Egyptian Journal of Soil Science
http://ejss.journals.ekb.eg/

Advancing Agricultural Resilience in Ararat Plain, Armenia: Utilizing Biogenic Nanoparticles and Biochar under Saline Environments to Optimize Food Security and Foster European Trade

Abhishek Singh[1], Gohar Margaryan[1], Anna Harutyunyan[1], Hasmik S. Movsesyan[1], Hrant Khachatryan[2], Vishnu D Rajput[3], Tatiana Minkina[3], Athanasios Alexiou[4,5,6,] , Dimitrios Petropoulos[7], Athanasios Kriemadis [8], Hassan El-Ramady[9*], Karen Ghazaryan[1]

[1] *Faculty of Biology, Yerevan State University, Yerevan, Armenia*
[2]*Armenian National Agrarian University, Yerevan, Armenia*
[3] *Academy of Biology and Biotechnology, Southern Federal University, Rostov on Don, Russia*
[4]*Department of Research & Development, Funogen, Athens, Greece*
[5]*Department of Research & Development, AFNP Med, Wien 1030, Austria*
[6] *Department of Science and Engineering, Novel Global Community Educational Foundation, Hebersham, NSW 2770, Australia*
[7]*Department of Agriculture, University of Peloponnese, Greece*
[8] *Department of Management Science and Technology, University of Peloponnese, Greece*
[9]*Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University, Egypt*

AGRICULTURE productivity is severely hampered by salinity stress in many parts of the world, including the Ararat Plain in Armenia. The need for food security is growing worldwide, and new strategies are essential to meet this challenge. In the context of the Ararat Plain, this paper examines the potential utility and promising role of biogenic nanoparticles (NPs) and biochar in reducing salinity stress, boosting crop resilience, and guaranteeing sustainable food production. This paper involves the mechanisms underlying salinity stress, as well as the properties and synthesis of biogenic nanoparticles and biochar, and their applications in increasing plant salinity tolerance. The potential application of biogenic nanoparticles and biochar to mitigate the adverse effects of salinity on crops, soil, and water resources has been recently illustrated by several case studies and research findings. Additionally, we go over the safety issues, environmental implications, and potential applications of biogenic nanoparticles and biochar in sustainable agriculture on the Ararat Plain and elsewhere. This paper advances our knowledge of innovative strategies for addressing salinity stress and improving food security in areas with comparable problems.

Keywords: Salinity stress, Bio-nanoparticles, Biochar, Ararat Plain, Soil, Crops, Dry area.

1. Introduction

With 29.740 square km of total land area, Armenia has a comparatively small amount of land used for agriculture about its total area. Merely 2.043 million hectares, or roughly 0.69%, of the nation's 2.974 million hectares of land are classified as agricultural land. Arable land covers 446.0 thousand hectares, or 21.8%, of this region's total agricultural land area. Of these arable lands, 68.1 thousand hectares, or 15.2%, are found in the Ararat Plain, an important agricultural region. However, salinity concerns significantly hinder this region's agricultural potential. About 30,000 hectares of Armenian land are salinized, a serious problem that jeopardizes food security and the sustainability of agriculture. This highlights the urgent need for novel strategies, like biogenic nanoparticles, to combat soil salinity in areas like the Ararat Plain (Ghazaryan et al., 2020a, 2022).

Salinity stress seriously threatens food security in Armenia's historically crucial agricultural region, the Ararat Plain. Salinity, which impairs crop growth, decreases yields, and jeopardizes the livelihoods of local farmers, is a result of increased soluble salt deposition in soil and water (Ghazaryan et al., 2020b). Given the world's ongoing population growth, ensuring food security in these areas, including the Ararat Valley, is crucial. Among other

---

*Corresponding author e-mail: ramady2000@gmail.com
Received: 20/12/2023; Accepted: 24/01/2024
DOI: 10.21608/EJSS.2024.257000.1703

stressors, soil salinity is widespread in arid and semi-arid agricultural environments (Van Zelm et al., 2020; El-Shahawy et al., 2022). When the amount of water-soluble salts in the soil is more than 4 dS m^{-1}, the soil is referred to as saline. Soil salinity and limited water resources are major obstacles to agricultural productivity and are predicted to deteriorate significantly in the coming century (Qureshi and Daba). The need for food is expected to increase by 70% by 2050 due to urbanization is pushing farming into drier or more marginalized areas, necessitating improvements in agricultural production on smaller land areas and with less water input (Pimentel, 2008).

Although numerous approaches have been attempted, depending on the particulars of each case, the majority are either unworkable or, at best, little successful (Khamidov et al., 2022). Both developed and developing countries struggle against salinity, but many are looking for long-term solutions implemented in significant portions of saline areas for better crop cultivation that also fits the environment (Figure 1). Furthermore, studies have been done to improve grain-producing plants that can thrive in extreme salinity environments. As an alternative, developing countries have attempted to address salinity by adopting short-term soil reclamation strategies, many of which have failed and, in some cases, have even worsened the soil salinity. Comparably, the health of the soil has been neglected for a very long time, and the most important area of the planet is still irrigated with salt water, which constantly adds salt to the soil (Zeng and Shannon, 2000; Rana et al., 2019; Ghazaryan et al., 2020a). On the other hand, salinity risk has increased as a result of poorly planned short-term initiatives and the exploitation of marginal areas. This growing concern casts doubt on the safety of food supplies in underdeveloped nations.

Similarly, less developed countries move much more slowly than their more developed counterparts to mitigate the damaging effects of salinity (Manuel et al., 2017). The moment has come to investigate what the developing world can learn from the sustainable practices of the industrialized world. This discovery may help develop better, longer-lasting solutions to the problem of salinity in the soil, which will help raise agricultural yields in many developing countries (Shokat and Großkinsky, 2019). To improve agricultural sustainability and mitigate the negative effects of salinity, creative solutions are needed (Kamran et al., 2019). By enhancing plant resistance to salinity stress, a new field of nanotechnology called biogenic nanoparticles provides promising ways to address this problem. Using biogenic NPs in the Ararat Plain region of Armenia may assist agricultural plants growing under salinity stress, as previous research reports showed that their application in an ecologically comparable saline location helped alleviate crop output (Daba et al., 2019; Shokat and Großkinsky, 2019; El-Ramady et al., 2020; Patil and Chandrasekaran, 2020; Daba and Qureshi, 2021; Dikshit et al., 2021; Rakgotho et al., 2022).

These days, various organic alterations have been applied to minimize the severe effects of salinity, including compost, farmyard manure, biochar, animal manure, and crop residues. Known as "black gold" for agriculture, biochar improves soil quality and crop yield while retaining more carbon (C) in the soil (Kim et al., 2017a; Zulfiqar et al., 2019; Soliman et al., 2022). The term "biochar" refers to biomass that has undergone a decomposition or compositional change caused by the application of high temperatures and heat. It has a significant potential to reduce potential climate change effects, like extended wet spells or harsh droughts (Rezende et al., 2011). By keeping nutrients in the soil and improving its chemical and physical characteristics, biochar serves as a soil conditioner that promotes plant growth (Lehmann et al., 2003). By enriching the physical, chemical, and biological properties and soil enzymatic activity of severely deteriorated soil, thereby supporting a beneficial platform for plant-soil interaction, biochar mitigates the salinity stress, Na^+ adsorption ratio, and electrical conductivity (EC) for sustainable crop production (Guo et al., 2020). Also, biochar limits the ability to absorb of heavy metals for crops growing in unfavorable or poor-quality soils (Gascó et al., 2016), stabilizes heavy metals, and enhances soil aeration, porosity, bulk density, infiltration rate, aggregate stability, water holding capacity, and hydraulic conductivity (Foster et al., 2016). Additionally, according to Zheng et al. (2017) biochar increases microbial quantity and diminishes the negative effects of salinity, heat, and drought on crops. It supports biological N fixation (Osman et al., 2022), increases crop growth and productivity (Murtaza et al., 2023), and eases carbon sequestration. However, recent years have seen a significant increase in interest in the potential application of biochar to enhance soil health (Haider et al., 2022). Many recent reviews (Saifullah et al., 2018; El-Naggar et al., 2020; Abhishek et al., 2022; Singh et al., 2024) have suggested the possible advantages of using biochar in several different fields. To clarify how different types of biochar affect soil and plants, however, synthesis and current knowledge on biochar-soil-plant interactions are desperately needed. This paper covers all the aspects of using biogenic NPs and biochar during salt stress.

Therefore, this study focuses on the role of biochar, and biogenic nanoparticles in mitigating the dry and salinity conditions in Ararat Plain, Armenia. The sustainable nano-approach to optimize food security and foster European Trade in such area also will be discussed.

2. Armenian Agriculture: Fostering European Trade and Sustainability

Armenia agricultural landscape is a rich tapestry, offering a diverse array of crops ranging from fruits to vegetables and grains (Strategy of the main directions ensuring economic development in agricultural sector of the Republic of Armenia for 2020-2030. | FAOLEX). In nowadays much more agriculture products are supply to Russia but Armenia exploring new reading partners in Europe and Middle East countries for increasing their agriculture marketing size. Moreover, Armenia's strategic geographical location provides a logistical advantage, facilitating efficient transportation and distribution of agricultural products to European markets (Better land management - better economic, social and ecological sustainability | FAO in Armenia | Food and Agriculture Organization of the United Nations). The emphasis on organic and sustainable farming practices in Armenia resonates with the increasing European demand for ethically produced and eco-friendly agricultural goods. The country's diverse climate not only supports a variety of crops but also allows for the cultivation of specialized ones that might be challenging to grow in certain European regions (Sustainable Development in Armenia: Learning From the EU - EVN Report). This presents an opportunity for European markets to access distinct and sought-after agricultural products, contributing to a more extensive and diverse food supply.

As collaboration between Armenia and Europe in the agricultural sector strengthens, there is potential for mutually beneficial trade partnerships that enhance economic cooperation. Additionally, introducing Armenian agricultural products to European cuisine can foster a rich cultural exchange, bringing unique flavors and ingredients to European tables. This collaboration supports European food security by diversifying sources and plays a pivotal role in Armenia economic development, contributing to stability and prosperity. The adaptability of Armenian agriculture to changing market preferences and its commitment to meeting international standards ensure that its products comply with European regulations, reinforcing the notion of a dynamic and responsive supply chain. Overall, integrating Armenian crop production into the European supply chain holds promise for bolstering resilience, supporting sustainability goals, and promoting a fruitful exchange between the two regions. There are following some key points for better understanding the need of Armenian agriculture production of European countries (The European Union and Armenia | EEAS):

A. **Diversity of Agricultural Products**
   Armenia has diverse agricultural products, including fruits, vegetables, grains, and livestock. This diversity can contribute to European markets by providing consumers a wider array of options and ensuring a stable and varied food supply.
B. **High-Quality Organic Produce**
   Armenia is known for its traditional and organic farming practices. The production of high-quality, organic agricultural goods aligns with the increasing consumer demand in Europe for healthier and environmentally sustainable products.
C. **Strategic Location for Trade**
   Armenia's geographical location at the crossroads of Europe and Asia makes it strategically important for facilitating agricultural trade. This can aid in improving trade routes and logistics for the import of agricultural goods into Europe.
D. **Climatic Conditions for Specialized Crops**
   Armenia's diverse climate and topography create favorable conditions for cultivating certain crops that may be challenging to produce in other European regions. This can lead to a complementary relationship where Armenia specializes in specific crops that are in demand in Europe.

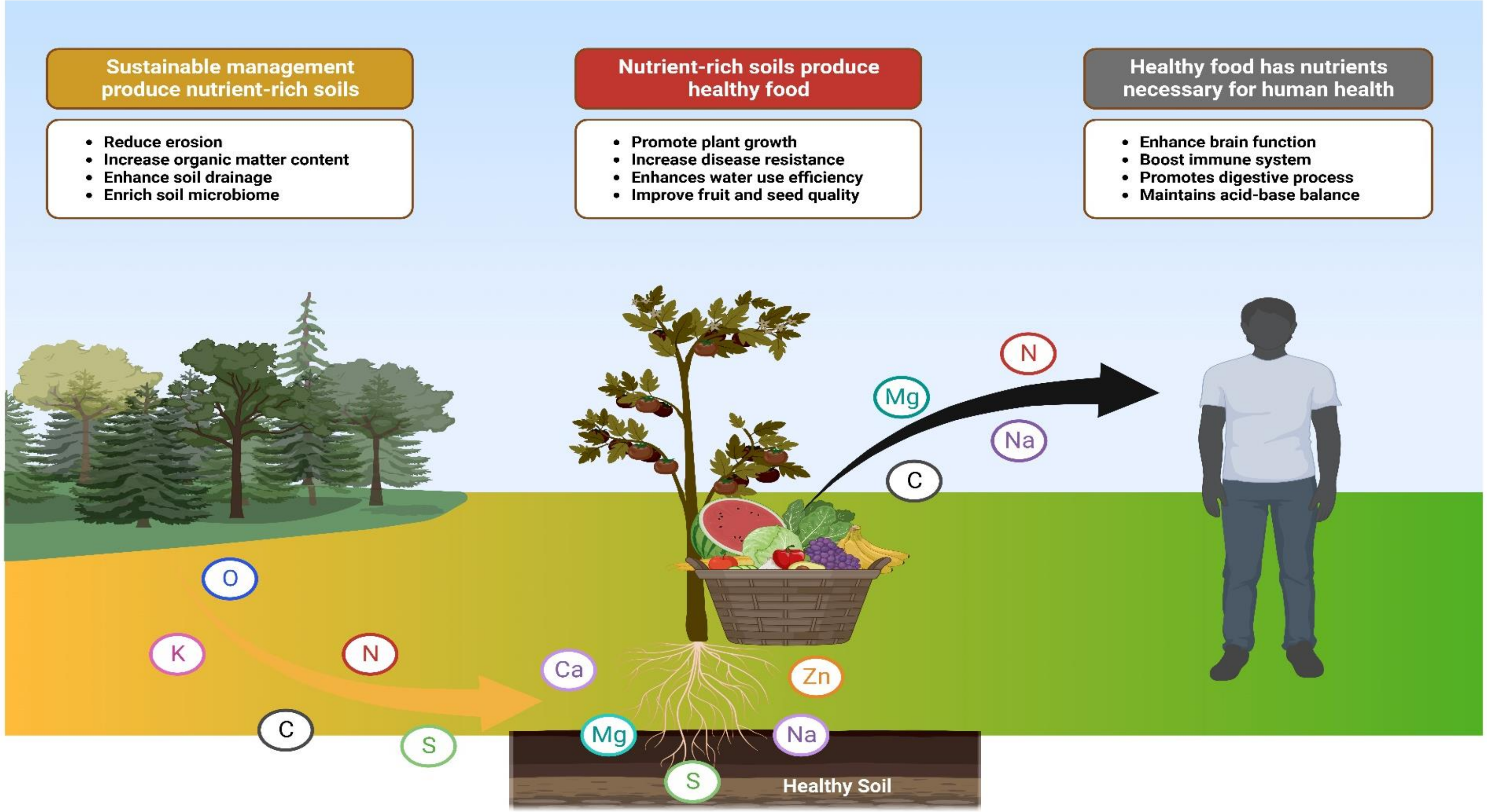

Fig. 1. **The healthy soil produced the healthy products and beneficial for human health.**

E. **Supporting Sustainable Agriculture Practices**
The expertise of European nations in sustainable agriculture presents a great opportunity for collaboration with Armenia. As European countries prioritize sustainable and eco-friendly farming practices, they can benefit from a collaborative effort with Armenia. By working together, Europe can support Armenia's initiatives for producing green and cleaner agricultural products while fostering a mutually beneficial exchange of sustainable agricultural practices.

F. **Market Diversification for European Consumers**
Importing agricultural products from Armenia not only provides European consumers with access to a broader range of products but also introduces traditional and high-value crops that may not be readily available or are produced at a lower cost in Europe. This diversification contributes to enhancing the choices available to consumers, offering unique and culturally significant crops that bring value to the European market. Additionally, the exchange of agricultural goods between Armenia and Europe fosters economic cooperation and strengthens trade relations, creating a mutually beneficial partnership in the agricultural sector.

G. **Economic Opportunities for Armenia**
A boost in agricultural exports to Europe can significantly contribute to Armenia's economic development. This, in turn, can have positive implications for stability and prosperity in the region, which aligns with European interests in fostering economic development globally.

