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*Conference Report*

# Abstracts of the 5th International Electronic Conference on Agronomy (IECAG 2025) †

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**Abstract**

The 5th International Electronic Conference on Agronomy (IECAG 2025) was held online from 15 to 18 December 2025. In line with the commitment to fostering collaboration and knowledge exchange, IECAG 2025 aimed to provide a unique platform for researchers, agronomists, and plant scientists, where they could showcase their work, discuss groundbreaking findings, and engage in meaningful conversations with fellow experts.

**Keywords:** agricultural robotics; biostimulation; climate-resilient crops; crop breeding; crop health; digital agriculture; plant-microbe interactions; plant physiology; irrigation and water use

## 1. Introduction

A large number of agronomists and plant scientists joined this event and shared their findings around the following general and related themes, covered by the different conference sessions:

S1. Biostimulation and Biocontrol Strategies;
S2. Breeding and Selection Technologies;
S3. "New" Crops for Adaptation to Climate Change;
S4. Crop Water and Nutrient Management;
S5. Crop Biotic Interactions;
S6. Basic Plant Science;
S7. Precision and Digital Agriculture;
S8. Sustainable Farming Systems and Soil Management.

## 2. Session 1: Biostimulation and Biocontrol Strategies

### *2.1. Ethnobotanical Meta-Screening of Dual-Action Allelopathic Biostimulants: From Traditional Mediterranean Knowledge to Precision Bioformulations*

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Agronomy faces the dual challenge of escalating herbicide resistance and the urgent demand to reduce synthetic inputs in crop production [1]. Conventional allelopathy research has largely overlooked compounds with dual functionality—those capable of suppressing weeds while simultaneously stimulating crop performance. This study develops a systematic ethnobotanical meta-screening framework to identify such dual-action

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allelochemicals, with a specific focus on Mediterranean plant diversity and traditional agroecological practices.

The objective is to uncover, characterize, and prioritize allelochemicals derived from ethnobotanically reported species that exhibit selective weed suppression and crop biostimulation at ultra-low concentrations ($\leq$1 μM). Our hypothesis posits that these compounds, when integrated with optimized plant growth-promoting rhizobacteria (PGPR), can synergistically disrupt weed metabolism while enhancing nutrient uptake, stress resilience, and yield potential in crops.

The methodology combines ethnobotanical database mining, cross-validation with phytochemical libraries, and machine learning–based pattern recognition to detect recurring plant interference traits [2]. Candidate compounds are further assessed through precision bioformulations composed of purified essential oil fractions and PGPR consortia, tested under representative Mediterranean pedoclimatic conditions.

Preliminary screening highlights compound families such as sesquiterpene lactones (e.g., artemisinin derivatives) and iridoid glycosides, which demonstrated selective weed inhibition (70–85%) and significant crop biomass increases (25–40%) through enhanced root development and nutrient assimilation [3]. Field validations indicate potential yield gains equivalent to 150–200% ROI compared with conventional herbicide–fertilizer programs.

This work establishes a novel paradigm in sustainable agriculture, bridging Mediterranean traditional ecological knowledge with precision bioformulation science. By leveraging underexplored ethnobotanical resources, the study introduces a transformative strategy for sustainable intensification, environmental protection, and global food security.

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### *2.2. Biocontrol of Fusarium Wilt in Okra (Abelmoschus esculentus) Using Glomus mosseae and Bradyrhizobium japonicum*

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Introduction: Fusarium wilt, caused by the soil-borne pathogen *Fusarium oxysporum*, is a major constraint to okra (*Abelmoschus esculentus* (L.) *Moench*) production, leading to significant yield losses. Due to the environmental and health concerns associated with chemical control, this study investigated the efficacy of biological control agents, specifically the separate and combined inoculations of the arbuscular mycorrhizal (AM) fungus *Glomus mosseae* and the bacterium *Bradyrhizobium japonicum*, in managing Fusarium wilt and enhancing okra growth.

Methods: A greenhouse experiment was conducted using a randomized complete block design with 13 treatments and three replications. Okra seedlings were subjected to various inoculation regimes with *G. mosseae*, *B. japonicum*, and *F. oxysporum*, applied either singly, simultaneously, or sequentially. Key growth parameters, including plant height, stem girth, leaf number, and leaf surface area, were measured over five weeks. Disease severity was assessed based on visual symptoms. Data were analyzed using Analysis of Variance (ANOVA).

Results: Plants inoculated with *F. oxysporum* alone exhibited severe wilting, chlorosis, necrosis, and stunted growth. In contrast, inoculation with *G. mosseae* alone significantly enhanced all growth parameters and suppressed disease symptoms. The suppressive effect on the pathogen was most pronounced in treatments involving dual inoculation of *G. mosseae* and *B. japonicum*, particularly when applied before the pathogen. *B. japonicum* alone could not effectively suppress the pathogen. The susceptibility of okra to *F. oxysporum* was found to be age-mediated, with the most significant growth changes occurring between the second and fourth weeks after inoculation.

Conclusions: The study demonstrates that *Glomus mosseae* is effective in suppressing Fusarium wilt and promoting okra growth. For *Bradyrhizobium japonicum* to be an effective biocontrol agent, it must be co-inoculated with *G. mosseae*. These findings highlight the potential of using these biological agents, especially in combination, as a sustainable strategy for managing Fusarium wilt in okra cultivation.

### *2.3. Molecular Characterization and Bioactivity Assessment of Ghost Pepper Metabolites: Novel Approaches for Sustainable Pathogen Control in Horticultural Systems*

**Eva Sánchez-Hernández [1], Ana Garcés-Claver [2], Oreto Fatos-Avellán [2], Vicente González-García [3], Jesús Martín-Gil [1] and Pablo Martín-Ramos [1]**

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Increasing restrictions on synthetic fungicides and pathogen resistance necessitate eco-friendly alternatives. This research investigated the antimicrobial potential of specialized metabolites from Capsicum chinense 'Bhut Jolokia', examining how genetic mutations affecting pungency influence the overall phytochemical profile and biological activity against economically important soil-borne pathogens. Hydromethanolic extracts were prepared from the pungent cv. C-449 (capsaicinoid-rich) and its non-pungent mutant C-449_mutant (capsinoid-rich). Gas chromatography–mass spectrometry (GC-MS) was employed to distinguish chemical profiles between metabolite extracts. Antifungal screening utilized standardized agar dilution techniques against six major horticultural pathogens (*Botrytis cinerea*, *Fusarium equiseti*, *Macrophomina phaseolina*, *Neocosmospora falciformis*, *N. keratoplastica*, and *Sclerotinia sclerotiorum*). Additionally, ex situ protective assays were conducted on cucumber slices artificially inoculated with *S. sclerotiorum* to validate real-world efficacy. GC-MS revealed that C-449 extract was dominated by *capsaicinoids* (30.64%: capsaicin 19.94%, *dihydrocapsaicin* 10.70%) and fatty acids (20.30%). C-449_mutant lacked intact *capsinoids*, showing degradation products (hydrolysis: e.g., 3-hydroxy-4-methoxybenzoic acid; thermolysis: e.g., guaiacols) and fatty acids (24.74%). Both extracts demonstrated broad-spectrum antifungal activity, with the capsaicinoid-rich extract achieving superior pathogen control (complete inhibition at 250–750 μg/mL) compared to the *capsinoid* variant (375–1000 μg/mL). *S. sclerotiorum* showed the highest sensitivity while *N. keratoplastica* exhibited the greatest resistance. Both natural extracts outperformed azoxystrobin and fosetyl-Al in comparative assessments. Given its commercial viability advantages (eliminating worker protection concerns and crop pungency risks), the non-pungent extract was selected for ex situ validation. In cucumber slice assays, it provided complete protection against *S. sclerotiorum* at 1125 μg/mL, while lower concentrations failed to prevent colonization. This study establishes *C. chinense* extracts, especially the low-pungency variant,

as viable candidates for sustainable disease management, addressing both efficacy and critical application constraints for modern horticulture.

### *2.4. Using Mint Essential Oil as a Bio-Insecticide in the Agricultural Industry*

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Abstract: The growing global emphasis on sustainable agricultural practices has accelerated the search for eco-friendly alternatives to synthetic pesticides. Among natural solutions, mint essential oil—extracted from Mentha species—has emerged as a promising bio-insecticide due to its high content of bioactive compounds such as menthol and menthone. These components are known for their insecticidal, repellent, and antimicrobial properties, making mint essential oil a viable candidate for integrated pest management (IPM) systems in organic and agro-ecological farming. This study is a comprehensive literature review analyzing peer-reviewed research published over the last two decades concerning the pesticidal efficacy of mint essential oil. This review focuses on its effects on common agricultural pests, the mode of action of its active compounds, environmental safety, and limitations related to formulation and application. The findings reveal that mint essential oil demonstrates significant insecticidal activity against a broad spectrum of pests, including aphids, whiteflies, and beetles. It is also considered safe for beneficial insects, such as pollinators, and poses minimal risks to human health and the environment. Nonetheless, its high volatility and sensitivity to environmental factors (e.g., sunlight, temperature) can limit field efficacy. Research also highlights the importance of microencapsulation and emulsification techniques to enhance the stability and controlled release of the oil. Mint essential oil offers a sustainable and low-toxicity alternative to synthetic pesticides. While its insecticidal potential is well-documented, addressing challenges related to formulation and delivery systems is essential for broader field adoption. Continued research and technological innovation are necessary to fully integrate mint essential oil into commercial pest management strategies and support the global transition toward sustainable agriculture.

### *2.5. A Comparative Study of the Effects of Native and Commercial Mycorrhizal Inoculants on the Growth and Physiological Performance of the "Picholine Marocaine" Olive Cultivar*

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Arbuscular mycorrhizal fungi (AMF) are recognized for their role in enhancing plant growth and productivity, leading to increased interest in their application as biofertilizers. This study aimed to evaluate and compare the efficacy of an autochthonous AMF consortium, the "Rhizolive consortium" (RC), against a widely used commercial strain of Rhizophagus irregularis (RI) on the growth, biomass accumulation, and key physiological

characteristics of "Picholine Marocaine" olive cultivar under greenhouse conditions. Our findings revealed that both AMF successfully established symbiotic relationships with the olive root systems, with RC showing 100% mycorrhizal frequency and RI the highest intensity. Additionally, the application of RC inoculum resulted in superior growth performance, shoot height reaching an average of 52 cm, and a higher number of leaves being developed, averaging 55 per plant. Furthermore, RC inoculation significantly boosted the accumulation of both fresh and dry shoot biomass by 34% and 38%, respectively. Beyond growth parameters, RC-inoculated plants exhibited markedly improved physiological efficiency. Stomatal conductance and chlorophyll fluorescence were significantly increased ($p < 0.05$) by approximately 21% and 2.5%, respectively. In addition, biochemical analyses revealed that RC inoculation led to substantial increases in the foliar content of chlorophyll a, total chlorophyll, and protective carotenoid pigments. These comprehensive results underscore the significant potential of "Rhizolive consortium" isolated from the olive-growing regions of Morocco, to not only promote robust root colonization and vegetative growth but also to enhance the physiological efficiency of the "Picholine Marocaine" olive cultivar. This study provides compelling evidence for the relevance of native AMF consortia as sustainable and potentially more effective alternatives to commercial mycorrhizal inoculants in olive cultivation, contributing to more environmentally friendly and economically viable agricultural practices. Further research is warranted to explore the specific mechanisms underlying the enhanced performance observed with the RC and to evaluate its efficacy under field conditions.

### *2.6. Amino Acid-Enriched Biostimulant Application Enhances Must Quality Parameters in Vitis vinifera L. cv. Tempranillo*

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The growing need for sustainable viticultural strategies has led to increased interest in the use of biostimulants. In this study, we evaluated the effects of foliar application of an amino acid-based biostimulant (Naturamin®, DAYMSA, Zaragoza, Spain) at two doses (500 and 1000 g/ha) on yield components and grape quality in *Vitis vinifera* L. cv. *Tempranillo* under rainfed conditions in La Rioja, Spain. While no significant effects on yield parameters were observed, the highest dose of Naturamin® significantly increased the concentration of several free amino acids in the grape must. These changes could enhance yeast nutrition and fermentation kinetics, while also contributing to the formation of aroma-active compounds and improving the sensory profile of wines. Additionally, a significant increase in hydroxycinnamic acid levels was detected, which may influence wine color stability and aromatic complexity. Interestingly, treated grapes reached phenolic maturity at lower sugar levels, which may be advantageous for producing balanced, lower-alcohol wines in the context of climate change. These results highlight the potential of amino acid-enriched biostimulants as a sustainable tool to improve grape composition without compromising yield. For the first time, we report a comprehensive evaluation of the effects of foliar application of the amino acid-based biostimulant Naturamin® on grapevines under rainfed conditions.

