Neutralization reactions that are commonly encountered today.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O \tag{1}$$

$$HCL + NAOH \rightarrow NACL + H_2O \tag{2}$$

$$HNO_3 + KOH \rightarrow KNO_3 + H_2O \tag{3}$$

The first reaction whereby Sodium Hydroxide reacts with Sulphuric acid results in Sodium Sulphate and water. This reaction also releases Sulphur dioxide gas. The second reaction whereby Hydrochloric acid reacts with Sodium Hydroxide results in Sodium Chloride and water. This reaction also releases Chlorine gas The third reaction whereby Nitric acid reacts with Potassium hydroxide results in Potassium nitrate and water. This reaction also releases Nitrous Oxide gas.

As we see the above reactions will change with Sulphur dioxide, Chlorine, and Nitrous Oxide gases on the right side of the equations (1), (2), and (3) respectively, thereby contradicting Neutralization reactions.

From the above discussion, we note that a Neutralization reaction whereby when an acid reacts with an alkali it results not just in Salt and water but also in a gas which is unaccounted in the present three neutralization reactions. Hence Neutralization reactions are contradicted as the reactions need to be re-balanced.

III. CONCLUSION

The Neutralization reactions are contradicted.

Acknowledgement
None.

REFERENCES

None.