H. **Fostering International Collaboration**
Collaborating with Armenia in the agricultural sector can strengthen diplomatic and economic ties between Armenia and European countries. This collaboration can include the exchange of expertise, technologies, and research in agriculture.

I. **Meeting Increasing Food Demand**
As the global population grows, there is an increasing demand for food. Armenia's agricultural production can contribute to meeting this demand, ensuring food security and stability, which is of interest to Europe as well.

J. **Cultural and Culinary Exchange**
Armenia's unique agricultural products and culinary traditions can offer Europeans an opportunity to experience and appreciate a different culinary culture. This cultural exchange can create new markets and preferences for Armenian agricultural products in Europe.

3. Problem of Saline Soil with Crop Cultivation

3.1 Classification of Salinity

Soils that are acidic or saline are typically the result of hydrological, pedological, and geological processes. These processes include: (1) seawater intrusion through subterranean porous shoreline structures, caused by upstream river flows (Franceschini and Signorini, 2016); (2) salt deposition by wind from saline or sodic water sources onto adjacent lands and (3) the native (parent) minerals' in situ dissolution and significant surface deposition, which affect initial soil salinization process (Ondrasek and Rengel, 2021).

Salinization in the Ararat Plain is a challenging task shaped by its unique geographical and environmental features (Yeghiazaryan, 2017). The existence of residual salts from geological deposits, which include pieces of past marine, lacustrine, alluvial, or colluvial sediments, is one crucial contributing factor. The minerals and salts found in these weathered deposits are rich in sodium and result from the local geological formations. Groundwater supplies and mineralized surface water are also common, which is contributing to the salinization of irrigation water. The problem is exacerbated by ineffective irrigation techniques, which apply salt-dissolved water to fields without proper management. Inadequate drainage systems compound the problem by trapping water in the soil, hindering the leaching of accumulated salts. The salinity problem worsens when lowland regions combine with an arid climate characterized by high evaporation rates and little rainfall. Historical agricultural techniques like crop rotation and selection have also influenced salt buildup. In order to preserve agricultural productivity in the Ararat Plain Valley, specific strategies that consider these particular factors—such as enhanced irrigation and drainage, crop varieties that can withstand salt, and sustainable land management techniques—are necessary to address salinization effectively. Of all these precautions, however, soil management—specifically, controlled nutrient management—is essential to crop production and sustainable agriculture in the Ararat Plain. Therefore, the most important step in determining the salinity level in the Ararat Plain Valley is identifying the saline soil classifications. Previous studies identified soils with salt concentrations of 0.34×109 ha (23%) or higher as saline (ECe > 4 dS m^{-1}) (Tanji and Wallender, 2011). The salinity of a region can be divided into four broad categories based on its ECe value: extreme salinized (ECe > 16 dS^{-1}), high salinized (ECe 8-16 dS^{-1}), moderate salinized (ECe 4-8 dS^{-1}), and slightly salinized (ECe 2-4 dS^{-1}) (Table 1) (Wicke et al., 2011).

Excess soluble salts in solution and Na^+ ions on exchange sites can be detrimental to the health of soil-plant systems (Shahid et al., 2018). Salt-affected soils are classified as saline, saline-sodic, or sodic based on total soluble salts (Electrical conductivity-(EC)) and sodium dangers (sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) of a soil system (Shahid et al., 2018). Classification of salts are particularly investment-worthy saline-sodic and sodic soils which is crucial for the overall rehabilitation and management of salt-affected soils. Understanding the kind of salts present in soils affected by salinity is crucial for management and rehabilitation (Shahid et al., 2018).

3.2 Key Factors for Salinity Stress in Ararat Plain in Armenia

The main region of soil salinity in the Ararat Plain in Armenia is primarily concentrated in the western part of the plain, bordering Turkey. This area faces significant salinity issues due to a combination of natural factors and human activities (Ghazaryan et al., 2024)(Figure 2). The total saline lands in Armenia are about 30,000 ha. In the Ararat Plain, a few major factors that affect soil salinity are as follows:

3.2.1. Natural Saline Deposits: Because the Ararat Plain is located in a closed basin, salts have accumulated in the soil over geological time as a result of natural processes. This phenomenon is exacerbated by the region's arid climate, which results in high evaporation rates, leaving salts behind in the soil (Flowers and Colmer, 2015; Moghanm et al., 2018).

3.2.2. Irrigation Practices: The cultivation of crops like wheat, barley, and cotton, which requires intensive irrigation practices, has significantly contributed to the enhancing in soil salinity. Irrigation water often contains dissolved salts, and when this water is applied to the fields, it leaves behind salts as it evaporates (Ganjegunte et al., 2014; Abd-Elrahman and Shalaby, 2017).

3.2.3. Inadequate Drainage: Inefficient drainage systems in certain parts of the Ararat Plain trap water in the soil, accumulating salts. This problem can be made worse by improperly managed irrigation, which saturates the soil with salt water (Abdel-Fattah and A Merwad, 2016; Kumar and Sharma, 2020; Masilamani et al., 2020).

3.2.4. Over-Extraction of Groundwater: Increasing groundwater salinity may result from excessive groundwater pumping for industrial and agricultural uses. Crop root zones may be impacted by salts that are brought closer to the surface by rising water tables (Rengasamy and Rengasamy, 2010; Mahgoub et al., 2015).

3.2.5. Historical Land Use Practices: Salts have accumulated in the soil over time due to historical land use practices like improper crop rotation and a lack of organic matter incorporation (Farifteh et al., 2006).

4. Navigating Agricultural Challenges in the Ararat Plain Armenia

4.1 Impact of Salt-Affected Soils on Soil Productivity

Scientific investigation is necessary in order to fully comprehend the complex problem of soil salinity and how it affects soil productivity in the Ararat Plain, an area with a long history of agriculture. This historically significant area has encountered a contemporary challenge in the form of salinity stress, necessitating a systematic investigation. The complex interactions among geological, climatic, and human activity in this setting have led to a scientific investigation into the effects of soil salinity on crop yield and soil health in general.

It has been demonstrated that salt affects soil's physical and chemical fertility, which lowers crop productivity. Excess sodium causes colloidal soil particles to swell and disperse, changing the physical properties of the soil and affecting water-holding capacity, root penetration, and seedling development (Singh et al., 2022b). The dispersive action of sodium on soil particles causes soil compaction, alters the pore size distribution, and reduces the total volume of soil, increasing A higher sodium component in the soil reduces the aggregation stability, encouraging clay to disperse (Setia et al., 2010). Second, poor aggregation effects on bulk density, hydraulic conductivity, and mean weight diameter were caused by the high exchangeable salt content, as demonstrated in Figure 1. This has a significant negative impact on crop productivity.

Table 1. According to the rating of EC classification, degree of soil salinity with crop tolerances (adapted from Stavi et al. 2021).

Salinity degree	Range of EC (dS m^{-1})	Crop's tolerance
Non	0-2	Salinity affects are negligible for all plant types
Slight	2-4	Yields of very sensitive crops may be restricted
Moderate	4-8	Yields of many crops are restricted
High	8-16	Only tolerant crops yield is satisfactory
Extreme	>16	Only some extremely tolerant crops can survive.

4.2 Effect of Soil Salinity on Crop Yield

Sodic and saline soils found in arid regions allow plants to maintain an unstable balance with their environment, as excess soluble salts and exchangeable sodium content can inhibit crop growth. Inappropriate management can result in decreased crop yield or complete crop failure, which decreases the land's value and eventually leads to the property to be abandoned for agricultural use (Ganjegunte et al., 2014). Salinity hinders the uptake of water and nutrients from the soil solution, adversely affecting seed germination, seedling establishment, and plant growth (Nekir, 2019). Even in moist soil, plants will die from drought or water stress if the concentration of salt in the field increases to a certain point (Chinnusamy et al., 2005; Ashraf and Foolad, 2007). Crop yields decrease as salt increases above the plants' threshold (Qureshi and Daba). According to research done in Armenia, higher salinity levels have been found to negatively affect wheat and barley genotypes' dry biomass yield and grain yield. Researchers have found that an increase in the osmotic pressure of the soil solution, an induction of ion toxicity and nutritional imbalance, and unfavourable soil physical qualities result in stress for plant growth and development The yields of broad beans and lentils decreased by 5% at an ECe of 2.0 dSm-1. Raising the salinity to 3.1 dSm-1 caused a 15% and 95% decrease in crop yield, respectively (Kitila et al.) . Due to excessive salt accumulation that affects the quality of the fodder, *Alfalfa* and *Rhodes* grass produce less dry matter and have an increased leaf-to-stem ratio (Shahid et al., 2018). Onion yield fell exponentially as soil pH, EC, and ESP increased. As Figure illustrates, enhancing salt stress also inhibited the germination of Rhodes grass (Daba et al., 2019). Increased salinity leads to poor cell elongation due to decreased turgor, cell volume, and cell growth. As a result, poor seed establishment caused by rising salt can reduce grain and biomass production (Chen et al., 2005; Singh et al., 2022b).

5. Unravelling the Multifaceted Impact of Soil Salinity on Crop Agronomy, Physiology, Biochemistry, and Yield

5.1 Effect on Crop Agronomical Traits

There is ample evidence regarding the impact of soil salinity on plant growth and development (Hachicha et al., 2018). How salt stress impairs plant growth depends on various factors, including salt concentrations, intervals, plant species, varieties, photochemical quenching capacities, growth stages, stress types, gas exchange characteristics, photosynthetic pigments, and environmental factors (Aghighi Shahverdi et al., 2018). Multiple investigations were conducted on *Zea mays* L. (Hamada, 1994), *Oryza sativa* L. seedlings (Lee et al., 2011), *Vigna unguiculata* L. (Ibrahim, 2016), *Brassica campestris* L. (Memon et al., 2010), and *Vicia faba* L. (Hanafy et al., 2013) all reached the same conclusion: modest levels of salinization improved plant length. However, the heights of *Vigna mungo* L. (Kapoor and Srivastava, 2010), *Helianthus annuus* L. (Jan), and *Tanacetum parthenium* L. (Mallahi et al., 2018) decreased when exposed to higher concentrations of sodium chloride salt The decrease in plant height revealed the negative effects of high salt levels on photosynthetic rate, growth inhibition caused by a drop in carbohydrate and growth hormone levels, and decreased protein synthesis due to changes in antioxidant enzyme activities (Abdul Qados, 2011). Because there are less soluble salts in the growth medium, the plant's osmotic activity may have changed, leading to an increase in height. It was hypothesized that because low water uptake efficiency results in less leaf area expansion than root growth, soil moisture is preserved during salinization to prevent the formation of a significant amount of soluble salts in the soil (Ahmadi et al., 2018).

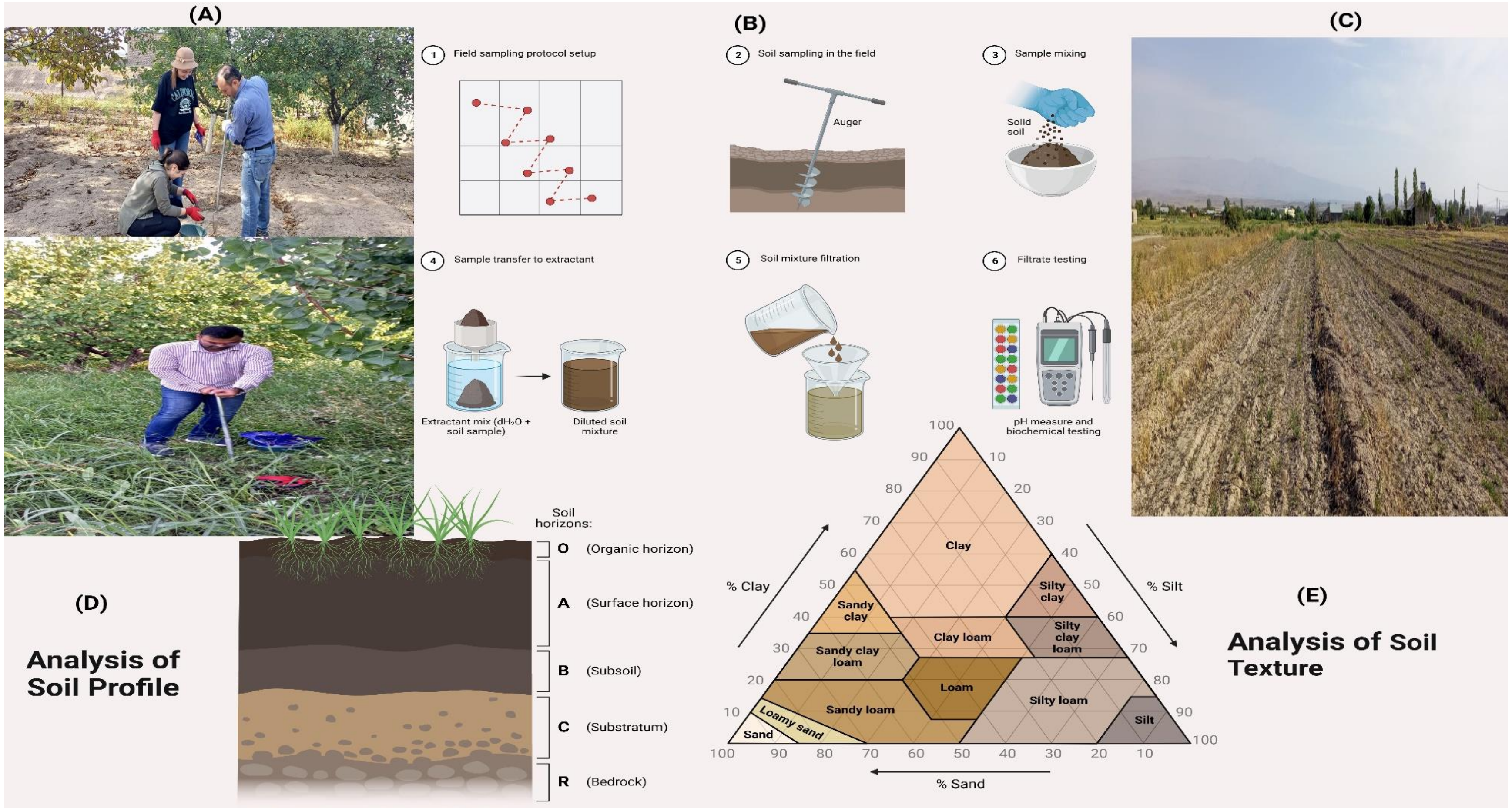

Fig. 2. (A) scientists, researchers, and PhD students from Yerevan State University and Armenian National Agrarian University conducting a soil sampling expedition in the Ararat Plain. (B) The diverse team's collaborative effort, scientific precision in soil collection, and (C-E) the unique landscape of the Ararat plain. Symbolic elements emphasize the global impact and genetic exploration involved.

Numerous studies have demonstrated that a low osmotic gradient in the feeding medium causes a notable build-up of Na^+ and Cl^-ions in the cell sap, which minimizes water intake and affects the plant's morphological characteristics (Aghighi Shahverdi et al., 2018; Van Zelm et al., 2020; Singh et al., 2022a). It has been established that Cl^- and NO_3 as well as Na^+ and NH_4^+ interact to limit N accretion in plants, which has an impact on plant growth and agricultural yield (Cantabella et al., 2017). Plant growth in saline environments may also be stunted by loss of photosynthesis due to stomatal closure and the consequent loss of carbon uptake (Chen et al., 2005). Reduced osmotic pressure causes a notable decrease in nutrient component absorption, which has been observed as a secondary effect of salinity stress on reduced plant feeding (Taha et al., 2000; Peng et al., 2016).