### *2.7. Biocompatibility Between Biopolymers and Trichoderma virens*

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The use of biopolymers as seed coating is an innovative, pre-germinative method of controlled seed hydration, combined with the inoculation of biological agents that act as biocontrollers or growth promoters, helping to improve germination, initial plant growth, and overcome different types of biotic or abiotic stress. Therefore, the objective of this work was to evaluate the compatibility between *Trichoderma virens* and biopolymers at different concentrations. The following biopolymers were used: Maltodextrin (M), Sodium Alginate (AlNa), Guar Gum (GG), and Arabig Gum (AG) in four different concentrations. The native *Trichoderma virens* fungus used as a biostimulant belongs to the fungal collection of the Plant Pathology Department of the Faculty of Agricultural Sciences of the National University of the Northeast (FCA-UNNE). Two methodologies were used in petri culture: Screening with PDA (potato dextrose agar) discs and spore viability counting for the different biopolymers and concentrations (treatments). Regarding the screening technique, the biopolymers with the lowest incidence on mycelial growth were M and AlNa, while those with the highest statistical impact were AG and GG. In the spore viability assay, the treatment that statistically yielded the highest number of viable spores was 1% guar gum, followed by 0.75% GG and 2% AlNa. In conclusion, these preliminary results on the compatibility between biopolymers and *T. virens* lay the groundwork for their inclusion as a coating in the seed. The assay indicates that GG was the most effective biopolymer for spore viability, while AG and GG significantly favored mycelial growth of *T. virens*. These differences could be attributed to the different nutritional requirements of the fungus during its growth and germination phases, underscoring the importance of selecting compatible biopolymers for each phase.

### *2.8. Bioestimulation of Trichoderma virens and Bacillus subtilis in Rice Crops in Argentina*

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Rice (*Oryza sativa*) is the main cereal crop in the province of Corrientes, Argentina. Biotic constraints are a constant threat to rice production. Studies conducted with microorganisms as alternatives for controlling economically important diseases have demonstrated their biostimulant action in plants. The use of microorganisms was evaluated as an alternative and sustainable measure to increase crop yields through biostimulation as a complement to nutrition plans. During 2022 and 2023, in two locations in the province of Corrientes (Argentina), the individual and combined effect of Trichoderma virens and Bacillus subtilis on rice yield was measured. The design was a completely randomized block design with nine treatments and three replicates per treatment. A control without application, one commercial treatment, and seven treatments with both individual and combined applications of the organisms were included. The grain yield obtained in each treatment was measured. The results indicated that the highest yields in both locations were obtained for the treatments with microorganisms. In the Itá Ibaté location, three of the treatments with biological agents exceeded the conventional treatment by 700 kg/ha, and in the Perrugorria location, conventional treatment was exceeded by 1870 kg/ha. These results demonstrate the biostimulant effect of microorganisms on

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the crop and suggest the need to investigate the metabolic pathways that benefit from the interaction between both organisms.

### *2.9. Biofertiliser Effects on Lettuce Morphological Traits for Fresh Consumption and Processing in Two Distinct Soil Types*

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Lettuce is a leafy vegetable consumed fresh or processed in ready-to-eat products, supporting lifestyle trends favouring quick, healthy, and convenient meals. Morphological traits impact yield, processing efficiency, shelf life, and product quality. Biofertilisers are gaining attention as eco-friendly, sustainable alternatives that enhance soil fertility, increase microflora diversity, stimulate plant growth, and reduce pollution in all agricultural systems. This study aimed to investigate the effect of biofertilisers on lettuce morphology traits for fresh consumption and processing. Six lettuce cultivars ('Kiribati', 'Murai', 'Aquino', 'Gaugin', 'Aleppo', and 'Carmesi') were cultivated over three consecutive seasons (autumn, winter, and spring) under greenhouse conditions. Experiments were conducted in two distinct soil types: Mollic Gleysol (Calcaric)-GL and Hortic Anthrosol (Terric, Transportic)-AT. Two biofertilisers, EM Aktiv and Vital Tricho, were applied alone and combined to the soil and foliar via a battery sprayer. Green cultivars, especially 'Kiribati' and 'Aleppo', had the highest levels in most morphological parameters, while red 'Gaugin' had the highest core ratio (stem to rosette height) in both soils. In GL soil, all biofertilisers increased rosette diameter, with Vital Tricho boosting dry leaf weight, and EM Aktiv and combined fertilisers raising core ratio. In contrast, in AT soil, all fertilisers significantly reduced fresh leaf weight and stem diameter, while Vital Tricho and combined treatment lowered rosette diameter and core ratio. Generally, morphological traits were higher in winter and spring trials than in autumn. Pearson correlation coefficients showed that fresh leaf weight was positively linked to all other traits in both soils. An increased core ratio negatively impacts processing quality; thus, maintaining it below 0.5 is essential. Although fertiliser did not influence all parameters, the interaction among all factors was significant, except for dry leaf weight in both soils, indicating the need to optimise biofertiliser application according to soil type.

### *2.10. Biostimulant-Induced Modulation of Photosynthetic Efficiency in Alfalfa (Medicago sativa L.)*

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Enhancing photosynthetic efficiency via biostimulant application could offer a sustainable pathway to improve alfalfa forage yield, quality traits and resilience against unfavourable environmental conditions. This current study was conducted at the University of Debrecen to evaluate the impact of two biostimulants on gas exchange parameters and chlorophyll fluorescence in alfalfa under field conditions. The experiment was arranged in a randomized complete block design with three treatment levels, namely,

Tricho Immun (T1) (21.6 g/3 L), a biostimulant containing Si, MTU®, and pidolic acid (T2) (2 mL/3 L) and a control (T3) (no biostimulant). Parameters measured include net photosynthetic rate (A), transpiration rate (E), intercellular $CO_2$ concentration (Ci), ambient $CO_2$ concentration (Ca), water use efficiency (WUE) and quantum yield of PSII (ΦPSII). Data gathered were subjected to analysis of variance using Genstat statistical software edition 18, where significant means were separated at a 5% probability level using the least significant difference, and DMRT was used to rank the performance of the individual treatment on measured traits. The results show that biostimulant application significantly improved net photosynthetic rate, transpiration rate, intercellular $CO_2$ concentration, water use efficiency, and quantum yield of PSII, indicating improved photochemical efficiency. However, no significant changes were observed in ambient $CO_2$ concentration. Our findings indicated that T2 significantly increased ΦPSII by 43.9%, net photosynthetic rate by 37.8%, and transpiration rate by 97.6%, while T1 also increased ΦPSII, net photosynthetic rate, and transpiration rate by 11.7%, 9.8%, and 39.5%, respectively, compared to the control (T3). These results suggest that biostimulants can enhance photosynthetic performance and resource-use efficiency in alfalfa under field conditions, offering a promising approach for sustainable forage production.

### *2.11. Biostimulation Effects of Plant Growth-Promoting Rhizobacteria and Spent Mushroom Compost on Maize Drought Tolerance*

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Maize (*Zea mays* L.) is one of the most important cereal crops worldwide but is highly vulnerable to drought stress, which impairs growth and yield through physiological and biochemical disruptions. Plant growth-promoting rhizobacteria (PGPR) and organic amendments have been proposed as sustainable strategies to mitigate water stress. This study aimed to evaluate the effects of PGPR isolates and spent mushroom compost (SMC) on maize growth under controlled drought conditions. A total of 23 bacterial isolates were initially screened for osmotic tolerance, biofilm formation, and exopolysaccharide (EPS) production. Several isolates demonstrated strong tolerance at 20% PEG-6000 and produced significant levels of EPS, supporting their potential role in enhancing stress resilience. Germination assays revealed that inoculated seeds exhibited higher germination rates and seedling vigor indices compared with uninoculated controls. In seedling assays, selected isolates significantly promoted root elongation, shoot length, and seminal root formation, indicating improved early growth performance. Two promising isolates, identified as Bacillus velezensis strains, were further tested in greenhouse conditions in combination with SMC at 30 t/ha (SMC30). Application of SMC alone enhanced plant height, root biomass, and chlorophyll content compared with untreated controls. Notably, the combined treatment of PGPR and SMC showed additive benefits, including greater root surface area, increased dry weight, and improved recovery following drought exposure. These improvements were accompanied by higher antioxidant enzyme activities and reduced stress markers, suggesting enhanced physiological adaptation to water deficit. Overall, the results demonstrate that both PGPR and SMC independently improve maize performance under drought, and their combined use may offer a synergistic strategy for sustainable maize production in water-limited environments.

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### *2.12. Comparative Genomic Analysis of Three Pseudomonas Strains Reveals Biosynthetic Potential Underlying Antifungal Activity Against Phytopathogens*

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Fungal phytopathogens cause major crop losses worldwide and are traditionally managed with chemical fungicides. However, excessive use of fungicides promotes resistance, affects non-target organisms, and raises environmental and food safety concerns. Bacterial strains with strong antifungal activity represent a sustainable alternative for biocontrol development. In a previous study, three bacterial strains (*Pseudomonas protegens* MH2, *Pseudomonas koreensis* CNI3, and *Pseudomonas* sp. R3) showed high inhibitory activity against plant pathogenic fungi, including *Phomopsis* sp., *Botryosphaeria* sp., and *Harpophora maydis* (unpublished data). To elucidate the molecular mechanisms underlying their antifungal activity, whole-genome sequencing was combined with functional annotation and secondary metabolite mining using antiSMASH. Biosynthetic gene clusters (BGCs) were compared across strains to identify metabolites potentially responsible for antifungal effects.

Strain MH2 exhibited strong inhibition ($\geq$70% mycelial inhibition) of *Phomopsis* sp. and *Botryosphaeria* sp. and encoded a diverse set of BGCs, including those for 2,4-diacetylphloroglucinol, pyoluteorin, pyrrolnitrin, orfamide-type lipopeptides, phenazines, hydrogen cyanide, and multiple siderophores. Strain CNI3 inhibited *H. maydis* and *Botryosphaeria* sp. and carried clusters for NRPS, PKS, WLIP-like lipopeptides, siderophores, betalactones, and hydrogen cyanide. Strain R3, active only against *H. maydis*, contained a smaller arsenal of BGCs, notably pyoverdine-like siderophores, hydrogen cyanide, arylpolyenes, and betalactones. Comparative analysis indicated that MH2 and CNI3 harbor unique NRPS/PKS clusters absent in R3, potentially explaining their broader antifungal spectra.

The genomic profiles of these strains reveal multiple antifungal determinants, with MH2 emerging as the most promising candidate for biocontrol development due to its broad activity and rich biosynthetic repertoire. These results provide a genomic basis for the antifungal potential of these isolates and establish a foundation for integrative transcriptomic, metabolomic, and functional studies to characterize their mechanisms and biotechnological applications.

### *2.13. Evaluating the Biostimulant Potential of Brown Seaweed Extracts on Tomato (Solanum lycopersicum) Germination and Early Growth for Sustainable Crop Production*

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In the context of promoting sustainable agriculture, this research explores the biostimulant potential of aqueous extracts from three brown seaweed species, *Sargassum trichocarpum*, *Cystoseira tamariscifolia* and *Fucus spiralis*, on the germination and early seedling growth of *Solanum lycopersicum*.

Extracts were prepared by cold maceration and sonication and applied at different concentrations (0.1–1.5%) in a completely randomized design, with positive and negative controls and ten replicates per treatment. The extracts were applied at different concentrations. Significant treatment effects were observed in the results for all evaluated parameters. *F. spiralis* at a 0.2% concentration significantly enhanced germination, outper-

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forming *C. tamariscifolia* treatments and both controls at higher concentrations. The extract's high content of phenolics, polysaccharides and essential minerals is likely responsible for this positive response. However, both *F. spiralis* and *C. tamariscifolia* at higher concentrations (1–2%) showed inhibitory effects, which could have been caused by osmotic stress due to excessive salinity. Macroscopic observations revealed that higher concentrations of *S. trichocarpum* enhanced hypocotyl growth and overall seedling vigor; however, root growth responses depended on species and concentration. Overall, this study highlights the concentration and species specificity of seaweed-based biostimulants. *F. spiralis* at low concentrations and *S. trichocarpum* at high concentrations have great potential to improve early tomato seedling growth, supporting their specific application in sustainable crop management practices.

### *2.14. Evaluating the Effects of Microalgal Extracts on the Germination and Phenolic Contents of Ayocote Bean (Phaseolus coccineus) Seeds*

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This study investigates the potential of microalgal extracts as natural biostimulants for scarlet runner bean, also known as ayocote bean (*Phaseolus coccineus*) germination. We evaluated the effects of different extract concentrations (0–100% $v/v$) over 120 h on germination dynamics and the levels of bioactive compounds (total phenolics and antioxidant power, FRAP) in the resulting seedlings. While extract concentration did not significantly affect the final germination percentage ($p = 0.086$), it had a pronounced effect on germination speed and seedling physiology. Higher concentrations generally suppressed germination, as measured by a decrease in the Continuous Germination Index (CGI, $p = 0.003$), which is a novel index derived from the functional data analysis of the smoothed germination curve that describes the trajectories of said curves. The highest concentration (100%) even exhibited moderate toxicity (Seed Germination Index: $-0.27$). In contrast, low to moderate concentrations (25–50%) enhanced the germination process, with peak performance observed at 50% (CGI: 112.32 area units). Bioactive compound levels were also significantly influenced, with total phenolics ($p = 0.003$) and FRAP ($p \leq 0.001$) varying throughout germination. A notable recovery in antioxidant power values between 72 and 96 h, particularly at lower concentrations, suggests a stress-adaptive response potentially linked to the increased phenolic content observed after 72 h. We conclude that microalgal extracts can effectively enhance the germination and bioactivity of ayocote beans, but their application requires careful dose calibration, with an optimal range at or below 50%, to maximise biostimulation and avoid phytotoxic effects.

### *2.15. From a Healthy Phytobiome to Healthier Food—Use of Natural Bioprotective Agents*

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The phytobiome—comprising plants, their associated microbiota, and the surrounding environment—represents a dynamic network critical to plant health and agricultural productivity. Recent advances highlight the phytobiome as a powerful lever for improving food quality and resilience through sustainable practices. This paper explores the use of natural bioprotective agents—beneficial microbes, microbial consortia, and plant-derived compounds—as key tools in promoting phytobiome integrity and, by extension, healthier food systems.

Natural bioprotectants enhance plant defense mechanisms, suppress phytopathogens, and stabilize plant–microbe interactions, contributing to reduced chemical input and increased ecological balance. By supporting native microbial communities within the rhizosphere and phyllosphere, these agents not only reduce susceptibility to pests and diseases, but also improve nutrient uptake, abiotic stress tolerance, and food nutritional quality. The integration of bioprotective agents into agricultural systems represents a shift from reactive crop management to a proactive, systems-based approach rooted in ecological principles.

This work discusses the mechanisms through which microbial agents such as *Bacillus*, *Trichoderma*, and *Pseudomonas* species act as bio-shields and growth promoters, while also highlighting the emerging role of microbial metabolites and plant signaling pathways in steering community dynamics. We propose a framework for assessing phytobiome functionality as a predictor of crop performance and advocate for multi-strain, niche-specific applications tailored to crop and climate.

Ultimately, fostering a healthy phytobiome through natural bioprotectants represents a pathway toward cleaner food, restored soil health, and reduced agricultural dependence on synthetic inputs. This approach aligns with global goals for sustainable food production and offers promising solutions to the intertwined challenges of climate change, biodiversity loss, and food security.

### *2.16. From Wild Plant to Biostimulant: Effects of Silene inflata Extracts on Lettuce Growth and Quality*

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Introduction: Plant biostimulants are pivotal to developing more sustainable agricultural systems, enhancing crop performance, and reducing reliance on synthetic inputs. Among them, botanical extracts remain underexplored, especially those derived from wild plant species. In this study, *Silene inflata*, a spontaneous herbaceous plant typical of Mediterranean grasslands, was investigated for its biostimulant potential on lettuce.

Methods: Leaves and roots of *S. inflata* were collected from greenhouse-grown plants and stored at −80 °C. Both tissues were biochemically characterized for polyphenols, ascorbate, proteins, saponins, chlorophylls, and carotenoids. Aqueous phosphate-buffered extracts from leaves (LES) and roots (RES) were prepared via ultrasound-assisted green extraction. A pilot study showed that irrigation was more effective than foliar spraying, and this method was used in the main experiment. Three-week-old *Lactuca sativa* L. (cv. Canasta) seedlings were transplanted into 10 cm pots and grown in a greenhouse under natural light (15 h day/9 h night; 7–25 °C). Plants were irrigated daily with 20 mL of tap water. On treatment days, 10 mL of tap water was applied, followed 1 h later by 10 mL of LES or RES at 1 or 10 mL/L once per week for three weeks. Controls received water or PBS.

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Seven days after the last treatment, plants were harvested for fresh/dry weight measurements and biochemical analyses.

Results: RES showed high saponin levels, while LES had five times more polyphenols. Ascorbate and soluble proteins were higher in leaves (17 mg/100 g FW and 0.5 mg/g FW, respectively). LES at 10 mL/L significantly improved biomass, while LES at 1 mL/L enhanced chlorophylls, carotenoids, and polyphenols. Protein content was reduced in LES 10-treated plants. Overall, LES had stronger biostimulant effects in a dose-dependent manner. Additionally, *S. inflata* was successfully cultured in vitro, suggesting its suitability for sustainable biomass production.

Conclusions: These findings reveal *S. inflata* as a promising biostimulant, highlighting the value of wild plant biodiversity for sustainable agricultural innovation.

### *2.17. Functional Data Analysis of Foliar Biostimulant Effects on Cucumber (Cucumis sativus) Yield Dynamics in Hydroponic Greenhouse Cultivation*

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This study evaluated the effect of foliar application of biostimulants on cucumber crops (*Cucumis sativus* var. *Centauro*) under greenhouse conditions in a hydroponic system with a substrate. Applications were made every 15 days after transplanting to analyze the influence of biostimulants on fruit productivity over four cuts. Treatments were as follows: T1 (control, water), T2 (algal extract with bioactive compounds from *Ascophyllum nodosum*, N, K, B and Zn), T3 (foliar formulation with a high concentration of Mg, B and Zn), and T4 (a mixture of T2 and T3). Additionally, a nutrient solution with 14 N, 1.5 P, 7 K, 8 Ca, 2.5 Mg and 3 S was supplied during the production cycle. This study also applied Functional Data Analysis (FDA) to evaluate the dynamic responses of accumulated cucumber yield. Raw data were converted into continuous functions and functional principal component analysis (FPCA) was used to decompose yield trajectories into principal components for each treatment. FDA revealed significant ($p = 0.04$) treatment effects, with biostimulant treatments exhibiting shapes similar to each other but different from T1. Functional principal component analysis (FPCA) identified one major variation mode (94.3% variance) linked to an increased response or acceleration between the second and third cut, particularly for T4. Functional ANOVA also confirmed significant ($p < 0.01$) treatment effects between these cuts, which was not observed with traditional repeated-measures ANOVA, as total harvest weight per cut was not affected by the application of biostimulants ($p \geq 0.9$). T4 (algal extract + Mg-B-Zn) maximized yield via early-phase acceleration. FDA captured continuous yield dynamics, revealing inflection points commonly missed by traditional methods.

### *2.18. Fungal Flora in Cowpea Crops in the Province of Corrientes, Argentina*

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Argentina is among the top 20 legume producers in terms of tonnage. Cowpea (*Vigna unguiculata* [L.] *Walp*., cv. Cuarentón) contains a high concentration of protein, minerals, vitamins, and carbohydrates and a low lipid content, making it of great importance in human nutrition. The seeds of various legumes have been reported to be an important source of primary inoculum for various pathogenic fungi, including species of the genera *Fusarium*, *Curvularia*, *Bipolaris*, *Alternaria*, and *Macrophomina*, etc. Therefore, the objective of this study was to quantify the presence of fungi in cowpea seeds from two agricultural seasons and to identify the fungi present in different parts of the seedling (root, leaf, and petiole). The plant material was sown in Petri dishes with potato glucose agar with the addition of an antibiotic (*streptomycin*) to avoid bacterial contamination. For the seeds, 200 seeds of the Cuarentón variety were used. The results obtained were as follows: seeds from the 22/23 campaign: *Trichoderma* (11.5%), *Fusarium* (9%), *Sordaria* (4%), *Alternaria* (4%), *Penicillium* (3.5%), *Aspergillus* (2%), *Bipolaris* (0.5%), and *Nigrospora* (0.5%). Seed Campaign 23/24: *Trichoderma* (22%), *Fusarium* (7%), *Curvularia* (3%), *Aspergillus* (1.5%), and *Nigrospora* (0.5%). The fungi found in the sowing of the different parts of the seedling are the following: root: *Fusarium* and *Exserohilum*; leaves: *Alternaria*, *Fusarium* and *Cladosporium*; and petiole: *Alternaria* and *Bipolaris*. It is noteworthy that the genus Trichoderma is the fungus with the highest incidence levels in both campaigns. This microorganism stands out for being an excellent antagonist of fungal pathogens. Its use in the biological control of diseases is an indispensable tool today in the integrated management of pests and diseases of different crops. This work makes a first contribution to the search for native fungal antagonists in cowpea crops, in order to improve the control of fungal diseases.

### *2.19. Gum Arabic-Based Bioactive Coatings Enriched with Natural Additives: A Biostimulation and Biocontrol Strategy for Postharvest Fruit Preservation*

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Postharvest deterioration of fruits remains a global challenge, leading to significant economic losses and reduced food security. Conventional synthetic packaging delays spoilage but raises environmental and health concerns. Edible coatings based on natural polymers offer a sustainable alternative. Gum Arabic, an exudate from Acacia species, possesses excellent film-forming capacity and is widely recognized for its safety and biodegradability. Its role can be further enhanced through incorporation of natural bioactive additives.

This study investigates gum Arabic coatings, applied alone and in combination with natural compounds such as essential oils, polyphenolic extracts, and waxes. Coating solutions were prepared at varying concentrations and applied to fruits by dipping or spraying. Physicochemical attributes (weight loss, firmness, color, and soluble solids), microbiological stability, and sensory qualities were monitored during storage. Encapsulation and hybrid polymer strategies were explored to stabilize volatile and sensitive additives.

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Pure gum Arabic coatings reduced respiration rate, water loss, and microbial contamination, maintaining fruit firmness, color, and nutritional value. When enriched with essential oils, coatings displayed enhanced antimicrobial efficacy against common pathogens. Polyphenolic extracts provided antioxidant protection, delaying browning and oxidative damage, while wax incorporation improved resistance to moisture loss. These combined effects contributed to extended shelf life and better consumer acceptance.

Gum Arabic-based coatings represent a novel strategy, integrating both biostimulator—through delayed ripening and quality preservation—and biocontrol—through antimicrobial and antioxidant protection. Their multifunctionality highlights their potential as sustainable alternatives to synthetic packaging, supporting eco-friendly and efficient postharvest management systems.

### *2.20. Harnessing Synergistic PGPR Consortia to Boost Legumes' Resiliency to Salt Stress*

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Increasing drought and rising water and soil salinity pose significant challenges to both agricultural productivity and nutrition security in the Mediterranean region. Pea crop (*Pisum sativum* L.), which is vital for sustainable agriculture, is highly sensitive to salt stress, leading to substantial yield losses due to osmotic and oxidative damage and to the degradation of key physiological processes. Pea plants were grown in pots filled with sterile soil under greenhouse conditions. Plants were subjected to two salinity conditions: non-saline control (0 mM NaCl) and progressively increasing salt concentration (100, 150, and 200 mM NaCl). The trial included an uninoculated control and a treatment inoculated with a consortium of salt-tolerant *Pseudomonas* sp. and *Bacillus* sp. strains.

The results demonstrated that salt stress significantly reduced plant growth, biomass accumulation, and nitrogen content in uninoculated plants, while increasing electrolyte leakage and tissue sodium concentration. In contrast, consortium inoculation under salt stress resulted in significantly higher total biomass, leaf number, and leaf area than all other treatments. Furthermore, consortium inoculation increased photosynthetic activity compared with uninoculated plants, as indicated by a significantly higher SPAD index and the maintenance of a high maximum quantum yield of photosystem II, suggesting limited photo-inhibition. Additionally, under salt stress, our consortium enhanced osmotic regulation, resulting in a 3.2-fold increase in proline content, and improved membrane stability, with a 38% reduction in electrolyte leakage compared to the uninoculated treatment.

Overall, synergistic PGPR consortium effectively mitigates salt stress in peas through a multi-faceted defense mechanism, representing a promising sustainable strategy to enhance legume resilience under saline conditions.

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### *2.21. In Planta Evaluation of Plant Extract-Loaded Chitosan Nanocarriers Against Fusarium Wilt: Efficacy Assessment in Controlled Environment Conditions*

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Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cubense* represents one of the most destructive banana diseases worldwide. With tropical race 4 (TR4) threatening global production and limited resistant varieties available, innovative biocontrol strategies are essential. Following promising in vitro results, this study evaluated the protective efficacy of chitosan-based nanocarriers loaded with *Rubia tinctorum* and *Uncaria tomentosa* extracts under controlled greenhouse conditions.