5.2 Effect on Crop Physiological Traits

Soil salinization is a serious issue that can harm crop growth and yield even in irrigated areas (Abbasi et al., 2015). Nearly half of the world's arable land is expected to disappear due to salinity by the middle of the twenty-first century, which could lower agricultural productivity in up to 20% of irrigated fields globally (Foronda, 2022). Salinity stress has recently been found to lower the physiological characteristics of both wheat (*Triticum aestivum* L.) and mung bean (*Vigna radiata* L.) (Hajihashemi et al., 2009; Zayed et al., 2017). Soil salinity may have negative effects on plant growth and yield due to decreased leaf chlorophyll content (Chl a, b, carotenoids) and photosynthesis capacity, as well as energy changes in the mechanisms of ion exclusion, osmotic adjustment, and nutrient imbalance (Flowers and Colmer, 2015; Akter and Oue, 2018). Plant growth in salt-affected soils is adversely affected by three main mechanisms: oxidative damage, ion imbalance, and osmotic stress (Munns and Tester, 2008b). The primary way that plants respond to soils impacted by salt is by becoming less vigorous because of the buildup of dangerous sodium (Na^+) and chloride (Cl^-) ions (Akter and Oue, 2018). While Na^+ ion buildup in plants under salinity stress disturbs ionic equilibrium plant metabolism and promotes oxidative damage, K^+ ion status in plant tissues helps plants develop tolerance towards soil salt (Hajihashemi et al., 2009; Zörb et al., 2019). The K^+ ion concentration in rice (*Oryza sativa* L.) grown in salt-affected soil was only minimally impacted, but the Na^+ ion content was increased in the leaves, and the K^+/Na^+ ratio was dramatically dropped (Singh et al., 2022a). Additionally, there was a noticeable slowdown in strawberry plant growth. These growth retardations may be partially explained by decreased photosynthetic activity caused by decreased Chl a and Chl b at different salinity levels (Talei et al., 2012; Rossi et al., 2019). Na^+ and Cl^-ions entering plant cells cause an ion imbalance in plants and soil, which can result in major physiological problems for the plant (Chen et al., 2005). A high concentration of salts in the soil profile may cause physiological drought because of a reduction in plant osmotic potential, a decrease in water uptake and salt accumulation in the root zone, and consequently the disruption of cell metabolic activities due to ion toxicity (Stavi et al., 2021). Plant cell membranes and organelles are harmed by excessive Na^+ exposure, which decreases the rate of net photosynthesis, stomatal conductance, transpiration, intracellular carbon dioxide, and soil plant analysis development (SPAD) value—all essential physiological processes (Gharaei et al., 2015; Palmqvist et al., 2017; Faizan et al., 2021; Zhang et al., 2021).

5.3 Effect on Crop Biochemical Traits

A breakdown in the cell membrane can cause changes in the antioxidant enzymes, slow down photosynthesis, and prevent the plant from detoxifying the reactive oxygen species (ROS) in the cytoplasm, among other effects on plant physiology (Trchounian et al., 2016). These oxidative processes can disrupt the regular functions of proteins, DNA, and lipids in plants when they are exposed to abiotic stress, especially soil salinity (Biczak et al., 2016). In addition to reducing chlorophyll synthesis, high salt exposure can also change the structure and functions of the pigment-protein complex in plants (Van Zelm et al., 2020). Many enzymes are assumed to be inactive under salt stress, including Mg-chelatase, 5-aminolevulinic acid dehydratase, coproporphyrinogen III oxidase, porphyrinogen IX oxidase, porphobilinogen deaminase, and protochlorophyllide oxidoreductase (Hasanuzzaman et al., 2019). These enzymes are responsible for a decline in leaf water potential, nitrogen absorption, photosynthesis, and an increase in chlorophyllase activity (Razzaque et al., 2010; Talei et al., 2012). Thylakoid and chloroplast membranes are destroyed by salinity-induced superoxide radicals and H_2O_2, which may be a factor in the degradation of chlorophyll (Gill and Tuteja, 2010a; Das and Roychoudhury, 2014; Biczak et al., 2016; Maity et al., 2020). Ultimately, through alterations to the lipid, protein, and nucleic acid structures, these ROS may interfere with regular plant metabolism (Das and Roychoudhury, 2014). Apoptosis, cell shrinkage, chromatin condensation, and DNA breakage have all been linked to the accumulation of greater levels of H_2O_2 caused by soil salinity (Gill and Tuteja, 2010b). Increased reactive oxygen species (ROS) formation in response to salt stress may lead to an increase in malondialdehyde (MDA) contents in thylakoid membranes (Das and Roychoudhury, 2014; Del Río and López-Huertas, 2016a; Qin et al., 2017). MDA content is a reliable biomarker of lipid peroxidation and can be used to estimate lipid peroxidation in plant cells (Del Río and López-Huertas, 2016b). The balance between the production of ROS and their elimination by the antioxidant defense mechanism in plants dictates the degree of damage to these molecules during metabolism (Imlay and Linn, 1988). Plants develop a complex antioxidant defense system to cope with the oxidative stress caused by salinity as a result of the acute oxidative damage that soil salinization causes to plant tissues (Kim et al., 2017b). Antioxidant enzymes protect cells from ROS produced from exposure to salt. It is believed that crop plants, with their robust antioxidant system, have a higher salt tolerance than other types of plants. *Tanacetum parthenium* L. (Mallahi et al., 2018), *Brassica napus* L. (Mohamed et al., 2020), *Oryza sativa* L. (Moradi and Ismail, 2007), and *Glycine max* L. (Gaafar et al., 2020) have all been studied for their varying responses to salinity stress on antioxidative enzymatic and non-enzymatic activities. The enzymatic antioxidative system is made up of enzymes such as peroxidase, superoxide dismutase, ascorbate peroxidase, glutathione reductase, polyphenol oxidase, and others, whereas the majority of the non-enzymatic antioxidative system is composed of carotenoids, ascorbic acid (vitamin C), -tocopherol, and flavonoids (Soltabayeva et al., 2021; Natasha et al., 2022). By eliminating the damaging radicals produced during oxidative stress, the enzymatic antioxidative system helps agricultural plants withstand abiotic stressors like soil salinity (Pulskamp et al., 2007; Mohamed et al., 2017; Tripathi et al., 2017b). Almost every portion of the plant contains antioxidants in their natural form. Natural antioxidants include vitamins, carotenoids, phenols, flavonoids, food-source glutathione, and endogenous metabolites (Noctor and Foyer, 2003). Plants produce antioxidant enzymes as a first line of defense against oxidative stress brought on by soils impacted by salt.

6. Needs of Biogenic NPs: An Environmental and Safety Considerations

Due to their unique physicochemical properties, NPs are valuable in many industries, such as electronics, agriculture, chemicals, pharmaceuticals, foods, etc (Saleh, 2020). Among the most often utilized NPs in a range of industries are metal oxide NPs, which include silicon oxide (SiO2), titanium dioxide (TiO_2), zinc oxide (ZnO), aluminum hydroxide [$Al(OH)_3$], cerium oxide (CeO), copper oxide (CuO), silver (Ag), nano-clay, carbon nanotubes, nanocellulose, etc (Pulit-Prociak and Banach, 2016; Kaphle et al., 2017). However, the local ecology and its inhabitants are suffering from the nano-waste created as a result of the massive release of NPs into the environment (air, water, and soil) by various sectors. NP toxicity is influenced by a number of factors, including size, nature, reactivity, mobility, stability, surface chemistry, aggregation, storage duration, etc (Wang et al., 2013a; Tripathi et al., 2017b). The use of NPs negatively impacts the health of both human and animal.

NP exposure has been related to a number of diseases, including diabetes, cancer, bronchial asthma, allergies, inflammation, and other conditions (Mukherjee et al., 2013). Numerous NPs, including Au, TiO_2, have been shown to be dangerous, and their toxicity even affects an animal's reproductive system (Fig 3) (Wang et al., 2013b). Inhaled or ingested, NPs are absorbed by cells through the processes of phagocytosis and endocytosis. Once inside the cell, they cause the release of reactive oxygen species (ROS) which damage mitochondria, cause lipid peroxidation, and so forth (Keunen et al., 2011; Nair and Chung, 2014; Kharusi et al., 2019; Li et al., 2022). It has been demonstrated that a number of NPs, such as Ag, Cu, ZnO, Ni, etc., block the activity of microbes' enzymes. The ecosystem's food network is also being disrupted by the overproduction of NPs (Tripathi et al., 2017b). The toxicity of NPs to a variety of organisms, including microbes, animals, and plants.

6.1 NPs based Phytotoxicity in Plants

Plants are extremely valuable to the ecosystem because they can produce oxygen and carry out photosynthesis. Compared to other organisms, plants may be more susceptible to NPs pollution because all plant parts—roots, shoots, and leaves—are regularly in contact with air, water, and soil.

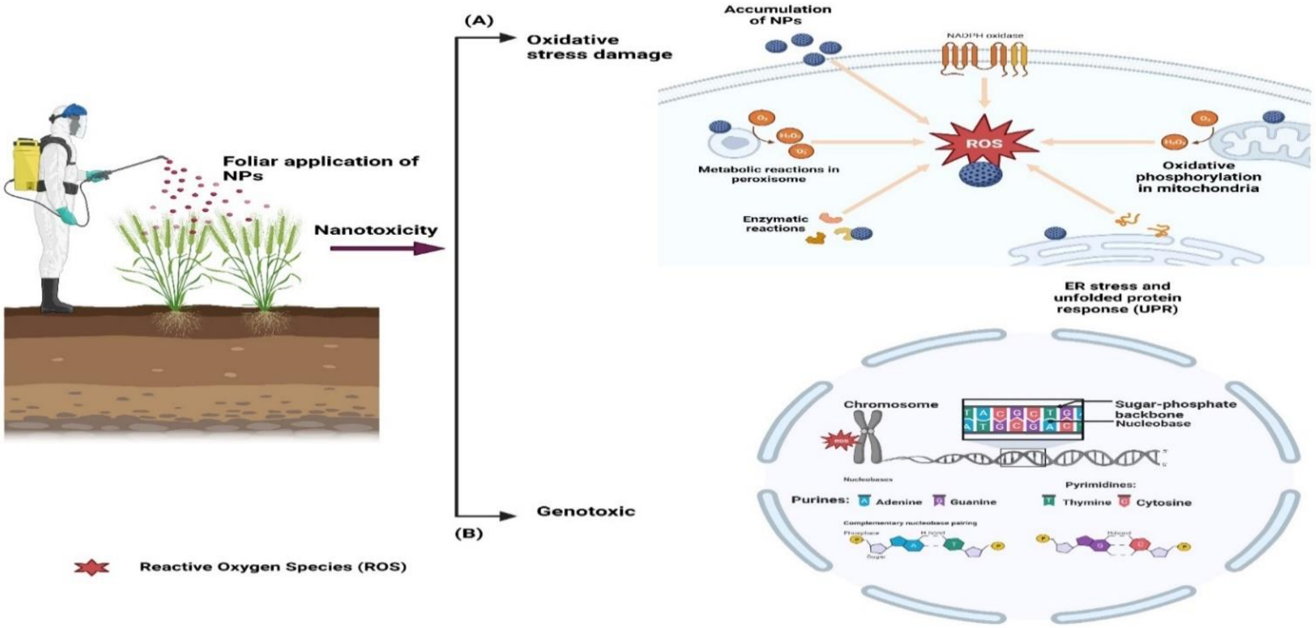

Fig. 3. Nanotoxicity effect on cells oxidative and genotoxic stress in plants (Singh et al., 2024).

While roots can specifically absorb NPs from soil and water, leaves allow atmospheric pollutants to enter the plant body through their stomatal pores (Wang et al., 2013a; Tripathi et al., 2017a).

It has been found that NPs damage and impede the growth and development of plants. ROS production is primarily responsible for plant toxicity; ROS triggers lipid peroxidation, which damages DNA and reduces photosynthetic pigments, plant biomass, soluble protein content, and other factors (Verma et al., 2018). Plants have an antioxidant defense against oxidative stress in the form of enzymatic and non-enzymatic antioxidants, but this process may be damaged in the presence of higher levels of oxygen (Verma et al., 2018).

6.2 NPs based Genotoxic in Plants

While gene toxicity can be demonstrated by DNA damage in plant cells, the morphological and physiological consequences of NPs on plants can be assessed. One can assess the phytotoxicity of nanoparticles by evaluating the effects on crucial physiological parameters of plants, such as germination, biomass production, leaf number, photosynthetic capacity, root and shoot length, etc. Examining plant root cellular analysis for aberrations in chromosomes, mitotic index, and other factors is the most straightforward method of observing genotoxic effects (Barbafieri and Giorgetti, 2016). Due to its extensive use and high demand, one of the most commonly produced metal oxide NPs is silicon dioxide. SiO_2 NPs have been found to have beneficial benefits on a wide range of plants, including *Oryza sativa, Vicia faba, Solanum lycopersicum, Medicago sativa,* etc (Adhikari et al., 2013; Simopoulos, 2022). *Slomberg* and *Schoenfisch* (Zmeeva et al., 2017) studied the toxicity of SiO_2 NPs in *Arabidopsis thaliana*, Karimi and Mohsenzadeh (Karimi and Mohsenzadeh, 2016) studied the toxicity in *Triticum aestivum* another researcher Silva and Monteiro studied the toxicity in *Allium cepa* (Silva and Monteiro, 2017). *Z. mays* and *Vicia narbonensis*, *V. narbonensis*, *V. faba*, etc. have all shown to be adversely impacted by TiO_2 NPs (Ruffini Castiglione et al., 2014, 2016). ZnO NPs have a sizable market share in agricultural applications, such as fertilizers and pesticides (Singh et al., 2023; Verma et al., 2021). AgNPs inhibited the growth of Chlorella vulgaris and Dunaliella tertiolecta, two types of green algae (Oukarroum et al., 2012). This was accompanied by increased ROS generation and lipid peroxidation. Green algae like *Pithophora oedogonia* and *Chara vulgaris* were also found to be sensitive to Ag NPs (Dash et al., 2012).

7. Needs of Biochar: An Environmental and Safety Considerations

Vegetable or animal-based biochar is a substitute for carbon sequestration and an organic soil conditioner. It can be added to agricultural soil to increase crop production potential and sequester carbon (Petter et al., 2012; Dennis et al., 2015; Zulfiqar et al., 2019). Biochar is used for more than just increasing crop productivity and sequestering carbon; it also reduces other major greenhouse gas emissions. According to research published in adding 30 g kg^{-1} of biochar to the soil significantly reduced nitrous oxide and methane emissions (Petter et al., 2012). The author speculates that these observations could be the result of enhanced soil aeration, a decrease in anaerobic conditions, and perhaps a reduction in the nitrogen cycle through an increase in the soil's C/N ratio. Additionally, by influencing nitrification and denitrification, two major processes that produce the greenhouse gas nitrous oxide, biochar can change the rates at which nitrogen cycles in soil systems. Some experiments were reported that biochar may have an effect on the activity of ammonia- and nitrite-oxidizing bacteria in soil, which could reduce N_2O emission; however, the rate at which biochar is applied to the soil will determine these effects (Helaoui et al., 2023; Wu et al., 2023; Zhang et al., 2023). Because biochar contributes to carbon sequestration and increases crop productivity, its use as a sustainable soil corrective has been suggested as a appealing approach to reduce greenhouse gas emissions (Singh et al., 2018; Nan et al., 2021; Qi et al., 2021). Calculation by using biochar could decrease yearly net emissions of CO_2, N_2O, and CH_4 by 12% without compromising soil health, availability of food, or ecosystems preservation (Woolf et al., 2010). These qualities exhibited by biochar not only help the soil retain more water and nutrients but also enable the adsorption of a variety of potentially harmful substances, such as pesticides heavy metals and other contaminants (Ali et al., 2017; Zhang et al., 2020).

Furthermore, by raising organic carbon and nutrient levels, cation exchange capacity (MSK), hydraulic conductivity, and cation exchange capacity (Lu et al. 2015; Chintala et al. 2014; Akhtar, Andersen, and Liu 2015a), a biochar supplement encourages plant growth. According to research by Akhtar et al. (2014), biochar considerably increased the levels of chlorophyll in drought-stressed plant leaves as well as their stomatal density, relative water contents (RWC), photosynthetic rate (Pn), stomatal conductance (Gs), and water use efficiency (WUE). Because of its great capacity for adsorption, biochar reduces the adverse effects of salinity by limiting the absorption of Na^+ (Akhtar, Andersen, and Liu 2015a). This function decreases the quantities of salt that builds up in plant tissues, which in turn minimizes electrolyte leakage (Lashari et al. 2015).

Improving K^+ availability is thought to be an efficient way to optimize the K:Na ratio to enhance plant development and yield under salt stressed conditions (Cakmak 2005; Chakraborty, Sairam, and Bhaduri 2016)., as Na^+ accumulation and K^+ nutrition issues are important characteristics of salt-stressed plants (Liu and Zhu 1997; Shams et al. 2020). According to Drake et al. (2016) and Usman et al. (2016), biochar limits the amount of Na^+ that crops can absorb and lessens salinity stress by increasing the concentration of K^+ in salt-affected soils. Thus, a variety of uses for biochar become evident, including improving soil structure through chemical bonds with inorganic macromolecular structures to prevent landslides during wet seasons; storing rainwater and using it for irrigation before releasing it during dry spells; H^+ and OH^- ions retention and release during soil pH regulation; retention of metal ions that are harmful to plants (e.g., Al) or nutrient metal ions (Ca, Fe, Cu) from plants; a boost in agricultural productivity and plant growth; reduction in the amount of N_2O released; less demand for mineral fertilizers; and rise in the soil's organic carbon stock through the sorption of soil's labile organic matter onto biochar particles, which inhibits the mineralization of the soil (Kookana, 2010). Thus, adding biochar to soil can change a number of its physical, chemical, and biological characteristics. The section below goes over each of these effects of biochar.

8. Biogenic Nanoparticles: Synthesis and Properties

An overview of biogenic nanoparticles, involving how they are made from biological materials like fungi, microbes, and plants, is presented in this section. We investigate the unique attributes of biogenic nanoparticles, making them excellent agricultural application options due to their small dimension, huge surface area, and biological compatibility. Green nanotechnology is rapidly expanding to produce novel NPs with little effect on the environment. It is feasible to synthesize NPs using natural decreasing and stabilizing agents via the biological production techniques (Figure 4). It is economical and environmentally safe to use this method because it does not require energy or hazardous substances. Organisms which vary from single-cellular to multicellular, including bacteria, fungi, actinomycetes and yeast, algae, and plant substances, are used in the top-down biological synthesis of nanoparticles (Shaligram et al., 2009; Thiruvengadam et al., 2018; Mukherjee et al., 2021). The production of nanoparticles via microbial mediated synthesis is another method. Extracellular and intracellular filtrates from microbial cultures are used as a means of reducing in this synthesis technique to produce nanoparticles. Actinomycetes, yeast, fungi, and bacteria are among the microorganisms that can survive in harsh conditions and withstand metals (Zhang et al., 2011). These characteristics enable microorganisms to withstand, build up, and alter metals into ions of metal.

For example, initial microbes nanoparticles made from gold were produced through Bacillus subtilis (Southam and Beveridge, 1994). Similar to this, the bacteria create a range of metal nanoparticles, involving those of silver, gold, copper, iron, zinc, platinum, and selenium. Redox reactions via the extracellular and intracellular channels commonly achieve transformation of metals into metal ions. The metal is taken up by bacterial cells and subsequently converted to metal ions by the enzymes NADH and NADH-dependent nitrate reductase. It has been demonstrated that the same enzymes used in the electron shuttle donor processes can also be used to synthesise *Bacillus licheniformis* silver nanoparticles (Kalishwaralal et al., 2008). Nitrate reductase and anthraquinones can be used by the fungus *Fusarium oxysporum* to produce nanoparticles of silver (Durán et al., 2005). The bacterial and fungal-mediated production of metal nanoparticles mentioned above suggests that NADPH nitrate reductase is possibly an essential bio-factor in the production of metal nanoparticles.

Green nanoparticles provide a substitute to the conventional approach, but it is still preferable to synthesize and produce NPs using a simple method. There were plenty of biodiversity (plants and germs) in the fictitious universe However, from the perspective of production and marketing, these bio-resources must be used. The cost of dealing with microbes, the challenge of expanding up production, the risk of genetic transformation, and the problems of large-scale cultivation and post-production processing are some of the factors that put an obstacle to the synthesis and application of nanoparticles. Potential avenues for a more rational direction of future investigations include using plants as sources for creating of nanoparticles. Phytochemicals like polysaccharides, polyphenols, alkaloids, phenols, terpenoids, saponins, tannins, and vitamins are widely found in plants. These components effectively diluted and stabilized the NPs. There are numerous advantages to using plant substances as a production resource, such as easy expansion, purgative properties, cost-effectiveness, ample availability, and easy scaling up for mass production. Biological entities can be effectively applied to synthesize well-characterized, extremely tolerate nanoparticles.

7.1 Biochar: Production and Properties

By pyrolyzing organic waste materials (such as crop residue, animal dung, or poultry manure) at high temperatures (300–600°C) and low oxygen levels, biochar—a product rich in carbon—is created (Kookana, 2010). Pyrolysis can proceed either slowly or rapidly. Therefore, both the pyrolysis temperature and roasted matrix have a major influence on the attributes of biochar. The type of raw biomass product and the pyrolysis process circumstances determine biochar's chemical and physical attributes (Qayyum et al. 2015). The biomass is transformed into a primarily stable and resistant organic carbon (C) compound when heated to high temperatures ranging from 300°C to 1000°C. Highly produced particular surface areas, elevated porosity, pH, charcoal, and carbon percentages are encouraged by high pyrolysis temperatures; however, small capacities for cation exchange (CEC) and volatile compounds are hindered (Kookana, 2010). Furthermore, the kind of substrates greatly impact the nutritional value of biochar (Ippolito et al., 2020).

Numerous farming and forestry production systems present a significant quantity of created waste, such as sliced waste, decaying wood, extra seedlings, lumber mill, and crop waste left in the field after harvesting. Biochar can be made from a large number of these leftovers (Glaser et al., 2002). Plant leftovers and animal waste materials were the two predominant kinds of substrates for biochar up until this point (Zhang et al., 2020). Manure-derived biochar’s made larger CEC even at higher pyrolysis temperatures, while biochar’s made from plants (crop leftovers and wood biomass) showed increased surface areas, carbon contents, and volatile compounds (Bruun et al., 2023).

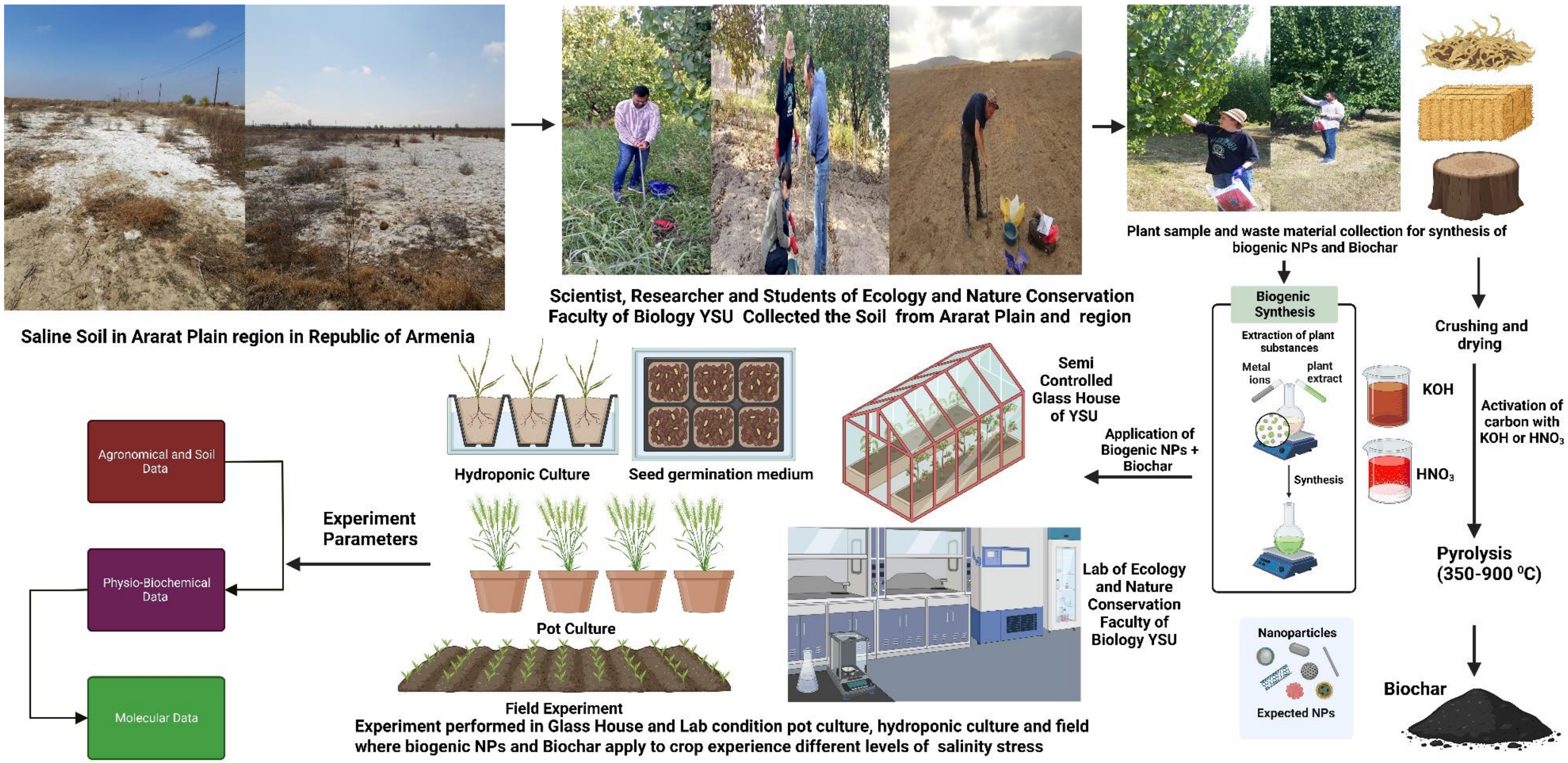

Fig. 4. The synthesis process of biogenic nanoparticles (NPs) and biochar derived from plant leaves and crop waste materials. The methods employed in this synthesis serve as a foundation for further research, exploring diverse avenues to comprehend salinity stress in various ways.

As a result of its warmth modification, this material decays more slowly than non-pyrolyzed organic material, resulting in an extensive permanent carbon reservoir in the soil that is approximately 1500–2000 times more durable. High-quality biochar has a reactive peripheral form that functions as the environment's typical organic material and an interior structure that is comparable to graphite, which retains carbon in the soil for hundreds or even thousands of years. The wide range of possible biomass that can be utilized for creating biochar makes it tough to define the material's characteristics. Furthermore, the description of the finished product is hampered by the carbonization circumstances used to convert biomass into biochar. It is distinguished by a significant amount of minerals (Na, K, Mg, Fe, etc.), a high pH, high electrical conductivity, a small amount of ash and unstable matter, and a high amount of overall organic carbon (30–70%) depending on the temperature, aeration, and time of pyrolysis (Glaser et al., 2002).

In order to assess the development of roots and shoots of barley (*Hordeum vulgare* L.), Hansen et al. (2016) used two types of biochar: grass gasification biochar and trees gasification biochar in sandy soil. Because grass gasification biochar offered significant potential for boosting yields of crops in rough sandy soils by improving soil water maintenance and promoting root growth, they found that it was more successful than applying trees gasification biochar to the soil.

Almaroai et al. (2014) applied two types of biochar made from maize. The study's findings showed that adding biochar to sandy loam soil positively impacted plant development, nutrient uptake by plants, soil mineral contents, and biological attributes.

9. Applications of Biogenic Nanoparticles for Salinity Stress Management

Plants' basic metabolism is changed by salt stress since it disrupts the ionic and osmotic equilibrium within the cells (Parida and Das, 2005). One of the primary causes of disruptions in the development of plants under salty conditions is an excessive amount of sodium and chloride ion accumulation (Munns and Tester, 2008b). This build-up causes changes in cellular metabolism, ionic equilibrium, and membrane function. Standardizing cellular osmotic potential and reestablishing cellular ionic equilibrium are two of the pathways by which plants naturally tolerate salt. It has been proved that applying NPs derived from plants may considerably mitigate the negative effects of salt stress on plants. Selenium NPs obtained from leaves of *Hordeum vulgare* have been found to be quite helpful in mitigating the adverse consequences of salt stress by enhancing flavonoid compounds and phenolic material contents, amount of photosynthetic pigments, root and shoot length, fresh and dry weight, and decreasing plant stress indicators, such as hydrogen peroxide and malondialdehyde (Habibi and Aleyasin, 2020). When exposed to salinity stress, *Abelmoschus esculentus* benefited from an exogenous application of zinc NPs made from *Sorghum bicolor* extract of leaves, which enhanced general plant development and photosynthetic indices (Zafar et al., 2021). Foliar application of zinc oxide NPs obtained from *Phoenix dactylifera* leaf extracts improved overall biomass, growth rate, and characteristics of *Vigna unguiculata* and *Abelmoschus esculentus* subjected to salinity stress (Alabdallah and Alzahrani, 2020; Mohammad Alabdallah and Saeed Alzahrani, 2020). When titanium oxide NPs from *Buddleja asiatica* leaves were applied to wheat, it was able to prevent damage and alterations brought on by salinity-induced morphological, physiological, and biochemical modifications (Mustafa et al., 2021). By improving their biochemical and growth parameters, gold and silver NPs made from *Mentha piperita* rhizome extracts have been demonstrated to mitigate the detrimental effects of salinity stress on the plant species (Aliakbarpour et al., 2020). *Phaseolus vulgaris* can benefit from the application of calcium oxide nanoparticles (NPs) synthesised with *Juglans regia* when it comes to salt stress and other crucial physiological and developing parameters (Koca et al. 2020) Potential Effects of CaO Nanoparticles on Germination of Common Bean Under Salinity Stress). By applying phytogenic NPs, one can control how plants respond to abiotic stress through their signalling mechanisms. It has been demonstrated that triggering calcium-mediated stress reaction paths in *Triticale callus* tissues is a useful tactic for reducing the harmful effects of salt stress (Yazıcılar et al., 2021). The *Punica granatum* fruit extract is used to create these NPs. Biosynthesized NPs defend plant cells from ionic toxicity when exposed to salt stress (Wahid et al., 2020; Zahra et al., 2021). Foliar administration of photogenic gold NPs significantly changed the extent of ionic accumulation in root and shoot by increasing the levels of protective enzymatic (e.g., glutathione reductase, superoxide dismutase, ascorbate and glutathione peroxidases) and non-enzymatic (e.g., glutathione and ascorbate antioxidants) during salinity stress (Zahra et al., 2021). When sulfur nanoparticles (NPs) derived from *Ocimum basilicum* were applied to wheat plants under salt stress, the plants exhibited improved ionic ratios of sodium and potassium ions in addition to increased nutrient uptake (particularly, potassium, nitrogen, and phosphorus content). Furthermore, by promoting proline levels and antioxidant enzyme activity in *Carthamus tinctorius* in response to salinity stress, ZnO NPs obtained from *Carica papaya* altered ROS and antioxidant metabolism (Heikal et al., 2022).

Mineral salts are a significant source of stress for plants, especially in arid and semiarid areas where they can negatively affect crops. Over 1.1 Gha, or more than 7% of the world's total land area, is predicted to be influenced by excessive soil salinity and/or sodicity (Qi et al., 2021). Salinity alters membrane permeability and the body's capacity to take in water and nutrients. These modifications impact the plant's water and nutrient equilibrium, metabolism, hormone balance, gas exchange, and the creation of ROS (Munns and Tester, 2008a; Naz et al., 2016; Mahmoud et al., 2019; Fan et al., 2020; Pastuszak et al., 2022). The plant ultimately dies as a result of all these modifications, which impair cell development and division, vegetative and reproductive progress, and the speed of leaf senescence (Feitosa De Vasconcelos).

When biochar is applied to saline soils, it enhances the amount of nutrients and organic matter in the soil, boosts the ability to convert cations, and substitutes Na substitution locations with Ca in the soil solution, which helps to maintain the structure of the soil. Consequently, biochar regulates soil water retention capacity and air porosity by improving physical characteristics. Furthermore, biochar serves as an environment for a variety of soil microorganisms that can enhance soils influenced by sodium chloride (Kim et al., 2017a; Abbas et al., 2020; Seleiman et al., 2020; Foronda, 2022).

Furthermore, biochar can accelerate salt leaching, which shortens the time needed to decrease the quantity of salt to a level appropriate for crop development (Zulfiqar et al., 2019). Additionally, as opposed to readily degraded molecules derived from additional organic changes, biochar enhances the endurance of biological molecules that would aid in binding soil aggregates for extended periods of time and enhances soil organic C (Abbas et al., 2020).