Banana plantlets were treated with nanocarrier formulations and subsequently inoculated with Foc. Disease severity was assessed using a 0–4 scale over 79 days, and the area under disease progress curve (AUDPC) was calculated. Additionally, physiological parameters including stomatal conductance, transpiration rate, and chlorophyll fluorescence were monitored using porometry and fluorometry.

Results demonstrated significant disease reduction with *R. tinctorum*-loaded nanocarriers, achieving 34.9% control efficacy compared to untreated infected plants (AUDPC: 134.5 vs. 206.6). This treatment showed statistically significant differences in disease severity from 31 days post-inoculation onwards, with final severity scores of 2.6 compared to 3.6 in infected controls. In contrast, *U. tomentosa* formulations provided limited protection (7.8% efficacy, AUDPC: 190.5) with no significant differences from the infected control. Physiological analyses revealed enhanced stomatal conductance and transpiration rates in *R. tinctorum*-treated plants. Growth parameters demonstrated significant improvements in *R. tinctorum*-treated plants, including 10–15% increases in leaf width, enhanced leaf length and fresh weight (16% increase), alongside 36–43% higher chlorophyll content compared to controls. DUALEX measurements confirmed elevated flavonoid levels (621.2 vs. 318.1) and anthocyanin content (231.0 vs. 168.4) in *R. tinctorum*-treated plants, indicating enhanced stress tolerance.

These findings validate the transition from laboratory to greenhouse conditions, demonstrating that *R. tinctorum*-based nanocarriers offer substantial disease suppression potential. The integration of nanotechnology with natural bioactive compounds presents a promising sustainable approach for Fusarium wilt management, contributing to the development of environmentally friendly alternatives for banana crop protection in commercial production systems.

### *2.22. Mitigating Combined Salinity and Drought Stress in Chickpea (Cicer arietinum L.) Through Biochar Amendment*

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Drought–salinity stress poses a significant threat to agriculture, negatively impacting the growth and productivity of vital crops like chickpea (*Cicer arietinum* L.). This study investigated the efficacy of biochar as a soil amendment to alleviate these concurrent stresses. In a controlled pot experiment, chickpea plants were subjected to two main conditions: a control (75% field capacity), and combined salinity–drought stress (150 mM NaCl at 35% field capacity). Each condition was tested with and without biochar soil amendment. Key morphological traits, photosynthetic activity, and biochemical stress indicators were assessed in chickpea plants.

Combined drought–salinity stress severely impaired plant growth. However, the application of biochar significantly mitigated these adverse effects, leading to a substantial recovery in key morphological traits, including a 56% increase in shoot biomass and an 87% improvement in root development compared to untreated stressed plants. Under drought–salinity stress, photosynthetic parameters and the integrity of chloroplast structure were compromised. The application of biochar significantly mitigated these damages by restoring photosynthetic efficiency. Moreover, biochar amendment effectively reduced oxidative stress markers, decreasing malondialdehyde and hydrogen peroxide levels by 37% and 45%, respectively, compared to the control. Correspondingly, the activities of crucial antioxidant enzymes, namely superoxide dismutase, catalase, and ascorbate peroxidase, which were suppressed by stress, were significantly enhanced following biochar treatment.

This study highlights the beneficial effects of biochar under drought–salinity stresses, which could be used in the management of chickpea cultivation in drought- and salinity-prone regions.

### *2.23. Patterns of Natural Egg Parasitism by Telenomus sp. (Hymenoptera: Scelionidae) on Stink Bug Pests in Argentine Rice Fields*

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Parasitoid wasps are highly effective biological control agents, capable of parasitizing eggs, larvae, and adults of various insect species. They often act with other natural enemies, highlighting their importance in pest management strategies for crops such as rice (*Oryza sativa* L.). However, their effective application requires understanding of their field interactions and the influence of crop cultivars and plot heterogeneity, providing essential insights for developing sustainable practices that optimize ecological interactions in agroecosystems. The aim of this study was to evaluate natural egg parasitism in two economically important rice pests, *Tibraca limbativentris Stål* and *Oebalus* spp., while considering the influence of local-scale factors (plot edge vs. center) and plant architectural traits (tall vs. short cultivars) on parasitoid incidence. To achieve this, ten rice paddies in Argentina were sampled throughout the crop cycle. Stink bug egg masses were manually collected from both plot zones (edge/center), considering two rice cultivars (tall/short plants). Eggs were placed in 250 cc containers covered with voile fabric and monitored daily until either parasitoids or nymphs emerged. Taxonomic determination was performed by examining nymphal characters, and parasitoids were identified using the relevant literature. In total, 1331 eggs (58.68% from *T. limbativentris* and 41.32% from *Oebalus* spp.) were obtained,

mainly collected during the crop reproductive phenology. Overall, 22.84% of eggs were parasitized by *Telenomus* sp., and parasitism was consistently higher at plot edges for both pest groups. The incidence of *Telenomus* sp. also varied with rice cultivars: no parasitism of *T. limbativentris* occurred in tall cultivars, but it did occur in short ones, while parasitism of *Oebalus* was highest in tall plants and lowest in short plants. These results demonstrate that local-scale factors and plant architecture affect *Telenomus* sp. activity, and despite agrochemical use, this parasitoid remain active, contributing to pest suppression and emphasizing their agroecological importance in local crops.

### *2.24. Plant-Based Biostimulants for Sustainable Crop Performance*

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Modern agriculture faces mounting challenges from climate change, soil degradation, and the overuse of synthetic agrochemicals, which contribute to environmental pollution, biodiversity loss, and the emergence of more resistant pests and diseases. Plant-derived biostimulants have emerged as sustainable tools to improve crop productivity while mitigating ecological impacts. Unlike conventional fertilizers that primarily supply nutrients, biostimulants act through diverse physiological and molecular mechanisms, including phytohormone regulation (e.g., auxin-like activity), activation of antioxidant defenses, and modulation of the soil microbiome. These actions enhance nutrient use efficiency, strengthen tolerance to abiotic stresses such as drought and salinity, and improve crop quality traits. Plant extracts rich in bioactive compounds, such as polyphenols and signaling compounds, have demonstrated strong potential to stimulate root development, increase photosynthetic activity in crops like tomato and wheat, and promote soil health. Despite these benefits, several barriers hinder their large-scale adoption, including the need for standardized extracts, consistent field performance across diverse conditions, and harmonized regulatory frameworks. This review highlights successful applications of plant-based biostimulants in major food crops and explores recent innovations in their production from agri-food by-products, with particular focus on advanced extraction methods (intensified by enzymes, microwaves, and ultrasound) and formulation strategies (such as emulsification). Ultimately, this work underscores the role of plant-derived biostimulants in fostering more sustainable and resilient agricultural systems, aligning with global food security and safety goals.

### *2.25. Postharvest Performance and Antioxidant Capacity of Kiwi Fruits Under the Application of a Glycine-Betaine-Based Biostimulant During the Growing Season*

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The demand for high-quality agricultural products is increasing; however, this requirement is becoming challenging due to climate change, which causes abiotic stresses. In this research, we studied the performance of the kiwi fruit, *Actinidia deliciosavar*. "Hayward", 60 days after their storage for two different cultivation periods, in which a glycine-betaine biostimulant (GB) was applied to the kiwi trees via irrigation. The experiment was car-

ried out in a kiwi orchard where two treatments were arranged: one treatment where the biostimulant was applied (GB) and a control treatment (C) that was biostimulant-free. Postharvest analysis was performed at the Productive Agriculture and Plant Health Laboratory of the Department of Agriculture of the University of Ioannina by measuring the fresh and dry weight of kiwi fruits (g), their soluble solids content (%), and titratable acidity (%). To assess the antioxidant traits of kiwi fruits, the DPPH (%) and ascorbic acid content (mg $DW^{-1}$) were recorded. The data analysis revealed that GB treatment was beneficial for kiwi fruits during storage, enhancing their antioxidant capacity as indicated by their higher ascorbic acid content (vitamin C) compared to the control. This qualitative difference may be beneficial for the commercial requirements of kiwifruit cultivation and promising for kiwi metabolism, strengthening their cultivation under the abiotic conditions of climate change. This prompts us to further investigate the application of amino acid biostimulants. This result complements the literature on the implementation of biostimulants, as reports regarding their application in kiwifruit cultivation are limited. This study took "Hayward" kiwifruits as the research object and found that the glycine-betaine (GB) biostimulant had a positive effect on kiwifruits during storage. This provides an optional solution for meeting the commercial needs of kiwifruit cultivation and improving the adaptability of kiwifruit cultivation under abiotic stress conditions.

### *2.26. Saponins as Sustainable Agrochemicals: Extraction and Recovery from Chenopodium quinoa Residues for Crop Protection*

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The increasing global demand for *Chenopodium quinoa* has driven a significant increase in grain processing, generating large volumes of scarification residues. This fine yellowish powder, which accounts for about 8% of the processed grain weight, has no commercial value and is typically discarded. However, it contains approximately 15% saponins, representing a valuable yet underutilized resource with potential applications in agriculture and other industries. In this study, an integrated valorization strategy was developed to recover and purify saponins from quinoa residues. Hydrodynamic cavitation-assisted extraction (HC) yielded an extract containing 12 g/L saponins with a purity of 30%. Subsequent purification through sequential membrane filtration (MF, UF, NF) increased purity to 42%, while final adsorption on macroporous AB-8 resin further enhanced it to 70%. This multi-step process demonstrates an efficient, scalable approach for producing high-quality saponins from agro-industrial byproducts. Saponins are bioactive compounds with well-documented insecticidal, antifungal, and antimicrobial properties. Their recovery from quinoa residues provides a renewable, sustainable source of agrochemicals, offering an eco-friendly alternative to synthetic pesticides. By valorizing this processing waste, the approach contributes to circular bioeconomy principles while promoting environmentally safe crop protection. Future work will focus on formulating saponin-based bio-inputs, including their application as natural surfactants, and conducting field trials to evaluate their effectiveness in pest management. This research highlights the potential of quinoa byproducts as a novel resource for sustainable agriculture.

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### *2.27. UAV Biostimulant Spraying in Tall Sugarcane: Field Efficacy and Rotor–Canopy Airflow Modeling*

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Biostimulants can improve crop vigor, yet delivering them efficiently in tall, dense canopies remains challenging. We conducted a randomized field experiment in sugarcane (Saharanpur, India; 2023) to compare UAV spraying with manual knapsack application for a seaweed-based foliar biostimulant at matched active ingredient rates. A micro-UAV generated NDVI maps to schedule two spray windows (Grand Growth and Elongation). Three treatments were tested: T1 manual (150 L $ha^{-1}$, flat-fan), T2 UAV–coarse (30–40 L $ha^{-1}$, pressure nozzles, VMD $\approx$ 250–300 μm), and T3 UAV–fine/ULV (20–30 L $ha^{-1}$, rotary atomizers, VMD $\approx$ 120–150 μm). Deposition and penetration were quantified with water-sensitive cards and a fluorescent tracer at upper/mid/lower strata; canopy response was tracked by SPAD and NDVI at 0, 7, 14, and 28 DAT; and yield and operational metrics were recorded. To interpret deposition patterns, we added a lightweight rotor–canopy airflow model: a momentum-disk downwash coupled to a porous-media canopy (sugarcane leaf-area density 2–4 $m^2$ $m^{-3}$) and a Lagrangian droplet settling–advection calculation for 120–300 μm droplets at 2.5–3.0 m AGL and 3–4 m $s^{-1}$. The model predicted higher residence time and interception for 120–150 μm droplets in the upper/mid canopy and guided flight-line overlap/height settings. Field results were consistent: UAV–ULV achieved more uniform mid/upper coverage at a $\geq$70% lower carrier volume versus manual, with comparable or improved NDVI/SPAD gains at 7–14 DAT, minimal off-target drift under 1–4 m $s^{-1}$ winds, and maintained or higher yield and net return. NDVI-guided, airflow-informed UAV biostimulant delivery appears technically feasible and operationally efficient for tall sugarcane canopies.

## 3. Session 2: Breeding and Selection Technologies

### *3.1. In Vitro Assessment of Tomato Rootstock–Scion Compatibility*

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The selection of vigorous, disease-resistant tomato rootstocks with high compatibility with cultivated scions is an important objective in tomato breeding.

This study aimed to assess the compatibility between experimental rootstocks and cultivated tomato varieties using in vitro micrografting techniques. The rootstocks included two interspecific hybrids, BK-88 (T-5 × *Solanum habrochaites*) and BK-96 (K-7311 × *S. habrochaites*). The scions were the Ukrainian tomato varieties Smakolyk, Rozheve sertse, Yantarny bogatyr, and Udavchyk. Sterilized seeds were germinated on hormone-free Murashige and Skoog (MS) medium, and 14-day-old seedlings were used for grafting according to a developed in vitro micrografting protocol. Grafted plants were cultivated for three weeks in 250 mL jars on fresh agar-solidified MS medium. Controls included ungrafted plants (control 1) and self-grafted plants (control 2) for each scion variety. The percentage of viable grafts, shoot height, leaf number, and root length were evaluated. Graft union formation occurred on average within 10–14 days. The mean survival rate of grafted plants ranged from 94% to 97%, comparable to the self-grafted control. The lowest survival (94%) was observed for the combination Yantarny bogatyr/BK-88. In all

treatments, grafted plants showed slightly lower biometric values than ungrafted controls, but differences were not statistically significant. The combination Rozheve sertse/BK-96 exhibited the highest relative performance (94% of control shoot height, 99% leaf number, and 95% root length). Between the two tested rootstocks, BK-96 showed slightly higher grafting efficiency, although differences between variants were not statistically significant.

These results indicate a high level of physiological compatibility between the tested interspecific hybrids and cultivated tomato varieties, supporting their potential use as rootstocks in breeding programs.

### *3.2. Agro-Morphological Evaluation of Gamma-Induced Bambara Groundnut [Vigna subterranea (L.) Verdc.] Mutants in North-Central Namibia*

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Abstract: Bambara groundnut [*Vigna subterranea* (L.) *Verdc.*] is an important legume for subsistence farming in Africa, valued for its ability to withstand adverse environmental factors. The experiment was conducted at the University of Namibia-Ogongo campus experimental field during the 2024/2025 cropping season. The study assessed the phenotypic variability of Bambara groundnuts induced by gamma(γ) irradiation. The four Bambara groundnut genotypes, namely Namblack, Nambrown, Namcream, and Namred seeds, were exposed to gamma irradiation doses at 100 Gy, 200 Gy, 300 Gy, 400 Gy, and 500 Gy, and 0 Gy as a control. The growth and yield phenotypic traits were evaluated in this study. The result from the analysis of variance on growth traits such as first emergence, 50% emergence, and plant leaves were significant at $p < 0.05$, and yield traits such as days to maturity, number of pods, and pod length were significant at $p < 0.05$ and yield per plot, pods weight, pod width, and biomass were significant at $p < 0.05$. The association between growth and yield-related traits was analyzed using Pearson's correlation, which revealed a strong association. The phenotypic variability observed in this study will be used as a basis for mutation breeding in Bambara groundnut. The study also encourages future research in other Bambara groundnut genotypes using gamma irradiation.

### *3.3. Analysis of Rosetta Disease Resistance in Advanced Groundnut Lines in Northern Mozambique*

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Groundnut Rosette Disease (GRD) is one of the most severe biotic constraints limiting groundnut (*Arachis hypogaea* L.) production in sub-Saharan Africa, often causing devastating yield losses in smallholder farming systems. This study evaluated the resistance to GRD and grain yield performance of 20 advanced groundnut lines across 11 diverse environments in northern Mozambique over four growing seasons (2014–2018). Trials were conducted using an alpha-lattice design with two replications per location, each comprising four incomplete blocks. Traits assessed included phenological development (days to emergence, flowering, and harvest), plant establishment (number of emerged and harvested plants),

yield components (pods per square meter, maturity percentage, 100-seed weight, grain percentage, pod yield, grain yield), and GRD incidence. Data were subjected to combined analysis of variance, genotype-by-environment (G × E) interaction assessment, stability analysis, AMMI and SREG biplot models, and principal component analysis. Significant G × E effects were observed, indicating that environmental factors played a dominant role in trait expression. GRD incidence was most pronounced in the NPL_15 environment, where the susceptible check JL-24 showed 70% infection. In contrast, advanced lines 7508, 7533, and 7566 consistently exhibited high resistance, with only 2% incidence. Yield performance was not consistently correlated with GRD incidence, but high grain yields were associated with superior plant stand at harvest, pod density, and grain recovery percentage. Line 7510 demonstrated broad adaptation across test sites, whereas lines 96,714 and 7539 displayed specific adaptation to Namapa and Mapupulo environments, respectively. These findings highlight promising resistant genotypes for deployment in breeding programs targeting GRD-endemic regions of Mozambique.

### *3.4. Characterization of EST-SSR Markers Associated with Oil Biosynthesis in Castor (Ricinus communis L.)*

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Molecular markers linked to specific traits are essential for accelerating marker-assisted selection in crop improvement. Castor (*Ricinus communis* L.), a non-edible oilseed crop, is highly valued for its high oil content (40–55%) and exceptionally high ricinoleic acid content (>85%), making it a key resource for industrial applications. In this study, we developed and characterized functionally relevant EST-derived SSR markers associated with oil biosynthesis. A total of 62,105 expressed sequence tags (ESTs) were retrieved from the NCBI dbEST database and assembled into 13,811 unigenes using TGICL. Mining these sequences revealed 2425 SSRs across 1955 unigenes, averaging one SSR every 4.7 kb. Tri-nucleotide repeats were the most abundant (54.4%), followed by di-nucleotide repeats (42.0%). Functional annotation using Blast2GO identified several SSR-containing sequences involved in fatty acid metabolism pathways. From 1555 designed primer pairs, 30 were selected for validation across 24 genetically diverse castor genotypes. Of these, 15 primers produced clear amplification, and 10 were polymorphic, with polymorphism information content (PIC) values ranging from 0.239 to 0.454 and an average of 2.5 alleles per locus. UPGMA clustering grouped the genotypes into three major clusters, revealing substantial genetic diversity. Notably, the polymorphic markers were associated with key genes involved in fatty acid biosynthesis, including oleosin 1, diacylglycerol acyltransferase, hydroxyacyl-ACP dehydrase, and 3-ketoacyl-CoA synthase. These newly developed EST-SSR markers represent the first functional SSR resource specifically targeting fatty acid metabolism in castor. They offer valuable tools for genetic diversity analysis and marker-assisted breeding, supporting efforts to enhance oil quality traits in this economically important crop.

### *3.5. Development of Herbicide Tolerant Varieties Through Mutagenesis in Chenopodium quinoa Willd*

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The quinoa crop (*Chenopodium quinoa Willd*) has gained global relevance due to its nutritional profile and adaptability to diverse agroecological zones. However, yield potential remains constrained by weed pressure and the lack of selective herbicides registered for quinoa. This research aimed to develop herbicide-tolerant varieties through chemical mutagenesis using ethyl methanesulfonate (EMS). In the first phase, three varieties (Nieves, Chucao, and Pincoya) were exposed to EMS at varying concentrations to identify the optimal mutagenic dose. A 2.5% EMS concentration was selected based on median lethal dose analysis, with Pincoya showing suitable sensitivity. Subsequently, seven post-emergent herbicides were applied to assess phytotoxicity and identify tolerant mutants. Survival rates ranged from 0.25% to 17.8%, with partial tolerance observed for sulfonylureas and photosystem II inhibitors.

In the second phase, 7 M1 lines derived from EMS-treated Pincoya plants were evaluated for the phenotypic behavior of herbicide tolerance. The herbicides applied according to their active ingredient were bentazon (Basagran®, BASF, Ludwigshafen, Germany), phenmedipham, desmedipham, ethofumesate (Betanal expert®, Bayer CropScience, Rhein, Germany), fomesafen (Flex®, Syngenta, Basel, Switzerland), triflusulfuron-methyl (Safari®, FMC, Philadelphia, PA, USA), and lenacil (Venzar®, FMC, Flintshire, UK), representing diverse modes of action. Survival and visual toxicity were assessed 7, 14, 21, 30, and 90 days post-application, revealing differential responses among lines and suggesting heritable mutations conferring partial tolerance.

These approaches demonstrate the potential of EMS mutagenesis to generate heritable herbicide tolerance in quinoa, offering a viable pathway for integrating chemical weed control into sustainable production systems. Molecular validation and field trials are currently underway to confirm genetic stability and agronomic performance.

### *3.6. DNA-Marker-Based Identification of Resistance to Root-Knot Nematodes (Meloidogyne spp.) in Tomato (Solanum lycopersicum L.) Germplasm*

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Root-knot nematodes (*Meloidogyne* spp.) represent a major constraint for tomato production worldwide, causing significant yield losses. The most efficient and sustainable approach to nematode management is the deployment of resistant cultivars. The Mi-1 gene, particularly Mi-1.2, confers resistance to several Meloidogyne species and has become a key target for marker-assisted selection.

A total of 174 tomato accessions (169 mutant lines and 5 wild relatives) from the germplasm collection of the Federal Research Centre for Biological Plant Protection (Russia) were analyzed. Genomic DNA was extracted using optimized CTAB and SDS protocols. PCR was conducted with the Mi23 SCAR marker linked to Mi-1.2. Standard controls included resistant tomato DNA, the susceptible accession L25, and nuclease-free water. In heterogeneous cases, seedlings were regenerated in vitro on MS medium and tested individually.

The Mi-1 marker was detected in 12 accessions (6.9%). Resistant genotypes included mutant lines (MO122, MO137, MO324, MO417, MO580, MO628, MO753, GK1971, MO147)

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and wild relatives (*L. glandulosum* CGN-15803, *L. chilense* CGN-15877, *L. peruvianum* CGN-17047). The majority (162 accessions) lacked Mi-1. Some bulk seed samples produced both resistant (380 bp) and susceptible (~430 bp) fragments, indicating heterogeneity, which was confirmed in in vitro clones.

Mi-1-mediated resistance was rare (7%) in the analyzed collection, but its presence in wild relatives highlights their role as valuable donors for breeding. The identification of heterogeneous accessions stresses the importance of complementing bulk screening with individual plant testing. The resistant accessions identified here can be employed in marker-assisted breeding to develop nematode-resistant tomato cultivars, contributing to sustainable crop production.

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### *3.7. Evaluation of Genetic Variability in Crataegus ×Macrocarpa Using ISSR Markers for the Selection of High-Value Forms for Breeding Purposes*

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Hawthorns (*Crataegus* L., Rosaceae) possess numerous health-promoting and medicinal properties affecting the circulatory system, and they are widely used in the prevention of coronary heart disease, cardiac disorders, and in the stabilization of blood pressure. High morphological variability and the presence of many spontaneous hybrids make it necessary to evaluate such diverse plant material from a genetic perspective. The study aimed to preliminarily assess the differentiation of native hawthorns in Poland using ISSR markers on samples obtained from the collection of the Garden of Medicinal Plants in Plewiska near Poznań (Western Poland, INF& MP-NRI). In this work, we present our findings on the natural hybrid *Crataegus ×macrocarpa Hegetschw.*, which is considered suitable for cultivation due to its large fruits. Molecular analysis enabled the generation of both monomorphic and polymorphic bands using 11 primers. Genotypes exhibiting high variability were identified, with a polymorphism index ranging from 50 to 75%. These results provide a basis for the identification of species-specific genetic markers and will facilitate the selection of forms with favourable yield-related traits for further breeding and cultivation of hawthorns.

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### *3.8. Exploiting Epigenetic Memory for Transgenerational Stress Adaptation in Wheat Breeding*

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Epigenetic mechanisms offer a largely untapped resource for breeding crops with enhanced resilience to environmental stresses. In this study, we investigated the role of transgenerational epigenetic memory in wheat exposed to recurrent drought and heat episodes. A factorial field and controlled-environment experiment was conducted using elite wheat lines subjected to repeated cycles of stress across three generations. DNA methylation profiling was performed using whole-genome bisulfite sequencing (WGBS), and

histone modification landscapes were analyzed with ChIP-seq to identify stable epigenetic markers associated with stress memory. Parallel physiological assessments, including stomatal conductance, canopy temperature depression, and grain yield stability, were integrated with molecular data to establish genotype–epigenotype–phenotype linkages. The results revealed that progeny derived from stressed parental lines consistently exhibited a 15–22% higher grain yield under recurrent drought compared to the controls, despite there being no changes in underlying nucleotide sequences. WGBS identified stable methylation patterns at loci linked to ABA signaling and root development, while ChIP-seq confirmed heritable enrichment of H3K4me3 markers at stress-responsive genes. Notably, plants inheriting both methylation and histone signatures showed superior water-use efficiency and sustained photosynthetic rates. Machine learning models integrating epigenetic and phenotypic datasets improved prediction accuracy of drought tolerance by 27% over genomic-only models, demonstrating the value of epigenetic markers in selection pipelines. This work provides strong evidence that epigenetic memory can be harnessed as a novel breeding resource for wheat improvement. Future efforts should integrate stable epigenetic signatures into genomic selection frameworks to accelerate the development of climate-resilient cultivars.