Because of its exceptional capacity for adsorbing salt (Na^+), biochar was found to be able to reduce salinity stress in potatoes when added to salt-affected soil. Another study found that implementing biochar improved grain yield and development in saline conditions (Helaoui et al., 2023).

The saline soil treated with pyroligneous solution (PS) and biochar poultry waste compost (BPC) enhanced the amount of microbial biomass carbon and the enzyme activity of urease, invertase, and phosphatase in large amounts and rhizosphere soils under maize growing (Kim et al., 2017a). Applying 30 g of biochar per m−2 of salt-affected soil resulted in a raise in electrical conductivity but did not change pH (Thomas et al., 2013). In contrast to that, in saline soil, a biochar made from furfural (utilized in the making of artificial resin) boosted soil organic matter, cation exchange capability (CEC), and accessible phosphorus while reducing the pH (Thomas et al., 2013). Therefore, adding biochar to salt-impacted soils may enhance plant development by increasing the physical and chemical characteristics of the soil as well as its biological function. One of the main advantages of applying biochar to saline soils is that it may also raise the quantity of K in the soil, which in salt-affected soils offsets the negative effects of Na^+ (Guo et al., 2021). In keeping with a study performed by Lin et al. (2015) revealed that the use of biochar in saline soil elevated the productivity of wheat and soybeans by boosting plant resistance to salt by raising the K^+/Na^+ ratio and substitute potassium concentration in plant cells.

10. Regulation NPs based goods in EU and Non-EU nations

This study reveals that numerous nations or regions worldwide market and employ nano-based goods in agriculture. Different methods are used to control and assure its safe usage. The EU and Switzerland are the only regions with nano-specific provisions in agriculture foods legislation, including information requirements for NMs risk assessment, legally binding definitions of "nanomaterial," and the obligation to label or report NMs in products. There is also an EU guideline for a generally applicable definition of “nanomaterial”. All EU regulatory definitions of “nanomaterial” employ size as the key descriptor. Cosmetics Regulation No 1223/2009 defines NMs as insoluble and bio-persistent compounds. All other uses have special information needs and risk assessment for qualities like solubility or deterioration. The European Parliament's Committee on Environment, Public Health, and Food Safety (ENVI) found that EU regulation is stricter and more consumer-friendly than US legislation (Mudgal, 2014). REACH mandates all chemicals, including NMs, to be registered and submit safety data. TSCA in the US requires safety data only in certain cases, but the US-EPA previously in April 2015 proposed using TSCA for one-time reporting and record-keeping of existing exposure and health and safety information on chemicals in the market that are manufactured or processed as nanoscale materials. The study found that EU food regulation covers manufacture, processing, and distribution from “farm to fork” (Mudgal, 2014). The US monitors only “registered facilities” in the manufacturing and processing supply chain to prevent and intercept tainted food. The EU's cautious approach considers scientific uncertainty, economic costs and benefits, and consumer perspectives when handling hazards. The US uses science-based evaluations to show hazards and regulate (Mudgal, 2014).

Several non-EU nations regulate NMs in agri/feed/food broadly. US, Australia, New Zealand, and Canada have non-mandatory frameworks and believe current regulatory frameworks competent to adapt to NMs. Malaysia is adding nanotechnology requirements to its agri/feed/food regulations (Unclassified DSTI/STP/NANO(2012)22/FINAL Organisation de Coopération et de Développement Économiques Organisation for Economic Co-operation and Development Directorate for Science, Technology and Industry Committee for Scientific and Technological Policy Working Party on Nanotechnology REGULATORY FRAMEWORKS FOR NANOTECHNOLOGY IN FOODS AND MEDICAL PRODUCTS, 2013).

Working definitions of NMs are used outside the EU because no legally enforceable definitions exist. Some nations (US, Canada) define NMs or nanotechnology by other features or occurrences outside size. This emphasises NMs with distinct hazards and higher risk assessment priorities. Iran, Taiwan, and Thailand have monitoring and labelling systems for consumer items containing NMs (e.g. NanoMark), however they differ from EU labelling requirements (Chavez-Hernandez et al., 2024).

A solid safety net and regulatory frameworks for nanotechnology goods are crucial as nanotechnology applications evolve and more, more complex items reach the market. A case-by-case risk evaluation of each NMs or nanoform, as advised and implemented in certain countries, is not the most efficient long-term approach to nanoproduct safety since it would demand too many resources and hinder innovation. Research, international organisations, and industry are identifying common determinants of NMs risks to improve approaches, such as grouping NMs and analysing hazard or exposure data (Arts et al., 2015). Risk management to reduce NM exposure is also advised. Certain products may not limit exposure, such as when the nanoform increases nutritional or active ingredient bioavailability (Salari et al., 2024).

Since nanotechnology-based agriculture food products may enter the worldwide commerce and be purchased online, harmonised NMs marketing and safe usage procedures would be useful. International guidance and standards on risk assessment (test) methodologies can be harmonised and updated as technology advances. Numerous OECD and ISO efforts are underway (Chavez-Hernandez et al., 2024). The intergovernmental Codex Alimentarius Commission, established by FAO and WHO, creates worldwide food standards, guidelines, codes of practice, and advisory texts, including nanotechnology-based goods. In this globalised era, a good infrastructure for sharing NMs use in agri/feed/food information and experience is likewise desirable.

11. Conclusion

In conclusion, the exploration of biogenic synthesis methods for the fabrication of metal NPs derived from plants and microorganisms unveils a promising avenue for sustainable and environmentally friendly technologies. In contrast to traditional approaches, these methods offer a cleaner and non-toxic route, presenting a wide array of applications across various materials and NP types. The diverse synthesis potential, ranging from plant extracts to microorganisms, enables the creation of metal and metal oxide NPs with applications in agriculture and beyond.

The synthesis process, influenced by numerous experimental parameters, highlights the need for a nuanced understanding of the governing factors that shape NP characteristics. Characterization techniques play a crucial role in unravelling the morphology and dimensions of these bio-fabricated NPs, laying the foundation for their potential commercialization. However, as we delve into the applications of biogenic NPs, it is imperative to acknowledge the potential risks associated with their introduction into ecosystems.

In the specific context of the Ararat Plain region in Armenia, where crop food security is a critical concern, the exploration of biogenic NPs and their application demands a comprehensive approach. Rigorous research is essential to assess bioavailability, potential adverse reactions, and the broader environmental and biological impacts. The unique agricultural landscape of the Ararat Plain, with its arid soil resources, necessitates a careful balance between scientific exploration and environmental stewardship.

Moreover, as we consider the broader implications of these technologies, it is crucial to draw connections with Europe, where sustainable agriculture practices are of increasing importance. Collaborative efforts between Armenia and European nations can facilitate the exchange of knowledge and best practices in utilizing biogenic NPs and biochar for enhancing crop resilience in saline soils. This collaboration can contribute not only to regional food security but also to the global conversation on sustainable agriculture and environmental stewardship.

In the journey ahead, a holistic approach that combines scientific innovation, environmental consciousness, and international collaboration will be pivotal in unlocking the full potential of biogenic NPs and biochar in addressing the challenges of salinity in agricultural ecosystems. By doing so, we pave the way for a sustainable and secure future for agriculture in the Ararat Plain region and beyond, contributing to the broader goals of resilient and environmentally conscious food production.

Acknowledgment: KG, GM, AH, HK, HSM is supported by, under grant numbers 21AG-4C075. AS is supported by the 23PostDoc-4D007 grant provided by the Science Committee of the Republic of Armenia. VDR and TM are supported by the Strategic Academic Leadership Program of Southern Federal University, known as "Priority 2030," and the Ministry of Science and Higher Education of the Russian Federation (grant number: FENW-2023-0008).

Conflicts of interest: The authors declare that they have no conflict of interest in the publication.

Author contribution: Authors AS, GM, AH, HSM, HK, VDR, TM, AA, DP, AK, KG, HER write the original draft, and Authors AS, GM, AH, HSM, HK, VDR, TM, AA, DP, AK, KG, HER edit and finalize the manuscript. All authors read and agree to the submission of the manuscript to the journal.

References

Abbas, Q., Yousaf, B., Ullah, H., Ali, M. U., Ok, Y. S., and Rinklebe, J. (2020). Environmental transformation and nano-toxicity of engineered nano-particles (ENPs) in aquatic and terrestrial organisms. *Crit. Rev. Environ. Sci. Technol.* 50, 2523–2581. doi:10.1080/10643389.2019.1705721.

Abbasi, G. H., Akhtar, J., Ahmad, R., Jamil, M., Anwar-ul-Haq, M., Ali, S., et al. (2015). Potassium application mitigates salt stress differentially at different growth stages in tolerant and sensitive maize hybrids. *Plant Growth Regul.* 76, 111–125. doi:10.1007/S10725-015-0050-1/METRICS.

Abd-Elrahman, S. H., and Shalaby, O. A.-E. (2017). Response of wheat plants to irrigation with magnetized water under Egyptian soil conditions. *Egypt. J. Soil Sci.* 57, 477–488. doi:10.21608/EJSS.2017.1605.1122.

Abdel-Fattah, M. K., and A Merwad, A. M. (2016). Approach for Reclamation and Improving Fertility of Saline-Sodic Soils. *Egypt. J. Soil Sci.* 56, 573–588. doi:10.21608/EJSS.2016.3330.

Abdul Qados, A. M. S. (2011). Effect of salt stress on plant growth and metabolism of bean plant Vicia faba (L.). *J. Saudi Soc. Agric. Sci.* 10, 7–15. doi:10.1016/J.JSSAS.2010.06.002.

Abhishek, K., Shrivastava, A., Vimal, V., Gupta, A. K., Bhujbal, S. K., Biswas, J. K., et al. (2022). Biochar application for greenhouse gas mitigation, contaminants immobilization and soil fertility enhancement: A state-of-the-art review. *Sci. Total Environ.* 853, 158562. doi:10.1016/J.SCITOTENV.2022.158562.

Adhikari, T., Kundu, S., and Rao, A. S. (2013). Impact of SiO 2 and Mo Nano Particles on Seed Germination of Rice (Oryza Sativa L .).

Aghighi Shahverdi, M., Omidi, H., and Tabatabaei, S. J. (2018). Plant growth and steviol glycosides as affected by foliar application of selenium, boron, and iron under NaCl stress in Stevia rebaudiana Bertoni. *Ind. Crops Prod.* 125, 408–415. doi:10.1016/J.INDCROP.2018.09.029.

Ahmadi, F. I., Karimi, K., and Struik, P. C. (2018). Effect of exogenous application of methyl jasmonate on physiological and biochemical characteristics of Brassica napus L. cv. Talaye under salinity stress. *South African J. Bot.* 115, 5–11. doi:10.1016/J.SAJB.2017.11.018.

Akter, M., and Oue, H. (2018). Effect of Saline Irrigation on Accumulation of Na+, K+, Ca2+, and Mg2+ Ions in Rice Plants. *Agric. 2018, Vol. 8, Page 164* 8, 164. doi:10.3390/AGRICULTURE8100164.

Alabdallah, N. M., and Alzahrani, H. S. (2020). The potential mitigation effect of ZnO nanoparticles on [Abelmoschus esculentus L. Moench] metabolism under salt stress conditions. *Saudi J. Biol. Sci.* 27, 3132–3137. doi:10.1016/J.SJBS.2020.08.005.

Ali, S., Rizwan, M., Qayyum, M. F., Ok, Y. S., Ibrahim, M., Riaz, M., et al. (2017). Biochar soil amendment on alleviation of drought and salt stress in plants: a critical review. *Environ. Sci. Pollut. Res. 2017 2414* 24, 12700–12712. doi:10.1007/S11356-017-8904-X.

Aliakbarpour, F., Vaziri, A., and Mohseni, M. (2020). Green synthesis of Au-Ag nanoparticles using Mentha piperita and effects of Au-Ag alloy nanoparticles on the growth of Mentha piperita under salinity stress. *J. Plant Process Funct.* 9.

Almaroai, Y. A., Usman, A. R. A., Ahmad, M., Moon, D. H., Cho, J. S., Joo, Y. K., et al. (2014). Effects of biochar, cow bone, and eggshell on Pb availability to maize in contaminated soil irrigated with saline water. *Environ. Earth Sci.* 71, 1289–1296. doi:10.1007/S12665-013-2533-6/FIGURES/4.

Arts, J. H. E., Hadi, M., Irfan, M. A., Keene, A. M., Kreiling, R., Lyon, D., et al. (2015). A decision-making framework for the grouping and testing of nanomaterials (DF4nanoGrouping). *Regul. Toxicol. Pharmacol.* 71, S1–S27. doi:10.1016/J.YRTPH.2015.03.007.

Ashraf, M., and Foolad, M. R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environ. Exp. Bot.* 59, 206–216. doi:10.1016/J.ENVEXPBOT.2005.12.006.

Barbafieri, M., and Giorgetti, L. (2016). Contaminant bioavailability in soil and phytotoxicity/genotoxicity tests in Vicia faba L.: a case study of boron contamination.

Environ. Sci. Pollut. Res. 23, 24327–24336. doi:10.1007/S11356-016-7653-6/METRICS.

Better land management - better economic, social and ecological sustainability | FAO in Armenia | Food and Agriculture Organization of the United Nations Available at: https://www.fao.org/armenia/news/detail-events/en/c/1293964/ [Accessed January 22, 2024].

Biczak, R., Telesiński, A., and Pawłowska, B. (2016). Oxidative stress in spring barley and common radish exposed to quaternary ammonium salts with hexafluorophosphate anion. *Plant Physiol. Biochem. PPB* 107, 248–256. doi:10.1016/J.PLAPHY.2016.05.016.

Bruun, E. W., Ravenni, G., Müller-Stöver, D., and Petersen, C. T. (2023). Small biochar particles added to coarse sandy subsoil greatly increase water retention and affect hydraulic conductivity. *Eur. J. Soil Sci.* 74, e13442. doi:10.1111/EJSS.13442.

Cantabella, D., Piqueras, A., Acosta-Motos, J. R., Bernal-Vicente, A., Hernández, J. A., and Díaz-Vivancos, P. (2017). Salt-tolerance mechanisms induced in Stevia rebaudiana Bertoni: Effects on mineral nutrition, antioxidative metabolism and steviol glycoside content. *Plant Physiol. Biochem.* 115, 484–496. doi:10.1016/J.PLAPHY.2017.04.023.

Chavez-Hernandez, J. A., Velarde-Salcedo, A. J., Navarro-Tovar, G., and Gonzalez, C. (2024). Safe nanomaterials: from their use, application and disposal to regulations. *Nanoscale Adv.* doi:10.1039/D3NA01097J.

Chen, Z., Newman, I., Zhou, M., Mendham, N., Zhang, G., and Shabala, S. (2005). Screening plants for salt tolerance by measuring K+ flux: a case study for barley. *Plant. Cell Environ.* 28, 1230–1246. doi:10.1111/J.1365-3040.2005.01364.X.

Chinnusamy, V., Jagendorf, A., and Zhu, J. K. (2005). Understanding and Improving Salt Tolerance in Plants. *Crop Sci.* 45, 437–448. doi:10.2135/CROPSCI2005.0437.

Daba, A. W., and Qureshi, A. S. (2021). Review of Soil Salinity and Sodicity Challenges to Crop Production in the Lowland Irrigated Areas of Ethiopia and Its Management Strategies. *L. 2021, Vol. 10, Page 1377* 10, 1377. doi:10.3390/LAND10121377.

Daba, A. W., Qureshi, A. S., and Nisaren, B. N. (2019). Evaluation of Some Rhodes Grass (Chloris gayana) Genotypes for Their Salt Tolerance, Biomass Yield and Nutrient Composition. *Appl. Sci. 2019, Vol. 9, Page 143* 9, 143. doi:10.3390/APP9010143.

Das, K., and Roychoudhury, A. (2014). Reactive oxygen species (ROS) and response of antioxidants as ROS-scavengers during environmental stress in plants. *Front. Environ. Sci.* 2, 53. doi:10.3389/FENVS.2014.00053/BIBTEX.

Dash, A., Singh, A. P., Chaudhary, B. R., Singh, S. K., and Dash, D. (2012). Effect of silver nanoparticles on growth of eukaryotic green algae. *Nano-Micro Lett.* 4, 158–165. doi:10.1007/BF03353707/METRICS.