### *3.9. Identification and Validation of SNP Markers with Relevance to Downy Mildew Resistance in Pearl Millet [Pennisetum glaucum (L.) R. Br.]*

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Pearl millet (*Pennisetum glaucum* (L.) *R. Br.*) is a nutritionally rich and climate-resilient staple crop cultivated widely across the semi-arid tropics of India. Despite its adaptability, productivity is significantly hampered by downy mildew, a destructive disease caused by the obligate biotrophic pathogen *Sclerospora graminicola*, leading to yield losses of 20–40%. To elucidate molecular mechanisms underlying resistance, transcriptome sequencing was performed on resistant (P310-17) and susceptible (7042-S) genotypes under both inoculated and control conditions. Assembly using Trinity yielded 26,690 high-quality transcripts. SNP and indel discovery revealed 6110 SNPs and 149 indels in the resistant genotype, and 6718 SNPs and 1626 indels in the susceptible genotype. Transition-to-transversion ratios were 1.83 and 1.88, respectively, with frequent substitutions including G/A and C/T transitions and C/G transversions. Functional annotation of SNP-containing transcripts showed strong homology with *Zea mays* and *Setaria italica*, highlighting conserved genomic regions. Gene Ontology analysis indicated enrichment in nucleotide binding, transport, and plastid-related functions. KEGG pathway classification revealed predominant roles in transferase (43%), hydrolase (28%), and oxidoreductase (15%) activities. From these, 20 SNP markers associated with putative disease resistance genes—such as transcription factors and pathogenesis-related proteins—were shortlisted. Validation across twelve diverse genotypes identified seven markers producing clear amplicons. Notably, three markers—ASP2 (beta-glucosidase 31-like), SNP14 (polyamine oxidase-like isoform x2), and SNP16 (SOBIR1-like receptor kinase)—were confirmed via sequencing to contain expected SNPs. These validated EST-derived SNP markers represent a valuable genomic resource for pearl millet, offering promising tools for marker-assisted selection (MAS) and the development of transcript-based genetic maps aimed at improving resistance to downy

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mildew. The findings contribute significantly to breeding strategies focused on enhancing disease resilience in this vital crop.

### *3.10. New Insights on the Production of Grafted Walnut Plants*

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The commercial production of walnut plants still relies on field or greenhouse grafting using seedling plants as rootstocks. This is a time-consuming process, requiring at least two years to produce a grafted plant, and often results in orchard heterogeneity, thereby complicating mechanization procedures. In recent years, in vitro micropropagation has enabled the clonal propagation of walnut cultivars and rootstocks; however, grafting practices remain largely dependent on traditional nursery methods. In vitro micrografting, based on the use of in vitro produced rootstocks and scions, may significantly reduce the time required to produce a grafted walnut plant. In this study, in vitro regenerated shoots of 'Paradox' (*Juglans hindsii* × *Juglans regia*) cl. 'Vlach' were used as rootstocks for micrografting, while *J. regia* cvs. 'Chandler' and 'Howard' were used as scions. Two cleft grafting types, top and side, were tested across three developmental stages of the rootstock (pre-rooting, post-rooting, and post-acclimatization). The results showed that for both cleft grafting methods and for the two cultivars, no statistically significant differences were found. In contrast, statistically significant differences emerged among the different phases in which micrografting was performed. The highest grafting success was achieved with cv. 'Howard' using the side cleft method during the pre-rooting phase of rootstock development. Although further optimization is required, the results highlight the potential of in vitro micrografting as an alternative to conventional grafting methods.

### *3.11. Optimized Method for Screening Wild Aegilops tauschii and Triticum dicoccoides for Resistance to Dry Root Rots Caused by Fusarium culmorum*

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Dry root rots caused by *Fusarium culmorum* are an increasing constraint to wheat production in Moroccan semi-arid regions. Wild relatives such as *Aegilops tauschii* and *Triticum dicoccoides* represent valuable sources of resistance. Developing a reliable screening method is crucial for identifying promising breeding lines. Six accessions from each wild species were evaluated under controlled conditions using a split-plot design with three replications, where soil type (sterilized vs. natural) was assigned to main plots and inoculum type (organic vs. spore suspension) to subplots. For each accession in each treatment, one pot containing five plants was established per block. Plants were

inoculated at the two-leaf stage after vernalization, and disease severity was assessed at flowering. Root and internode infection, spike number, dry biomass, and plant height were measured to integrate both pathological and agronomic responses. Results showed that methodological choices strongly influenced the ability to discriminate between resistant and susceptible lines. Internode assessment was the most sensitive criterion, revealing clear genetic variability both within and between species. Suspension inoculum consistently generated higher and more uniform disease pressure than organic inoculum. At the same time, soil type influenced resistance expression differently across species: in *A. tauschii*, non-sterilized soil amplified root severity, whereas in *T. dicoccoides* responses were stable across soil types. Agronomic traits further supported the approach. In *A. tauschii*, spike number depended on genotype × inoculum and genotype × soil interactions, while in *T. dicoccoides* it was largely genotype-dependent. Biomass also varied with genotype × inoculum interactions. Plant height exhibited the most complex pattern: in *A. tauschii*, it was primarily driven by genotype × inoculum interactions, whereas in *T. dicoccoides*, it was influenced by the combined effects of genotype, soil type, and inoculum. Overall, combining suspension inoculum, non-sterilized soil, and internode evaluation provides a robust screening method for identifying resistant germplasm in wheat improvement programs.

### *3.12. Optimized Micropropagation for the Production of Disease-Free Planting Materials of Zingiber officinale Roscoe 'Bentong'*

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Ginger (*Zingiber officinale Roscoe*) is a high-value spice and medicinal crop, yet its global production is constrained by infrequent sexual reproduction and pathogen accumulation in vegetatively propagated rhizomes. Micropropagation offers a means of producing disease-free planting materials; however, genotype-dependent protocols with well-defined hormonal requirements remain limited. This study aimed to establish an efficient in vitro protocol for the sustainable production of disease-free planting materials of 'Bentong' ginger. The synergistic effects of 6-benzylaminopurine (BAP) and 1-naphthaleneacetic acid (NAA) were evaluated for shoot multiplication, while Murashige and Skoog (MS) medium at quarter, half, and full-strength supplemented with 3 μM NAA and varying sucrose concentrations was assessed for rooting and acclimatization. MS medium containing 3% sucrose, 12 μM BAP, and 1.5 μM NAA significantly enhanced shoot proliferation (>6 shoots per explant). However, in subsequent subcultures, continued BAP supplementation suppressed shoot growth and induced callus formation in some cultures, likely due to residual BAP accumulation; hormone-free MS medium achieved comparable multiplication rates. Rooting was optimized on quarter-strength MS medium with 2% sucrose and 3 μM NAA, resulting in vigorous root development and successful acclimatization. The optimized protocol provides a reliable platform for large-scale production of disease-free planting materials of 'Bentong' ginger. By reducing dependence on rhizome-based propagation, this

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approach offers a sustainable strategy to strengthen 'Bentog' ginger production systems and enhance food security.

### *3.13. Papaya Germplasm Evaluation for Resistance to Papaya Ringspot Virus Using Artificial Inoculation*

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Papaya ringspot disease, caused by *papaya ringspot virus P* (PRSV-P), is restricting the commercial cultivation of papaya worldwide. Several measures have been taken to control the disease, including the application of aphicides, identification of host plant resistance, and the use of transgenics. However, only genetically engineered papayas carrying the viral coat protein have been found to effectively control the disease. Transgenic papayas are not cultivated worldwide due to ethical regulations. Assessing the diverse papaya germplasm for resistance to PRSV-P could be a suitable alternative. Therefore, the present study was undertaken to assess PRSV resistance in 79 accessions, including commercial hybrids/varieties and wild accessions. To identify novel resistant sources, the accessions were mechanically inoculated with PRSV under controlled conditions. The inoculated plants were continuously monitored for the appearance of PRSV-like symptoms and scored for disease severity on a scale of 0 to 5. Additionally, PRSV-P infection was confirmed by performing RT-PCR with coat protein-specific primers. The presence of the ~900 bp amplicon confirmed PRSV-P infection in the inoculated plants. Among all the accessions tested, only two accessions, HCAR 46 (*Vasconcellea pubescens*) and HCAR 177 (*V. stipulate*), did not show any symptoms. All Carica papaya accessions were susceptible to PRSV-P, whereas only *Vasconcellea* sp. showed resistance. The PRSV-resistant genotype identified in the present study could be used in breeding programs to breed PRSV-resistant cultivars.

### *3.14. Phenotypic Diversity of Barley (Hordeum vulgare L.) Accessions in Ethiopia on the Basis of Qualitative Traits*

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This research was carried out to determine the morphological diversity of barley accessions in Ethiopia via an alpha lattice design with two replications. All the qualitative data were subjected to statistical analysis via Minitab 17th Edition and SPSS software. Principal component (PC) analysis, cluster analysis, the Shannon–Weaver diversity index (H'), and distribution frequency were used for the qualitative traits. The frequency distribution of the phenotypic traits revealed a considerable degree of genetic variability among the accessions. The estimate of H' ranged from 0.83 (glume hairiness) to 0.99 (lemma awn). The highest value of H' in the zones of origin was (H' = 1.00) for the kernel row number in Shewa, growth habit and spike attitude in Gojam, glume hairiness in Harerge, and

lemma awn in Semen omo. For the altitude classes, the trait lemma awn had the highest value of H′ (H′ = 1.00) in accessions collected at an altitude of ≥2600 m.a.s.l. Among the total variation among the populations, 71% was found within the zones of origin, and 75% was found within the altitude classes. The ANOVA for H′ values on the basis of the altitude class and zones of origin showed very highly significant ($p \leq 0.001$) variation to significant ($p \leq 0.05$) variation. On the basis of eigenvalues greater than 1, the first 3 PCs had cumulative contribution rates of 70.6%, 77.4%, and 95.7% of the total variation among accessions, zones of origin, and altitude classes, respectively. Cluster analysis revealed four distinct groups among the zones of origin and altitudinal classes. In general, traits such as kernel color, lemma color, and growth habit in the zone of origin and traits such as lemma color, lemma awn, and lemma color at physiological maturity in altitude classes were the most determinant traits among the barley accessions and could be used as selection criteria for crop improvement.

### *3.15. Population Genetic and Diversity Analysis in Selected Bambara Groundnut [Vigna subterranea (L.) Verdc] Diversity Panel Accessions for Drought-Prone Areas*

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The effective use of conserved insitu and exsitu genetic resources of *Bambara groundnut* (BG)—an orphan crop, in pre-breeding programs is hampered by a lack of well-characterized germplasm and associated traits in the collections. Genotype-by-sequencing (GBS) is a next-generation sequencing technology that enables high-throughput SNP (single-nucleotide polymorphism) marker discovery, facilitating genomic studies and faster development of improved cultivars through genomic-assisted breeding tools. In this study, 361 accessions of Bambara groundnut from the Genetic Resources Center, International Institute of Tropical Agriculture (GRC-IITA), and individual breeding programs in Southern Africa were genotyped using single plants. We sought to determine the genetic diversity and population structure, to facilitate various downstream genomic applications of GBS-derived SNP data and to guide the formulation of a focused, trait-specific core set for Bambara groundnut. A total of 7592 SNPs were generated from the GBS pipeline. After SNP quality control filtering for missing data ≤ 15% and MAF ≤ 0.01, a total of 3848 high-quality SNPs were retained and used in the clustering analysis and investigation of population structure in the BG population. An NJ tree showed that 361 accessions were grouped into three major clusters, with two West African collections that were distinctly separated from the East and Southern African collections. The Q-matrix plot also confirmed the grouping of subpopulations into three groups; however, STRUCTURE revealed only two main groups: Southern and East Africa, and West Africa. The heatmap revealed that accessions from countries near each other were highly genetically similar, suggesting high gene flow due to seed exchanges. Due to the highly structured population by country of origin, we recommend considering proximity to capture the highest diversity.

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### *3.16. Unravelling the Proteomic Landscape of Olive Somatic Embryogenesis Through LC-MS/MS*

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Somatic embryogenesis (SE) is the process by which embryo-like structures are formed from somatic cells. Although SE has been successfully applied to several herbaceous annual species, most woody species, including olive (*Olea europaea* L.), remain recalcitrant, exhibiting low capacity for somatic embryo development, particularly when adult tissues are used as initial explants. To overcome these limitations, a deeper understanding of the molecular mechanisms underlying SE is essential. In olive, however, these mechanisms remain largely unexplored, and the pathways controlling induction of SE and further embryonic differentiation and development are still poorly understood. To contribute to this knowledge, high- and low-embryogenic efficiency lines were established using SE cultures of the olive cultivar 'Arbequina', with zygotic embryos used as initial explants. Somatic embryogenic lines were maintained in Embryogenesis Cyclic Olive (ECO). At the end of the third subculture, plant material was collected, and whole proteome analysis was performed using liquid chromatography–tandem mass spectrometry (LC-MS/MS), applying both Suspension-Trapping (S-Trap)- and Orbitrap Mass Spectrometer (OT-2)-based workflows. A total of 13,583 proteins and 9119 protein groups were identified using the S-Trap method, while 13,686 proteins and 9211 protein groups were identified using the OT-2 method. From these, several well-known SE biomarkers were identified. Isoforms from Class III peroxidases were identified as characteristic of high-embryogenic efficiency lines. These findings provide novel molecular insights into the regulation of SE in olive and may support the development of improved propagation protocols for recalcitrant genotypes.

## 4. Session 3: "New" Crops for Adaptation to Climate Change

### *4.1. Pleurotus ostreatus (Orellana) as a Sustainable Alternative Crop: Insights from Cultivation and Postharvest Management*

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Climate change, with its growing impact on agriculture, demands resilient, sustainable, and resource-efficient food production systems. Edible fungi, traditionally valued for their nutritional and culinary qualities, are increasingly recognised for their potential in sustainable crop diversification. While *Agaricus bisporus* (button mushroom) dominates global production, species with higher adaptability and lower environmental footprints are gaining attention. Among these, *Pleurotus ostreatus* (commonly known in Latin America as "orellana") stands out as a promising alternative due to its ability to grow on various agro-industrial residues, rapid production cycles, and suitability for small- and medium-scale farming. This study developed and assessed cultivation protocols for substrate preparation,

harvesting, postharvest handling, and transportation to enhance product quality and shelf life. The proposed procedures incorporated agricultural by-products such as coffee husks, sawdust, and sugarcane bagasse, alongside detailed recommendations for sterilisation, inoculation, and incubation. Harvesting and postharvest strategies emphasised optimal timing, humidity control, and packaging methods to minimise mechanical damage, microbial contamination, and senescence. Implementing these guidelines resulted in higher yields, improved texture, and extended fruiting-body freshness, thereby increasing their commercial value. Systematising these practices reinforces *P. ostreatus* as a sustainable alternative crop under climate change scenarios, contributing to rural income diversification and food security. Future research should focus on scaling up under varied agroecological conditions, assessing energy efficiency in controlled environments, and exploring biodegradable packaging solutions to further strengthen sustainability across the value chain.

### *4.2. Vachellia tortilis subsp. raddiana: Pillar of Deserts and Model of Resilience to Climate Change*

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In the context of climate change and increasing aridification, *Vachellia tortilis subsp*. raddiana stands out for its remarkable ability to adapt to Morocco's arid environments. It mobilizes physiological and biochemical mechanisms that strengthen its resilience to water stress. This study examines its responses to drought and highlights the potential of exploiting its bioactive compounds. Under severe water deficit, relative water content decreases from 62 ± 3% to 38 ± 2%, while proline increases from 0.8 ± 0.1 to 2.8 ± 0.3 µmol/g DM and soluble sugars rise from 12.3 ± 1.5 to 32.8 ± 2.1 mg/g DM, ensuring effective osmotic adjustment and the maintenance of cellular homeostasis. At the same time, chlorophyll a and b contents decrease by 46% and 30%, respectively, indicating an adaptive regulation of the photosynthetic apparatus. Beyond these physiological strategies, the leaves of *Vachellia tortilis subsp*. raddiana respond to environmental stresses through the remarkable accumulation of secondary metabolites, contributing both to defense and functional potential. They exhibit high concentrations of polyphenols (281 ± 1.2 mg GAE/g DM) and flavonoids (57.5 ± 0.9 mg QE/g DM), conferring notable antibacterial activity of leaf extracts against *Escherichia coli* (9 ± 1.1 to 12 ± 1.4 mm) and *Staphylococcus aureus* (12 ± 1.4 to 17 ± 1.3 mm). These findings highlight the dual value of the species: a model of physiological resilience and a promising resource for the sustainable development of crops adapted to arid regions under climate change.

### *4.3. Experimental Insights into Chickpea Responses to Climate Stress*

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Introduction: Chickpea (*Cicer arietinum* L.) is a critical source of dietary protein in semi-arid regions, which are increasingly vulnerable to climate change. Rising temperatures and erratic rainfall patterns, particularly during the sensitive reproductive stage, pose a severe threat to global chickpea yield. While drought tolerance is a known trait in chickpeas, the synergistic impact of combined drought and heat stress remains poorly characterized, limiting the development of resilient cultivars. This study aimed to physiologically and biochemically dissect the responses of diverse chickpea genotypes to individual and combined stress scenarios.

Methods: A controlled-environment experiment was conducted using ten chickpea genotypes with varying genetic backgrounds. Plants were subjected to four treatments at the flowering stage: well-watered control, drought stress, heat stress, and combined

drought-heat stress. Physiological parameters (photosynthetic rate, stomatal conductance, canopy temperature) and biochemical markers (proline content, antioxidant enzyme activity) were measured. Yield components, including pod set percentage and seed weight, were quantified at maturity.

Results: The results demonstrated that combined stress inflicted significantly greater damage than individual stresses. While all stresses reduced photosynthetic efficiency by over 50%, the combined stress led to a near-complete shutdown (85% reduction). Genotype ICC 4958 maintained superior relative water content and photosystem integrity under drought, but its advantage diminished under heat and combined stress. In contrast, genotype ICC 15614 exhibited a robust antioxidant response, with a 3-fold increase in catalase activity under combined stress, correlating with a 30% higher pod retention compared to the most sensitive genotype.

Conclusions: This study demonstrates that combined heat-drought stress is the critical limiter of chickpea productivity, requiring distinct tolerance mechanisms beyond drought resilience alone. Genotypes with robust antioxidant responses offer a key target for breeding programs aimed at safeguarding yields under future climates.

### *4.4. Economic Viability of Different Coloured Shade Nets on Water Use Efficiency and Nutrients in Keitt Mango*

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This study examined the economic viability of various colored shade nets on mango production (*Mangifera indica* L. cv. Keitt) in terms of climatic conditions, growth and productivity, nutrient status, and water use efficiency. The study investigated the effects of different screen net colors on plant growth over two seasons (2023 and 2024), focusing on minimum and maximum air temperatures and relative humidity under various screen net colors compared to open-field conditions. All shade nets resulted in elevated relative humidity and lower maximum temperatures. The black screen net and open-field treatments produced the lowest mango yields. In contrast, the use of white or yellow screen nets significantly increased both the number of fruits per plant and overall yield per plant compared to other treatments. The results indicate that white and yellow nets provided the most favorable environment for mango cultivation in Egypt, with yields of 3663 kg/2000 $m^2$ and 2997 kg/2000 $m^2$, respectively, in the first season. The black greenhouse net cover produced the lowest yield, at 1998 kg/2000 $m^2$, in the first season. Over the two seasons, the open-field treatment had the lowest macro- and micronutrient content. Furthermore, various screen net covers demonstrated higher water use efficiency throughout both seasons, with white screen nets outperforming yellow screen nets.

### *4.5. Establishment of Vitis vinifera Varieties for Table Grape Production as an Alternative to Climate Change in Veracruz, Mexico*

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The Mexican countryside is not exempt from the effects of global climate change. Abrupt changes in environmental temperature, rainfall patterns and the duration of

droughts are part of the process that has led to soil erosion and an increase in the presence and incidence of pests. These conditions suggest changes in growing patterns. Grape in Mexico has been identified in primarily arid areas where even soil conditions appear to be a disadvantage. The present study is conducted in Mata de Sarza, Veracruz, Mexico; the objective is to identify table grape (*Vitis vinífera*) as a cultivation alternative for this region from three varieties, Perlette, Flame Seedless and Summer Royal, under agro-productive conditions in the local climate through reproduction by cuttings. The agronomic evaluation includes the length of cuttings, the number of growth nodes for subsequent antifungal treatment and rooting in root production chambers, once the cuttings have been removed from the root chamber and before the final planting of the cut, the percentage of cuttings with primary radiculae and root bulbs, the physico-chemical characteristics of the soil, the monthly development of the stems, and the photosynthetic capacity of the leaf area as main indicators in the preliminary stage. There were cuttings with values within $68 \pm 5.3$ cm, with roots ranging from 2.2 cm to 17.3 cm; the number of root bulbs per cut was on average up to 8, while the number of growth nodes ranged between 4 and 7. The soils had an average clay content of 65% and sand of 23%, and the average monthly stem growth was 17.3 cm. Cultivation, in this preliminary stage of development, has adapted to the physical–climatic conditions, different from the main wine-growing areas of the country, while establishing the bases for a production model.

### *4.6. Potato, Potato: Field Insights to Selecting and Breeding for Hail Resilience in Potato Cultivars*

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Climate change has led to a significant increase in the frequency and intensity of hailstorms, posing a major threat to produce supply and tuber quality in the potato industry. This study investigated yield and tuber quality hail recovery responses of four potato cultivars to different hail intensities, aiming to develop a cultivar-driven strategy for hail resilience. Field experiments were conducted during the 2023/2024 and 2024/2025 seasons, using a 5 [0, 25, 50, 75 and 100% canopy disruption levels] $\times$ 4 [early- (Sababa), mid- (Tyson, Mondial), and late-maturing (Panamera) cultivars] factorial arrangement in a randomized complete block design. Data collected included yield, tuber grading, dry matter and starch recovery. Yield and tuber quality recovery were statistically consistent across seasons ($p > 0.05$), indicating that seasonal variation did not influence yield or quality traits. Therefore, values were averaged across the two seasons to provide a single comparative estimate for each cultivar. Panamera exhibited superior yield recovery (63.75%), large tuber recovery (88.61%), dry matter recovery (66.36%) and starch content recovery (56.36%) across planting seasons. The superior recovery was attributed to its high yield potential and environmental adaptability, supported by a higher canopy cover and long growing season enabling extended recovery. Sababa, on the other hand, even though it had lower recovery in other traits, maintained relatively high starch recovery (52.8%), which was statistically similar to Panamera. This suggests that Sababa adopts a more conservative allocation strategy, prioritizing starch biosynthesis under hail stress over other traits. This recovery is likely supported by elevated *ADP-glucose pyrophosphorylase* (AGPase), a key enzyme in starch biosynthesis, which may have enabled Sababa to sustain starch production and retention despite canopy damage. These traits can be exploited for cultivar selection and breeding to reduce climate-related risks in hail-prone potato-producing regions.

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### *4.7. Evaluation of Cold Tolerance in Local Barley (Hordeum vulgare L.) Genotypes and the Role of Salicylic Acid in Their Resilience*

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Barley (*Hordeum vulgare* L.) is a crop of vital importance for human and animal food security in Algeria. However, in the high plateau and mountainous regions, its yields are severely affected by low-temperature stress and winter frosts.

To address this limitation, a controlled laboratory experiment was conducted to evaluate the cold tolerance of three local barley genotypes (Saida, Tihert, and Oued el Maleh) and to assess the potential role of salicylic acid (SA)—a phytohormone known for its involvement in abiotic stress tolerance—in enhancing plant resilience. Barley seeds were germinated under low-temperature conditions (0–4 °C) for 10 days. Morphological and physiological parameters, such as germination rate and root length, were measured and statistically analyzed using Statistica software.

Significant genotypic differences were observed. In the absence of SA, the Tihert genotype achieved a germination rate of 65%, compared with 20% for Saida and 5% for Oued el Maleh. The application of SA (0.5 mM) markedly enhanced post-germination growth and resilience in the sensitive genotypes, increasing germination rates to 55% for Saida and 25% for Oued el Maleh, while its effect remained limited in Tihert, which already exhibited high natural tolerance.

Hierarchical clustering analysis based on Euclidean distances confirmed Tihert as the most cold-tolerant genotype. The observed improvement in the sensitive genotypes (Saida and Oued el Maleh) suggests that SA may activate antioxidant defense systems and membrane-stabilizing mechanisms.

These findings highlight the importance of genetic diversity among local barley varieties and demonstrate the potential of salicylic acid as a physiological inducer of cold tolerance. Genotypes such as Tihert represent valuable genetic resources for breeding programs aimed at developing barley varieties better adapted to Algeria's harsh climatic conditions.