Del Río, L. A., and López-Huertas, E. (2016a). ROS Generation in Peroxisomes and its Role in Cell Signaling. *Plant Cell Physiol.* 57, 1364–1376. doi:10.1093/PCP/PCW076.

Del Río, L. A., and López-Huertas, E. (2016b). ROS Generation in Peroxisomes and its Role in Cell Signaling. *Plant Cell Physiol.* 57, 1364–1376. doi:10.1093/PCP/PCW076.

Dennis, S., Deng, Q., Hui, D., Wang, J., Iwuozo, S., Yu, C.-L., et al. (2015). In-Field Management Practices for Mitigating Soil CO2 and CH4 Fluxes under Corn (Zea mays) Production System in Middle Tennessee. *Am. J. Clim. Chang.* 4, 367–378. doi:10.4236/AJCC.2015.44029.

Dikshit, P. K., Kumar, J., Das, A. K., Sadhu, S., Sharma, S., Singh, S., et al. (2021). Green Synthesis of Metallic Nanoparticles: Applications and Limitations. *Catal. 2021, Vol. 11, Page 902* 11, 902. doi:10.3390/CATAL11080902.

Durán, N., Marcato, P. D., Alves, O. L., De Souza, G. I. H., and Esposito, E. (2005). Mechanistic aspects of biosynthesis of silver nanoparticles by several Fusarium oxysporum strains. *J. Nanobiotechnology* 3, 1–7. doi:10.1186/1477-3155-3-8/FIGURES/9.

El-Naggar, M. E., Abdelsalam, N. R., Fouda, M. M. G., Mackled, M. I., Al-Jaddadi, M. A. M., Ali, H. M., et al. (2020). Soil Application of Nano Silica on Maize Yield and Its Insecticidal Activity Against Some Stored Insects After the Post-Harvest. *Nanomater. 2020, Vol. 10, Page 739* 10, 739. doi:10.3390/NANO10040739.

El-Ramady, H., El-Henawy, A., Amer, M., Omara, A. E.-D., Elsakhawy, T., Elbasiouny, H., et al. (2020). Agricultural Waste and its Nano-Management: Mini Review. *Egypt. J. Soil Sci.* 60, 349–364. doi:10.21608/EJSS.2020.46807.1397.

El-Shahawy, A., El-Refaey, A., Ibrahim, M., El-Halim, A., Talha, N., and Mahmoud, E. (2022). Effect of nanomaterials on Soil Quality and Yield of Canola (Brassica napus) Grown in Heavy Clayey Soils Asmaa El-shahawy a,. *Egypt. J. Soil Sci.* 62, 361–371. doi:10.21608/EJSS.2022.152942.1522.

Faizan, M., Bhat, J. A., Hessini, K., Yu, F., and Ahmad, P. (2021). Zinc oxide nanoparticles alleviates the adverse effects of cadmium stress on Oryza sativa via modulation of the photosynthesis and antioxidant defense system. *Ecotoxicol. Environ. Saf.* 220, 112401. doi:10.1016/J.ECOENV.2021.112401.

Fan, X., Cao, X., Zhou, H., Hao, L., Dong, W., He, C., et al. (2020). Carbon dioxide fertilization effect on plant growth under soil water stress associates with changes in stomatal traits, leaf photosynthesis, and foliar nitrogen of bell pepper (Capsicum annuum L.). *Environ. Exp. Bot.* 179, 104203. doi:10.1016/J.ENVEXPBOT.2020.104203.

Farifteh, J., Farshad, A., and George, R. J. (2006). Assessing salt-affected soils using remote sensing, solute modelling, and geophysics. *Geoderma* 130, 191–206. doi:10.1016/J.GEODERMA.2005.02.003.

Feitosa De Vasconcelos, A. C. Biochar Effects on Amelioration of Adverse Salinity Effects in Soils. Available at: www.intechopen.com [Accessed December 19, 2023].

Flowers, T. J., and Colmer, T. D. (2015). Plant salt tolerance: adaptations in halophytes. *Ann. Bot.* 115, 327–331. doi:10.1093/AOB/MCU267.

Foronda, D. A. (2022). Reclamation of a Saline-Sodic Soil with Organic Amendments and Leaching. *Environ. Sci. Proc. 2022, Vol. 16, Page 56* 16, 56. doi:10.3390/ENVIRONSCIPROC2022016056.

Foster, E. J., Hansen, N., Wallenstein, M., and Cotrufo, M. F. (2016). Biochar and manure amendments impact soil nutrients and microbial enzymatic activities in a semi-arid irrigated maize cropping system. *Agric. Ecosyst. Environ.* 233, 404–414. doi:10.1016/J.AGEE.2016.09.029.

Franceschini, F., and Signorini, R. (2016). Seawater intrusion via surface water vs. deep shoreline salt-wedge: A case history from the Pisa coastal plain (Italy). *Groundw. Sustain. Dev.* 2–3, 73–84. doi:10.1016/J.GSD.2016.05.003.

Gaafar, R. M., Diab, R. H., Halawa, M. L., El-Shanshory, A. R., El-Shaer, A., and Hamouda, M. M. (2020). Role of

Zinc Oxide Nanoparticles in Ameliorating Salt Tolerance in Soybean. *Egypt. J. Bot.* 60, 733–747. doi:10.21608/EJBO.2020.26415.1475.

Ganjegunte, G. K., Sheng, Z., and Clark, J. A. (2014). SOIL SALINITY AND SODICITY APPRAISAL BY ELECTROMAGNETIC INDUCTION IN SOILS IRRIGATED TO GROW COTTON. *L. Degrad. Dev.* 25, 228–235. doi:10.1002/LDR.1162.

Gascó, G., Cely, P., Paz-Ferreiro, J., Plaza, C., and Méndez, A. (2016). Relation between biochar properties and effects on seed germination and plant development. *Biol. Agric. Hortic.* 32, 237–247. doi:10.1080/01448765.2016.1166348.

Gharaei, A., Amiri, M., Karami, R., Rostami, M., Keikha, M., Najafi Vafa, Z., et al. (2015). Effects of nano zinc and humic acid on quantitative and qualitative characteristics of savory (Satureja hortensis L.). *Artic. J. Biosci. Biotechnol.* doi:10.12692/ijb/6.3.124-136.

Ghazaryan, K. A., Gevorgyan, G. A., Movsesyan, H. S., and Khachatryan, H. E. (2020a). SOIL SALINIZATION IN THE AGRICULTURAL AREAS OF ARMENIAN SEMI-ARID REGIONS: CASE STUDY OF MASIS REGION. *Proc. YSU B Chem. Biol. Sci.* 54, 159–167. doi:10.46991/PYSU:B/2020.54.2.159.

Ghazaryan, K. A., Margaryan, G. H., Minkina, T. M., Rajput, V. D., and Movsesyan, H. S. (2024). Chenopodium album L.: a promising NaCl accumulating and tolerant plant for mitigation of salinity stress. *Rev. Bras. Bot.*, 1–20. doi:10.1007/S40415-023-00974-W/METRICS.

Ghazaryan, K. A., Movsesyan, H. S., Minkina, T. M., Nevidomskaya, D. G., and Rajput, V. D. (2022). Phytoremediation of copper-contaminated soil by Artemisia absinthium: comparative effect of chelating agents. *Environ. Geochem. Health* 44, 1203–1215. doi:10.1007/S10653-021-01151-2.

Ghazaryan, K., Movsesyan, H., Gevorgyan, A., Minkina, T., Sushkova, S., Rajput, V., et al. (2020b). Comparative hydrochemical assessment of groundwater quality from different aquifers for irrigation purposes using IWQI: A case-study from Masis province in Armenia. *Groundw. Sustain. Dev.* 11, 100459. doi:10.1016/J.GSD.2020.100459.

Gill, S. S., and Tuteja, N. (2010a). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiol. Biochem.* 48, 909–930. doi:10.1016/J.PLAPHY.2010.08.016.

Gill, S. S., and Tuteja, N. (2010b). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiol. Biochem. PPB* 48, 909–930. doi:10.1016/J.PLAPHY.2010.08.016.

Glaser, B., Lehmann, J., and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biol. Fertil. Soils* 35, 219–230. doi:10.1007/S00374-002-0466-4/METRICS.

Guo, L., Bornø, M. L., Niu, W., and Liu, F. (2021). Biochar amendment improves shoot biomass of tomato seedlings and sustains water relations and leaf gas exchange rates under different irrigation and nitrogen regimes. *Agric. Water Manag.* 245, 106580. doi:10.1016/J.AGWAT.2020.106580.

Guo, X. xia, Liu, H. tao, and Zhang, J. (2020). The role of biochar in organic waste composting and soil improvement: A review. *Waste Manag.* 102, 884–899. doi:10.1016/J.WASMAN.2019.12.003.

Habibi, G., and Aleyasin, Y. (2020). Green synthesis of Se nanoparticles and its effect on salt tolerance of barley plants. *Int. J. Nano Dimens* 11, 145–157. Available at: http://creativecommons.org/licenses/by/4.0/. [Accessed September 18, 2023].

Hachicha, M., Kahlaoui, B., Khamassi, N., Misle, E., and Jouzdan, O. (2018). Effect of electromagnetic treatment of saline water on soil and crops. *J. Saudi Soc. Agric. Sci.* 17, 154–162. doi:10.1016/J.JSSAS.2016.03.003.

Haider, F. U., Wang, X., Zulfiqar, U., Farooq, M., Hussain, S., Mehmood, T., et al. (2022). Biochar application for remediation of organic toxic pollutants in contaminated soils; An update. *Ecotoxicol. Environ. Saf.* 248, 114322. doi:10.1016/J.ECOENV.2022.114322.

Hajihashemi, S., Kiarostami, K., Enteshari, S., and Saboora, A. (2009). Effect of paclobutrazol on wheat salt tolerance at pollination stage. *Russ. J. Plant Physiol.* 56, 251–257. doi:10.1134/S1021443709020149/METRICS.

Hamada, A. M. (1994). Alleviation of the adverse effects of NaCl on germination of maize grains by calcium. *Biol. Plant. 1994 364* 36, 623–627. doi:10.1007/BF02921194.

Hanafy, M. S., El-Banna, A., Schumacher, H. M., Jacobsen, H. J., and Hassan, F. S. (2013). Enhanced tolerance to drought and salt stresses in transgenic faba bean (Vicia faba L.) plants by heterologous expression of the PR10a gene from potato. *Plant Cell Reports 2013 325* 32, 663–674. doi:10.1007/S00299-013-1401-X.

Hansen, V., Hauggaard-Nielsen, H., Petersen, C. T., Mikkelsen, T. N., and Müller-Stöver, D. (2016). Effects of gasification biochar on plant-available water capacity and plant growth in two contrasting soil types. *Soil Tillage Res.* 161, 1–9. doi:10.1016/J.STILL.2016.03.002.

Hasanuzzaman, M., Borhannuddin Bhuyan, M. H. M., Anee, T. I., Parvin, K., Nahar, K., Al Mahmud, J., et al. (2019). Regulation of Ascorbate-Glutathione Pathway in Mitigating Oxidative Damage in Plants under Abiotic Stress. *Antioxidants 2019, Vol. 8, Page 384* 8, 384. doi:10.3390/ANTIOX8090384.

Heikal, Y. M., El-Esawi, M. A., El-Ballat, E. M., and Abdel-Aziz, H. M. M. (2022). Applications of nanoparticles for mitigating salinity and drought stress in plants: an overview on the physiological, biochemical and molecular genetic aspects. *https://doi.org/10.1080/01140671.2021.2016870*, 1–31. doi:10.1080/01140671.2021.2016870.

Helaoui, S., Boughattas, I., Mkhinini, M., Ghazouani, H., Jabnouni, H., Kribi-Boukhris, S. El, et al. (2023). Biochar application mitigates salt stress on maize plant: Study of the agronomic parameters, photosynthetic activities and biochemical attributes. *Plant Stress* 9, 100182. doi:10.1016/J.STRESS.2023.100182.

Ibrahim, E. A. (2016). Seed priming to alleviate salinity stress in germinating seeds. *J. Plant Physiol.* 192, 38–46. doi:10.1016/J.JPLPH.2015.12.011.

Imlay, J. A., and Linn, S. (1988). DNA damage and oxygen radical toxicity. *Science* 240, 1302–1309. doi:10.1126/SCIENCE.3287616.

Ippolito, J. A., Cui, L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizabal, T., et al. (2020). Feedstock choice, pyrolysis temperature and type influence biochar characteristics: a comprehensive meta-data analysis review. *Biochar* 2, 421–438. doi:10.1007/S42773-020-00067-X/TABLES/6.

Jan, M. Morpho-physiological characterization of sun-flower genotypes under saline conditions. Available at: https://www.researchgate.net/publication/236119484 [Accessed September 24, 2023].

Kalishwaralal, K., Deepak, V., Ramkumarpandian, S., Nellaiah, H., and Sangiliyandi, G. (2008). Extracellular biosynthesis of silver nanoparticles by the culture supernatant of Bacillus licheniformis. *Mater. Lett.* 62, 4411–4413. doi:10.1016/J.MATLET.2008.06.051.

Kamran, M., Parveen, A., Ahmar, S., Malik, Z., Hussain, S., Chattha, M. S., et al. (2019). An Overview of Hazardous Impacts of Soil Salinity in Crops, Tolerance Mechanisms, and Amelioration through Selenium Supplementation. *Int. J. Mol. Sci. 2020, Vol. 21, Page 148* 21, 148. doi:10.3390/IJMS21010148.

Kaphle, A., Navya, P. N., Umapathi, A., and Daima, H. K. (2017). Nanomaterials for agriculture, food and environment: applications, toxicity and regulation. *Environ. Chem. Lett. 2017 161* 16, 43–58. doi:10.1007/S10311-017-0662-Y.

Kapoor, K., and Srivastava, A. (2010). Assessment of Salinity Tolerance of Vigna mungo Var. Pu-19 Using ex vitro and in vitro Methods. *Asian J. Biotechnol.* 2, 73–85. doi:10.3923/AJBKR.2010.73.85.

Karimi, J., and Mohsenzadeh, S. (2016). Effects of silicon oxide nanoparticles on growth and physiology of wheat seedlings. *Russ. J. Plant Physiol.* 63, 119–123. doi:10.1134/S1021443716010106/METRICS.

Keunen, E., Remans, T., Bohler, S., Vangronsveld, J., and Cuypers, A. (2011). Metal-Induced Oxidative Stress and Plant Mitochondria. *Int. J. Mol. Sci. 2011, Vol. 12, Pages 6894-6918* 12, 6894–6918. doi:10.3390/IJMS12106894.

Khamidov, M., Ishchanov, J., Hamidov, A., Donmez, C., and Djumaboev, K. (2022). Assessment of Soil Salinity Changes under the Climate Change in the Khorezm Region, Uzbekistan. *Int. J. Environ. Res. Public Heal. 2022, Vol. 19, Page 8794* 19, 8794. doi:10.3390/IJERPH19148794.

Kharusi, L. Al, Yahyai, R. Al, and Yaish, M. W. (2019). Antioxidant Response to Salinity in Salt-Tolerant and Salt-Susceptible Cultivars of Date Palm. *Agric. 2019, Vol. 9, Page 8* 9, 8. doi:10.3390/AGRICULTURE9010008.

Kim, J., Yoo, G., Kim, D., Ding, W., and Kang, H. (2017a). Combined application of biochar and slow-release fertilizer reduces methane emission but enhances rice yield by different mechanisms. *Appl. Soil Ecol.* 117–118, 57–62. doi:10.1016/J.APSOIL.2017.05.006.

Kim, Y. H., Khan, A. L., Waqas, M., and Lee, I. J. (2017b). Silicon regulates antioxidant activities of crop plants under abiotic-induced oxidative stress: A review. *Front. Plant Sci.* 8, 510. doi:10.3389/FPLS.2017.00510/BIBTEX.

Kitila, K., Chala, A., and Workina, M. Effect of Gypsum and compost Application in Reclaiming Sodic soils at Small Scale Irrigation Farm in Bora District of East Shewa Zone, Oromia, Ethiopia. doi:10.38112/agw.2020.v08i01.005.

Kookana, R. S. (2010). The role of biochar in modifying the environmental fate, bioavailability, and efficacy of pesticides in soils: a review. *Soil Res.* 48, 627–637. doi:10.1071/SR10007.

Kumar, P., and Sharma, P. K. (2020). Soil Salinity and Food Security in India. *Front. Sustain. Food Syst.* 4, 533781. doi:10.3389/FSUFS.2020.533781/BIBTEX.

Lee, D. G., Park, K. W., An, J. Y., Sohn, Y. G., Ha, J. K., Kim, H. Y., et al. (2011). Proteomics analysis of salt-induced leaf proteins in two rice germplasms with different salt sensitivity. *Can. J. Plant Sci.* 91, 337–349. doi:10.4141/CJPS10022/ASSET/IMAGES/CJPS10022TAB5.GIF.

Lehmann, J., Da Silva, J. P., Steiner, C., Nehls, T., Zech, W., and Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertilizer, manure and charcoal amendments. *Plant Soil* 249, 343–357. doi:10.1023/A:1022833116184/METRICS.

Li, Z., Zhu, L., Zhao, F., Li, J., Zhang, X., Kong, X., et al. (2022). Plant Salinity Stress Response and Nano-Enabled Plant Salt Tolerance. *Front. Plant Sci.* 13, 714. doi:10.3389/FPLS.2022.843994/BIBTEX.

Lin, X. W., Xie, Z. B., Zheng, J. Y., Liu, Q., Bei, Q. C., and Zhu, J. G. (2015). Effects of biochar application on greenhouse gas emissions, carbon sequestration and crop growth in coastal saline soil. *Eur. J. Soil Sci.* 66, 329–338. doi:10.1111/EJSS.12225.

Mahgoub, N. A., Ibrahim, A. M., and Ali, O. M. (2015). Effect of Fresh and Saline Water Intrusion in Bitter Lakes Region on Agricultural Soil Degradation. *Egypt. J. Soil Sci.* 55, 483–499. doi:10.21608/EJSS.2015.1571.

Mahmoud, A. W. M., Abdeldaym, E. A., Abdelaziz, S. M., El-Sawy, M. B. I., and Mottaleb, S. A. (2019). Synergetic Effects of Zinc, Boron, Silicon, and Zeolite Nanoparticles on Confer Tolerance in Potato Plants Subjected to Salinity. *Agron. 2020, Vol. 10, Page 19* 10, 19. doi:10.3390/AGRONOMY10010019.

Maity, S., Chatterjee, A., Guchhait, R., De, S., and Pramanick, K. (2020). Cytogenotoxic potential of a hazardous material, polystyrene microparticles on Allium cepa L. *J. Hazard. Mater.* 385. doi:10.1016/J.JHAZMAT.2019.121560.

Mallahi, T., Saharkhiz, M. J., and Javanmardi, J. (2018). Salicylic acid changes morpho-physiological attributes of feverfew (Tanacetum parthenium L.) under salinity stress. *Acta Ecol. Sin.* 38, 351–355. doi:10.1016/J.CHNAES.2018.02.003.

Manuel, R., Machado, A., Serralheiro, R. P., Alvino, A., Freire, M. I., and Ferreira, R. (2017). Soil Salinity: Effect on Vegetable Crop Growth. Management Practices to Prevent and Mitigate Soil Salinization. *Hortic. 2017, Vol. 3, Page 30* 3, 30. doi:10.3390/HORTICULTURAE3020030.

Masilamani, P., Arulmozhiselvan, K., and Alagesan, A. (2020). Prospects of biodrainage to mitigate problems of waterlogging and soil salinity in context of India - A review. *J. Appl. Nat. Sci.* 12, 229–243. doi:10.31018/JANS.VI.2285.

Memon, S. A., XiLin, H., and LiangJu, W. (2010). Morphological analysis of salt stress response of pak choi. *Electron. J. Environ. Agric. Food Chem.* 9, 248–254.

Moghanm, F.S, Darwish, A., El Wakeel, E., Elshahawy, M., and Shalaby, A. (2018). Sustainable Land Management Using Spatial Analyst in North Nile Delta soil, Egypt. *Egypt. J. Soil Sci.* 58, 435–442. doi:10.21608/EJSS.2018.5378.1210.

Mohamed, A. K. S. H., Qayyum, M. F., Abdel-Hadi, A. M., Rehman, R. A., Ali, S., and Rizwan, M. (2017). Interactive effect of salinity and silver nanoparticles on photosynthetic and biochemical parameters of wheat. *http://dx.doi.org/10.1080/03650340.2017.1300256* 63, 1736–1747. doi:10.1080/03650340.2017.1300256.

Mohamed, I. A. A., Shalby, N., El-Badri, A. M. A., Saleem, M. H., Khan, M. N., Nawaz, M. A., et al. (2020). Stomata and Xylem Vessels Traits Improved by Melatonin Application Contribute to Enhancing Salt Tolerance and Fatty Acid Composition of Brassica napus L. Plants. *Agron. 2020, Vol. 10, Page 1186* 10, 1186. doi:10.3390/AGRONOMY10081186.

Mohammad Alabdallah, N., and Saeed Alzahrani, H. (2020). Impact of ZnO Nanoparticles on Growth of Cowpea and Okra Plants under Salt Stress Conditions. *Biosci. Biotechnol. Res. Asia* 17, 329–340. doi:10.13005/BBRA/2836.

Moradi, F., and Ismail, A. M. (2007). Responses of Photosynthesis, Chlorophyll Fluorescence and ROS-Scavenging Systems to Salt Stress During Seedling and Reproductive Stages in RiceMoradi and Ismail — Responses of Rice to SalinityMoradi and Ismail — Responses of Rice to Salinity. *Ann. Bot.* 99, 1161–1173. doi:10.1093/AOB/MCM052.

Mudgal, S. (2014). DIRECTORATE GENERAL FOR INTERNAL POLICIES POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY ENVI Relevant Legislative Areas of the EU-US Trade and Investment Partnership Negotiations (TTIP) STUDY.

Mukherjee, A., Peralta-Videa, J. R., Bandyopadhyay, S., Rico, C. M., Zhao, L., and Gardea-Torresdey, J. L. (2013). Physiological effects of nanoparticulate ZnO in green peas (Pisum sativum L.) cultivated in soil. *Metallomics* 6, 132–138. doi:10.1039/C3MT00064H.

Mukherjee, A., Sarkar, D., and Sasmal, S. (2021). A Review of Green Synthesis of Metal Nanoparticles Using Algae. *Front. Microbiol.* 12, 2152. doi:10.3389/FMICB.2021.693899/BIBTEX.

Munns, R., and Tester, M. (2008a). Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol.* 59, 651–681. doi:10.1146/ANNUREV.ARPLANT.59.032607.092911.

Munns, R., and Tester, M. (2008b). Mechanisms of Salinity Tolerance. *http://dx.doi.org/10.1146/annurev.arplant.59.032607.092911* 59, 651–681. doi:10.1146/ANNUREV.ARPLANT.59.032607.092911.

Murtaza, G., Ahmed, Z., Eldin, S. M., Ali, B., Bawazeer, S., Usman, M., et al. (2023). Biochar-Soil-Plant interactions: A cross talk for sustainable agriculture under changing climate. *Front. Environ. Sci.* 11, 1059449. doi:10.3389/FENVS.2023.1059449/BIBTEX.

Mustafa, N., Raja, N. I., Ilyas, N., Ikram, M., Mashwani, Z. U. R., and Ehsan, M. (2021). Foliar applications of plant-based titanium dioxide nanoparticles to improve agronomic and physiological attributes of wheat (Triticum aestivum L.) plants under salinity stress. *Green Process. Synth.* 10, 246–257. doi:10.1515/GPS-2021-0025/MACHINEREADABLECITATION/RIS.

Nair, P. M. G., and Chung, I. M. (2014). Impact of copper oxide nanoparticles exposure on Arabidopsis thaliana growth, root system development, root lignificaion, and molecular level changes. *Environ. Sci. Pollut. Res.* 21, 12709–12722. doi:10.1007/S11356-014-3210-3/FIGURES/8.

Nan, Q., Xin, L., Qin, Y., Waqas, M., and Wu, W. (2021). Exploring long-term effects of biochar on mitigating methane emissions from paddy soil: a review. *Biochar* 3, 125–134. doi:10.1007/S42773-021-00096-0/FIGURES/2.

Natasha, N., Shahid, M., Bibi, I., Iqbal, J., Khalid, S., Murtaza, B., et al. (2022). Zinc in soil-plant-human system: A data-analysis review. *Sci. Total Environ.* 808, 152024. doi:10.1016/J.SCITOTENV.2021.152024.

Naz, H., Akram, N. A., and Ashraf, M. (2016). Impact of ascorbic acid on growth and some physiological attributes of cucumber (Cucumis sativus) plants under water-deficit conditions. *Pakistan J. Bot.* 48, 877–883.

Nekir, B. (2019). Effect of Organic Matter on Rice Nitrogen and Phosphorus Use Efficiency Under Calcareous Sodic Soil of Amibara District, Ethiopia. *J. Agric. Crop.*, 178–185. doi:10.32861/JAC.59.178.185.

Noctor, G., and Foyer, C. H. (2003). ASCORBATE AND GLUTATHIONE: Keeping Active Oxygen Under Control. *http://dx.doi.org/10.1146/annurev.arplant.49.1.249* 49, 249–279. doi:10.1146/ANNUREV.ARPLANT.49.1.249.

Ondrasek, G., and Rengel, Z. (2021). Environmental salinization processes: Detection, implications & solutions. *Sci. Total Environ.* 754, 142432. doi:10.1016/J.SCITOTENV.2020.142432.

Osman, A. I., Fawzy, S., Farghali, M., El-Azazy, M., Elgarahy, A. M., Fahim, R. A., et al. (2022). Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review. *Environ. Chem. Lett.* 20, 2385–2485. doi:10.1007/S10311-022-01424-X.

Oukarroum, A., Bras, S., Perreault, F., and Popovic, R. (2012). Inhibitory effects of silver nanoparticles in two green algae, Chlorella vulgaris and Dunaliella tertiolecta. *Ecotoxicol. Environ. Saf.* 78, 80–85. doi:10.1016/J.ECOENV.2011.11.012.

Palmqvist, N. G. M., Seisenbaeva, G. A., Svedlindh, P., and Kessler, V. G. (2017). Maghemite Nanoparticles Acts as Nanozymes, Improving Growth and Abiotic Stress Tolerance in Brassica napus. *Nanoscale Res. Lett.* 12, 1–9. doi:10.1186/S11671-017-2404-2/FIGURES/13.

Parida, A. K., and Das, A. B. (2005). Salt tolerance and salinity effects on plants: a review. *Ecotoxicol. Environ. Saf.* 60, 324–349. doi:10.1016/J.ECOENV.2004.06.010.

Pastuszak, J., Dziurka, M., Hornyák, M., Szczerba, A., Kopeć, P., and Płażek, A. (2022). Physiological and Biochemical Parameters of Salinity Resistance of Three Durum Wheat Genotypes. *Int. J. Mol. Sci. 2022, Vol. 23, Page 8397* 23, 8397. doi:10.3390/IJMS23158397.

Patil, S., and Chandrasekaran, R. (2020). Biogenic nanoparticles: a comprehensive perspective in synthesis, characterization, application and its challenges. *J. Genet. Eng. Biotechnol. 2020 181* 18, 1–23. doi:10.1186/S43141-020-00081-3.

Peng, J., Liu, J., Zhang, L., Luo, J., Dong, H., Ma, Y., et al. (2016). Effects of Soil Salinity on Sucrose Metabolism in Cotton Leaves. *PLoS One* 11, e0156241. doi:10.1371/JOURNAL.PONE.0156241.

Petter, F. A., Madari, B. E., da Silva, M. A. S., Carneiro, M. A. C., Carvalho, M. T. de M., Júnior, B. H. M., et al. (2012). Soil fertility and upland rice yield after biochar application in the Cerrado. *Pesqui. Agropecuária Bras.* 47, 699–706. doi:10.1590/S0100-204X2012000500010.

Pimentel, D. (2008). Global warming, population growth, and natural resources for food production. *https://doi.org/10.1080/08941929109380766* 4, 347–363. doi:10.1080/08941929109380766.

Pulit-Prociak, J., and Banach, M. (2016). Silver nanoparticles - A material of the future...? *Open Chem.* 14, 76–91. doi:10.1515/CHEM-2016-0005/ASSET/GRAPHIC/J_CHEM-2016-0005_FIG_004.JPG.

Pulskamp, K., Diabaté, S., and Krug, H. F. (2007). Carbon nanotubes show no sign of acute toxicity but induce intracellular reactive oxygen species in dependence on contaminants. *Toxicol. Lett.* 168, 58–74. doi:10.1016/J.TOXLET.2006.11.001.

Qi, L., Ma, Z., Chang, S. X., Zhou, P., Huang, R., Wang, Y., et al. (2021). Biochar decreases methanogenic archaea abundance and methane emissions in a flooded paddy soil. *Sci. Total Environ.* 752, 141958. doi:10.1016/J.SCITOTENV.2020.141958.

Qin, X., Sun, X., Huang, H., Bai, Y., Wang, Y., Luo, H., et al. (2017). Oxidation of a non-phenolic lignin model compound by two Irpex lacteus manganese peroxidases: Evidence for implication of carboxylate and radicals.

Biotechnol. Biofuels 10, 1–13. doi:10.1186/S13068-017-0787-Z/FIGURES/6.

Qureshi, A. S., and Daba, A. W. AMERICAN-EURASIAN JOURNAL OF SUSTAINABLE AGRICULTURE Differential analysis of five quinoa (Chenopodium quinoa W.) genotypes under different salt stresses in a controlled environment. *J. Sustain. Agric.* 13, 2020. doi:10.22587/aejsa.2020.14.1.2.

Rakgotho, T., Ndou, N., Mulaudzi, T., Iwuoha, E., Mayedwa, N., and Ajayi, R. F. (2022). Green-Synthesized Zinc Oxide Nanoparticles Mitigate Salt Stress in Sorghum bicolor. *Agric.* 12, 597. doi:10.3390/AGRICULTURE12050597/S1.

Rana, M. M., Takamatsu, T., Baslam, M., Kaneko, K., Itoh, K., Harada, N., et al. (2019). Salt tolerance improvement in rice through efficient SNP marker-assisted selection coupled with speed-breeding. *Int. J. Mol. Sci.* 20. doi:10.3390/ijms20102585.

Razzaque, M. A., Talukder, N. M., Roy, T. S., Hasanuzzaman, M., and Bhadra, A. K. (2010). Salinity stress effect on biochemical changes in leaves of rice genotypes differing in salt tolerance. *Recent Res. Sci. Technol.* 2, 40–46.

Rengasamy, P., and Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Funct. Plant Biol.* 37, 613–620. doi:10.1071/FP09249.

Rezende, E. I. P., Angelo, L. C., Dos Santos, S. S., and Mangrich, A. S. (2011). Biocarvão (Biochar) e Sequestro de Carbono. *Rev. Virtual Química* 3, 426–433. doi:10.5935/1984-6835.20110046.

Rossi, L., Fedenia, L. N., Sharifan, H., Ma, X., and Lombardini, L. (2019). Effects of foliar application of zinc sulfate and zinc nanoparticles in coffee (Coffea arabica L.) plants. *Plant Physiol. Biochem. PPB* 135, 160–166. doi:10.1016/J.PLAPHY.2018.12.005.

Ruffini Castiglione, M., Giorgetti, L., Becarelli, S., Siracusa, G., Lorenzi, R., and Di Gregorio, S. (2016). Polycyclic aromatic hydrocarbon-contaminated soils: bioaugmentation of autochthonous bacteria and toxicological assessment of the bioremediation process by means of Vicia faba L. *Environ. Sci. Pollut. Res.* 23, 7930–7941. doi:10.1007/S11356-016-6049-Y/METRICS.

Ruffini Castiglione, M., Giorgetti, L., Cremonini, R., Bottega, S., and Spanò, C. (2014). Impact of TiO2 nanoparticles on Vicia narbonensis L.: potential toxicity effects. *Protoplasma* 251, 1471–1479. doi:10.1007/S00709-014-0649-5/METRICS.

Saifullah, Dahlawi, S., Naeem, A., Rengel, Z., and Naidu, R. (2018). Biochar application for the remediation of salt-affected soils: Challenges and opportunities. *Sci. Total Environ.* 625, 320–335. doi:10.1016/J.SCITOTENV.2017.12.257.

Salari, S., Sadeghi-Yarandi, M., and Golbabaei, F. (2024). An integrated approach to occupational health risk assessment of manufacturing nanomaterials using Pythagorean Fuzzy AHP and Fuzzy Inference System. *Sci. Rep.* 14. doi:10.1038/S41598-023-48885-W.

Saleh, T. A. (2020). Nanomaterials: Classification, properties, and environmental toxicities. *Environ. Technol. Innov.* 20, 101067. doi:10.1016/J.ETI.2020.101067.

Seleiman, M. F., Alotaibi, M. A., Alhammad, B. A., Alharbi, B. M., Refay, Y., and Badawy, S. A. (2020). Effects of ZnO Nanoparticles and Biochar of Rice Straw and Cow Manure on Characteristics of Contaminated Soil and Sunflower Productivity, Oil Quality, and Heavy Metals Uptake. *Agron. 2020, Vol. 10, Page 790* 10, 790. doi:10.3390/AGRONOMY10060790.

Setia, R., Marschner, P., Baldock, J., and Chittleborough, D. (2010). Is CO2 evolution in saline soils affected by an osmotic effect and calcium carbonate? *Biol. Fertil. Soils* 46, 781–792. doi:10.1007/S00374-010-0479-3/METRICS.

Shahid, S. A., Zaman, M., and Heng, L. (2018). Soil Salinity: Historical Perspectives and a World Overview of the Problem. *Guidel. Salin. Assessment, Mitig. Adapt. Using Nucl. Relat. Tech.*, 43–53. doi:10.1007/978-3-319-96190-3_2.

Shaligram, N. S., Bule, M., Bhambure, R., Singhal, R. S., Singh, S. K., Szakacs, G., et al. (2009). Biosynthesis of silver nanoparticles using aqueous extract from the compactin producing fungal strain. *Process Biochem.* 44, 939–943. doi:10.1016/J.PROCBIO.2009.04.009.

Shokat, S., and Großkinsky, D. K. (2019). Tackling Salinity in Sustainable Agriculture—What Developing Countries May Learn from Approaches of the Developed World. *Sustain. 2019, Vol. 11, Page 4558* 11, 4558. doi:10.3390/SU11174558.

Silva, G. H. Da, and Monteiro, R. T. R. (2017). Toxicity assessment of silica nanoparticles on Allium cepa. *Ecotoxicol. Environ. Contam.* 12, 25–31. doi:10.5132/EEC.2017.01.04.

Simopoulos, A. P. (2022). The Healthiest Diet for You: Scientific Aspects. *Heal. Diet You Sci. Asp.*, 252. doi:10.3390/BOOKS978-3-0365-2734-5.

Singh, A., Agrawal, S., Rajput, V. D., Ghazaryan, K., Movsesyan, H. S., Minkina, T., et al. (2023). Seed Nanopriming. 290–313. doi:10.4018/978-1-6684-7232-3.CH013.

Singh, A., Rajput, V. D., Varshney, A., Sharma, R., Ghazaryan, K., Minkina, T., et al. (2024). Revolutionizing Crop Production: Nanoscale Wonders - Current Applications, Advances, and Future Frontiers. *Egypt. J. Soil Sci.* 64, 0–0. doi:10.21608/EJSS.2023.246354.1684.

Singh, A., Sengar, R. S., Rajput, V. D., Agrawal, S., Ghazaryan, K., Minkina, T., et al. Impact of Zinc Oxide Nanoparticles on Seed Germination Characteristics in Rice (Oryza Sativa L.) Under Salinity Stress. *J. Ecol. Eng.* Available at: http://www.jeeng.net/Impact-of-Zinc-Oxide-Nanoparticles-on-Seed-Germination-Characteristics-in-Rice-Oryza,169142,0,2.html [Accessed July 14, 2023].

Singh, A., Sengar, R. S., Rajput, V. D., Minkina, T., and Singh, R. K. (2022a). Zinc Oxide Nanoparticles Improve Salt Tolerance in Rice Seedlings by Improving Physiological and Biochemical Indices. *Agric. 2022, Vol. 12, Page 1014* 12, 1014. doi:10.3390/AGRICULTURE12071014.

Singh, A., Sengar, R. S., Shahi, U. P., Rajput, V. D., Minkina, T., and Ghazaryan, K. A. (2022b). Prominent Effects of Zinc Oxide Nanoparticles on Roots of Rice (*Oryza sativa* L.) Grown under Salinity Stress. *Stresses* 3, 33–46. doi:10.3390/STRESSES3010004/S1.

Singh, N. K., Patel, D. B., and Khalekar, G. D. (2018). Methanogenesis and Methane Emission in Rice / Paddy Fields. 135–170. doi:10.1007/978-3-319-99076-7_5.

Soliman, M. H., Alnusairi, G. S. H., Khan, A. A., Alnusaire, T. S., Fakhr, M. A., Abdulmajeed, A. M., et al. (2022). Biochar and Selenium Nanoparticles Induce Water Transporter Genes for Sustaining Carbon Assimilation and Grain Production in Salt-Stressed Wheat. *J. Plant Growth Regul.* 42, 1522–1543. doi:10.1007/S00344-022-10636-Y/FIGURES/3.

Soltabayeva, A., Ongaltay, A., Omondi, J. O., and Srivastava, S. (2021). Morphological, Physiological and Molecular Markers for Salt-Stressed Plants. *Plants 2021, Vol. 10,* *Page 243* 10, 243. doi:10.3390/PLANTS10020243.

Southam, G., and Beveridge, T. J. (1994). The in vitro formation of placer gold by bacteria. *Geochim. Cosmochim. Acta* 58, 4527–4530. doi:10.1016/0016-7037(94)90355-7.

Stavi, I., Thevs, N., and Priori, S. (2021). Soil Salinity and Sodicity in Drylands: A Review of Causes, Effects, Monitoring, and Restoration Measures. *Front. Environ. Sci.* 9, 712831. doi:10.3389/FENVS.2021.712831/BIBTEX.

Strategy of the main directions ensuring economic development in agricultural sector of the Republic of Armenia for 2020-2030. | FAOLEX Available at: https://www.fao.org/faolex/results/details/en/c/LEX-FAOC201644/ [Accessed January 22, 2024].

Sustainable Development in Armenia: Learning From the EU - EVN Report Available at: https://evnreport.com/economy/sustainable-development-in-armenia-learning-from-the-eu/ [Accessed January 22, 2024].

Taha, R., Mills, D., Heimer, Y., and Tal, M. (2000). The relation between low K+/Na+ ratio and salt-tolerance in the wild tomato species Lycopersicon pennellii. *J. Plant Physiol.* 157, 59–64. doi:10.1016/S0176-1617(00)80136-4.

Talei, D., Kadir, M. A., Yusop, M. K., Valdiani, A., and Abdullah, M. P. (2012). Salinity effects on macro and micronutrients uptake in medicinal plant King of Bitters (Andrographis paniculata Nees.). *POJ* 5, 271–278.

Tanji, K. K., and Wallender, W. W. (2011). Nature and extent of agricultural salinity and sodicity. *Agric. Salin. Assess. Manag. Second Ed.*, 1–26. doi:10.1061/9780784411698.CH01/ASSET/B9C97BC1-3CD4-4561-A644-6E72FC505AF5/ASSETS/9780784411698.CH01.FP.PNG.

The European Union and Armenia | EEAS Available at: https://www.eeas.europa.eu/armenia/european-union-and-armenia_en?s=216 [Accessed January 22, 2024].

Thiruvengadam, M., Rajakumar, G., and Chung, I. M. (2018). Nanotechnology: current uses and future applications in the food industry. *3 Biotech* 8, 1–13. doi:10.1007/S13205-018-1104-7/METRICS.

Thomas, S. C., Frye, S., Gale, N., Garmon, M., Launchbury, R., Machado, N., et al. (2013). Biochar mitigates negative effects of salt additions on two herbaceous plant species. *J. Environ. Manage.* 129, 62–68. doi:10.1016/J.JENVMAN.2013.05.057.

Trchounian, A., Petrosyan, M., and Sahakyan, N. (2016). Plant cell redox homeostasis and reactive oxygen species. *Redox State as a Cent. Regul. Plant-Cell Stress Responses*, 25–50. doi:10.1007/978-3-319-44081-1_2/COVER.

Tripathi, A., Liu, S., Singh, P. K., Kumar, N., Pandey, A. C., Tripathi, D. K., et al. (2017a). Differential phytotoxic responses of silver nitrate (AgNO3) and silver nanoparticle (AgNps) in Cucumis sativus L. *Plant Gene* 11, 255–264. doi:10.1016/J.PLGENE.2017.07.005.

Tripathi, D. K., Shweta, Singh, S., Singh, S., Pandey, R., Singh, V. P., et al. (2017b). An overview on manufactured nanoparticles in plants: Uptake, translocation, accumulation and phytotoxicity. *Plant Physiol. Biochem.* 110, 2–12. doi:10.1016/J.PLAPHY.2016.07.030.

Unclassified DSTI/STP/NANO(2012)22/FINAL Organisation de Coopération et de Développement Économiques Organisation for Economic Co-operation and Development Directorate for Science, Technology and Industry Committee for Scientific and Technological Policy Working Party on Nanotechnology REGULATORY FRAMEWORKS FOR NANOTECHNOLOGY IN FOODS AND MEDICAL PRODUCTS (2013).

Van Zelm, E., Zhang, Y., and Testerink, C. (2020). Salt Tolerance Mechanisms of Plants. *https://doi.org/10.1146/annurev-arplant-050718-100005* 71, 403–433. doi:10.1146/ANNUREV-ARPLANT-050718-100005.

Verma, N., Sao, P., Srivastava, A., and Singh, S. (2021). Physiological and Molecular Responses to Drought, Submergence and Excessive Watering in Plants. *Harsh Environ. Plant Resil.*, 305–321. doi:10.1007/978-3-030-65912-7_12/COVER.

Verma, S. K., Das, A. K., Patel, M. K., Shah, A., Kumar, V., and Gantait, S. (2018). Engineered nanomaterials for plant growth and development: A perspective analysis. *Sci. Total Environ.* 630, 1413–1435. doi:10.1016/J.SCITOTENV.2018.02.313.

Wahid, I., Kumari, S., Ahmad, R., Hussain, S. J., Alamri, S., Siddiqui, M. H., et al. (2020). Silver Nanoparticle Regulates Salt Tolerance in Wheat Through Changes in ABA Concentration, Ion Homeostasis, and Defense Systems. *Biomol. 2020, Vol. 10, Page 1506* 10, 1506. doi:10.3390/BIOM10111506.

Wang, W. N., Tarafdar, J. C., and Biswas, P. (2013a). Nanoparticle synthesis and delivery by an aerosol route for watermelon plant foliar uptake. *J. Nanoparticle Res.* 15, 1–13. doi:10.1007/S11051-013-1417-8/METRICS.

Wang, W. N., Tarafdar, J. C., and Biswas, P. (2013b). Nanoparticle synthesis and delivery by an aerosol route for watermelon plant foliar uptake. *J. Nanoparticle Res.* 15, 1–13. doi:10.1007/S11051-013-1417-8/METRICS.

Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburg, W., et al. (2011). The global technical and economic potential of bioenergy from salt-affected soils. *Energy Environ. Sci.* 4, 2669–2681. doi:10.1039/C1EE01029H.

Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., and Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nat. Commun. 2010 11* 1, 1–9. doi:10.1038/ncomms1053.

Wu, Y., Wang, X., Zhang, L., Zheng, Y., Liu, X., and Zhang, Y. (2023). The critical role of biochar to mitigate the adverse impacts of drought and salinity stress in plants. *Front. Plant Sci.* 14, 1163451. doi:10.3389/FPLS.2023.1163451/BIBTEX.

Yazıcılar, B., Böke, F., Alaylı, A., Nadaroglu, H., Gedikli, S., and Bezirganoglu, I. (2021). In vitro effects of CaO nanoparticles on Triticale callus exposed to short and long-term salt stress. *Plant Cell Rep.* 40, 29–42. doi:10.1007/S00299-020-02613-0/METRICS.

Yeghiazaryan, A. G. (2017). About the issue of monitoring method of Ararat valley soils salinization. *Ann. Agrar. Sci.* 15, 464–471. doi:10.1016/J.AASCI.2017.08.003.

Zafar, S., Hasnain, Z., Aslam, N., Mumtaz, S., Jaafar, H. Z. E., MegatWahab, P. E., et al. (2021). Impact of Zn Nanoparticles Synthesized via Green and Chemical Approach on Okra (Abelmoschus esculentus L.) Growth under Salt Stress. *Sustain. 2021, Vol. 13, Page 3694* 13, 3694. doi:10.3390/SU13073694.

Zahra, N., Shaukat, K., Hafeez, M. B., Raza, A., Hussain, S., Chaudhary, M. T., et al. (2021). Physiological and Molecular Responses to High, Chilling, and Freezing Temperature in Plant Growth and Production: Consequences and Mitigation Possibilities. *Harsh Environ. Plant Resil.*, 235–290. doi:10.1007/978-3-030-

65912-7_10/COVER.

Zayed, M. M., Elkafafi, S. H., Zedan, A. M. G., and Dawoud, S. F. M. (2017). Effect of Nano Chitosan on Growth, Physiological and Biochemical Parameters of Phaseolus vulgaris under Salt Stress. *J. Plant Prod.* 8, 577–585. doi:10.21608/JPP.2017.40468.

Zeng, L., and Shannon, M. C. (2000). Salinity Effects on Seedling Growth and Yield Components of Rice. *Crop Sci.* 40, 996–1003. doi:10.2135/CROPSCI2000.404996X.

Zhang, H., Wang, R., Chen, Z., Cui, P., Lu, H., Yang, Y., et al. (2021). The Effect of Zinc Oxide Nanoparticles for Enhancing Rice (Oryza sativa L.) Yield and Quality. *Agric. 2021, Vol. 11, Page 1247* 11, 1247. doi:10.3390/AGRICULTURE11121247.

Zhang, W., Wei, J., Guo, L., Fang, H., Liu, X., Liang, K., et al. (2023). Effects of Two Biochar Types on Mitigating Drought and Salt Stress in Tomato Seedlings. *Agron. 2023, Vol. 13, Page 1039* 13, 1039. doi:10.3390/AGRONOMY13041039.

Zhang, X., Yan, S., Tyagi, R. D., and Surampalli, R. Y. (2011). Synthesis of nanoparticles by microorganisms and their application in enhancing microbiological reaction rates. *Chemosphere* 82, 489–494. doi:10.1016/J.CHEMOSPHERE.2010.10.023.

Zhang, Y., Ding, J., Wang, H., Su, L., and Zhao, C. (2020). Biochar addition alleviate the negative effects of drought and salinity stress on soybean productivity and water use efficiency. *BMC Plant Biol.* 20, 1–11. doi:10.1186/S12870-020-02493-2/FIGURES/3.

Zheng, J., Han, J., Liu, Z., Xia, W., Zhang, X., Li, L., et al. (2017). Biochar compound fertilizer increases nitrogen productivity and economic benefits but decreases carbon emission of maize production. *Agric. Ecosyst. Environ.* 241, 70–78. doi:10.1016/J.AGEE.2017.02.034.

Zmeeva, O. N., Daibova, E. B., Proskurina, L. D., Petrova, L. V., Kolomiets, N. E., Svetlichny, V. A., et al. (2017). Effects of Silicon Dioxide Nanoparticles on Biological and Physiological Characteristics of Medicago sativa L. nothosubsp. varia (Martyn) in Natural Agroclimatic Conditions of the Subtaiga Zone in Western Siberia. *Bionanoscience* 7, 672–679. doi:10.1007/S12668-017-0395-1/METRICS.

Zörb, C., Geilfus, C. M., and Dietz, K. J. (2019). Salinity and crop yield. *Plant Biol.* 21, 31–38. doi:10.1111/PLB.12884.

Zulfiqar, U., Farooq, M., Hussain, S., Maqsood, M., Hussain, M., Ishfaq, M., et al. (2019). Lead toxicity in plants: Impacts and remediation. *J. Environ. Manage.* 250, 109557. doi:10.1016/J.JENVMAN.2019.109557.