### *4.8. How Climate Change Could Affect Drought Risk in Portugal's Traditional and Super-Intensive Olive Orchards*

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Portugal, a leading producer of olive oil, boasts six Protected Designation of Origin (PDO) regions, each characterised by distinct olive orchard (OR) densities, ranging from traditional to super-intensive. Although the analysis of drought and aridity conditions has been widely addressed, the impacts of these factors have not been analysed in relation to OR densities. To address this gap, a new metric, the Olive Drought and Aridity Risk Index (ODAR), was developed to assess future risk levels for each OR by quantifying the combined effects of climate and soil water availability, weighted by OR density. To achieve this, drought and aridity indicators were analysed for both a historical baseline (ERA5: 1981–2000) and two future periods (2041–2060 and 2081–2100) under two anthropogenic forcing scenarios (RCP4.5 and RCP8.5). A seven-member ensemble of global climate models was employed for the projections to address inter-model variability and reduce

single-model uncertainties. From Spearman's correlation analysis, Annual Mean Aridity (AIA) was identified as the most representative indicator of climatic exposure for OR. Readily Available Soil Water (RAW, in mm) was used to represent the soil's water-holding capacity available to olive trees. ODAR was calculated as the Euclidean distance between each future scenario/period and the historical period, using the weighted AIA and RAW indices according to OR densities. Future projections indicate that central and northern PDOs will be characterised by intermediate conditions (AIA $\approx$ 0.60 and RAW > 90 mm), exhibiting variable risk levels ranging from low to high. In the southern PDO, where AIA is projected to reach 0.69 and RAW is expected to fall below 60 mm, the risk will be very high, potentially jeopardising olive tree growth, fruit development, and olive oil quality. These findings underscore the need for targeted adaptation strategies to strengthen the climate resilience of olive production in Portugal's PDO regions.

### *4.9. Integrating Genomics, Molecular Breeding, and Predictive Bio-Nano Systems to Develop Novel Crops for Marginal Lands*

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Marginal lands affected by salinity, water scarcity, nutrient deficiency, and climate extremes represent critical frontiers for addressing global food security challenges. Conventional staple crops often exhibit limited productivity under these abiotic stress conditions, necessitating exploration of novel and underutilized species with intrinsic resilience. This work synthesizes evidence demonstrating how integrated biotechnological approaches, high-resolution genomics, precision molecular breeding, and predictive bio-nano systems, can systematically enhance stress tolerance traits in climate-adaptive crops. High-throughput genomic mapping has identified key regulatory networks conferring drought tolerance, salinity adaptation, and nutrient-use efficiency. For instance, quinoa's transmembrane protein genes and millet stress-responsive pathways exemplify natural adaptations that can be exploited through genomic-assisted breeding. CRISPR-based genome editing technologies have successfully enhanced abiotic stress tolerance in major cereals by targeting specific genes, such as ZmHDT103 for drought tolerance in maize and TaBAS1 for salt tolerance in wheat. Molecular breeding strategies, including marker-assisted selection and genomic selection, have demonstrated 10–20% improvements in selection efficiency for stress tolerance traits, significantly accelerating genetic gains. Predictive bio-nano systems integrating AI-driven computational models with nanoscale sensors enable real-time monitoring of soil–plant–atmosphere dynamics, facilitating proactive stress management. Empirical evidence confirms that millets, quinoa, halophytes, and orphan legumes exhibit substantial resilience in marginal environments while delivering nutritional, ecological, and economic co-benefits. However, significant challenges persist: regulatory barriers create market access uncertainties for genome-edited varieties, high implementation costs limit adoption by resource-poor farmers, and knowledge gaps remain in translating genomic insights into field-ready cultivars. This integrative framework demonstrates potential to establish resilient agroecosystems on marginal lands, yet successful implementation requires addressing regulatory harmonization, economic accessibility, and bridging the genotype-to-phenotype gap in diverse environmental contexts.

### *4.10. Leveraging Chickpea (Cicer arietinum) as a Resilient Crop for Diversified Agricultural Systems in a Warming Climate*

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Introduction: Climate change poses unprecedented challenges to global food security, with rising temperatures and erratic precipitation threatening major cropping systems. Chickpea (*Cicer arietinum* L.), a protein-rich legume, offers strategic value for climate-resilient agriculture due to its drought tolerance, nitrogen fixation, and adaptability to marginal environments. This study explores the genetic and physiological bases of chickpea's resilience, aiming to identify key mechanisms and genomic markers underpinning its adaptive performance under warming climate scenarios.

Methods: An integrated framework combining multi-location field trials, controlled-environment assays, and genome-wide association studies (GWAS) was applied to 120 chickpea genotypes representing global diversity. Drought tolerance was evaluated using key physiological indicators such as photosynthetic efficiency, osmotic adjustment, and antioxidant responses. GWAS identified quantitative trait loci (QTLs) associated with these adaptive traits. Climate modeling projected genotype performance under 1.5–3 °C warming scenarios, while rotation trials assessed soil fertility and water-use efficiency benefits.

Results: Chickpea exhibited distinct genotype-dependent resilience mechanisms, including up to 60% higher osmolyte accumulation and over twofold enhancement in antioxidant capacity under terminal drought stress. GWAS revealed 22 significant marker–trait associations linked to stress-responsive genes, with key QTLs explaining up to 32.4% of phenotypic variance. Climate projections indicated a 15–25% yield stability advantage over conventional cereals under moderate warming. Diversified rotations improved soil nitrogen by up to 18% and water-use efficiency by 35%.

Conclusions: This study provides a mechanistic and genomic basis for chickpea's climate resilience, linking specific allelic variants to field-level performance. While genotype-by-environment interactions and climate projection uncertainties remain, the findings advance current understanding by offering molecular and agronomic targets for climate-adaptive breeding. Chickpea thus stands as a cornerstone crop for sustainable intensification and agricultural resilience under a changing climate.

### *4.11. Selecting 27 Field-Grown Common Bean (Phaseolus vulgaris L.) Genotypes for Symbiotic Performance and Drought Tolerance at Malkerns Research Station, Eswatini*

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Legume crops, such as common bean (*Phaseolus vulgaris* L.), are significant in many Sub-Saharan African (SSA) countries including Eswatini, due to their numerous health benefits, high protein, fiber, vitamins, and minerals. Common beans are a staple food in many parts of the world and play a crucial role in nitrogen fixation, thereby improving soil fertility. However, climate change poses a significant threat to global food security and agricultural productivity. Eswatini's production declined due to drought, resulting in 700 metric tons in 2016 and 582.5 metric tons in 2023, falling far short of its 7370 metric ton annual consumption, causing a supply deficit. The declines in common bean production compelled the country to rely on imports to meet local demand. The aim of this study was to assess the symbiotic performance and carbon accumulation of 27 common bean genotypes grown under field conditions. The experiment was conducted during the 2023/2024 cropping season. A Randomized Complete Block Design was used to test 27 common bean germplasms (11 red speckled sugar and 16 red mottled). The beans were planted in 13.5 $m^2$ plots (4.5 m $\times$ 3.0 m) with 50 cm inter-row and 10 cm intra-row spacings. Each plot consisted of 4 rows, with 20 plants per row. The data revealed significant differences among

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genotypes, with Cim-Rm-36 exceling in growth with 47.43 g.plant$^{-1}$ shoot dry matter yield and 1927.07 mg.plant$^{-1}$ carbon content, and Mwctz20a-Rm19 showing strong nitrogen fixation with 155.73 kg.ha$^{-1}$ of N-fixed. Genotype Mwctz20a-Rm-4 had the highest grain yield (1747.39 kg.ha$^{-1}$), showing high productivity potential, while Cim-Rm-14-Als61 had the highest nitrogen concentration (3.50%), indicating efficient nitrogen uptake. The δ13C values (−27.38‰ to −28.06‰) suggested similar water use efficiency among genotypes. The finding showed that common bean can make a significant contribution to N fertility, with carbon accumulation highlighting the potential for selecting genotypes with desirable traits to enhance crop productivity.

### *4.12. The Impact of Climate Variability on Corn Yield in the North-East Region of Romania*

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Climate change poses a major challenge to agricultural sustainability, particularly in regions where variations in temperature and precipitation directly affect crop productivity. This study examines the relationship between interannual climate variations and corn production in northeastern Romania, using official data from the National Institute of Statistics and the National Meteorological Administration for the period 2017–2022. Pearson correlation coefficients were applied to assess the direction and strength of associations between yield, temperature, and precipitation in six representative counties. The results indicate predominantly negative correlations between average annual temperature and yield (r = −0.808, $p$ = 0.052 in Neamț; r ≈ −0.406, $p > 0.10$ in Iași), suggesting that high temperatures limit production by increasing evapotranspiration and heat stress during sensitive growth stages. In contrast, precipitation shows positive and often statistically significant correlations (r = 0.957, $p$ = 0.003 in Botoșani; r = 0.890, $p$ = 0.017 in Bacău; r = 0.799, $p$ = 0.057 in Neamț), confirming the decisive role of moisture availability in maintaining yield stability. Spatial differences in correlation strength reflect local interactions between precipitation timing, soil water retention, and crop management practices, including hybrid selection, planting density, and access to irrigation. The analysis found no significant link between cultivated area and yield, indicating that interannual fluctuations are primarily driven by climate, rather than the result of land expansion. Despite the short observation period, the findings underscore the need for regionally tailored climate change adaptation strategies, such as the use of drought- and heat-tolerant hybrids, optimized planting schedules, conservation tillage, and efficient irrigation systems, supported by agrometeorological monitoring and forecasting tools. Integrating these measures into local and national agricultural policies is essential for maintaining corn productivity under conditions of increased hydrothermal stress.

### *4.13. The Response of Amaranthaceae halophytes to Various Hydroponic Solution Salinities*

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Interest in the ecological and nutritional significance of halophytes has led researchers to explore their cultivation under different salinity levels. To assess the potential and adaptive strategies of halophytes in the *Amaranthaceae* family, hydroponic cultivation provides an effective method for growing these plants as alternative crops in a controlled environment. This study aimed to examine the effect of hydroponic solution salinity (0, 150, and 300 mM NaCl) on the growth responses of three *Amaranthaceae* halophytes, including *A. lividus*, A. passion, and A. red Aztec, and their suitability for cultivation in controlled environments. The environmental conditions, Blue/Red/Far-Red LED spectrum

at 22:65:13, an intensity of 250 µmol $m^{-2}s^{-1}$, and a temperature of 18/22 ± 2 °C, were maintained in a walk-in growth chamber throughout the experiment. A strong negative correlation between hydroponic solution salinity and survival rate, height, fresh weight, root length, leaf area, and antioxidant activity in all tested *Amaranthaceae* species was detected, except for a strong positive correlation between salinity and total phenolic compounds in *A. passion*. Based on survival rate, shoot and root biomass, and an antioxidant assay, the hydroponic solution salinity of 150 mM NaCl seems to be the salt tolerance level for the tested *Amaranthaceae* halophytes. However, further investigations of osmotically active metabolites, specific proteins, and scavenging of oxygen radicals under salt stress conditions are needed.

### *4.14. Using Google Earth Engine to Assess the Impacts of Climate Change on Land Use in the Gheris Watershed, Morocco*

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In recent decades, climate change in Morocco has been characterized primarily by water imbalance resulting from rainfall deficits and increasingly severe drought periods, which are not evenly distributed. Among the areas most affected by these changes is the southeastern region, which includes the Gheris watershed, the subject of this study. This watershed extends from northwest to southeast, between 30°40′ N and 32°00′ N and between 4°20′ W and 6°00′ W, covering an area of 17,500 hectares. Its arid-to-semi-desert climate is characterized by highly variable annual rainfall, reflecting the irregularity of precipitation, and summer temperatures exceeding 40 °C. This study aims, on one hand, to characterize and quantify the effects of climate change on land use in the Gheris watershed, and on the other hand, to provide scientifically reliable data and methodology for identifying and monitoring the impacts of climate change in the region. To achieve these aims, geospatial data for the Gheris watershed from 1990 to 2024 were obtained from the Google Earth Engine (GEE) platform. Using machine learning algorithms (Support Vector Machine (SVM) and Random Forest (RF)), land use and land cover (LULC) maps were generated, and the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and surface temperature (Ts) were calculated. Spatial analysis of the temporal images generated (LULC, Ts, NDVI, and NDWI) for the selected years allowed for monitoring the evolution of land use, surface temperature, vegetation, and water surfaces during the period between 1990 and 2024. This analysis shows that the impact of climate change on the Gheris watershed is manifested by significant changes in land use, marked mainly by a strong regression in vegetation and water surfaces and the progression of desertification, which has strongly affected local agriculture.

## 5. Session 4: Crop Water and Nutrient Management

### *5.1. Osmoprotective Mechanisms of Exogenous Proline in Salt-Stressed Physalis ixocarpa: Integrated Morphophysiological, Spectroscopic and Metabolomic Analysis*

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Soil salinization threatens agricultural sustainability in semi-arid regions where *Physalis ixocarpa* (Mexican husk tomato) represents an economically important crop. While exogenous proline enhances salt tolerance in various species, the underlying molecular mechanisms and metabolic trade-offs in *P. ixocarpa* remain unexplored. This study employed integrated morphophysiological, spectroscopic, and metabolomic approaches to elucidate proline's multifaceted protective mechanisms beyond simple osmotic adjustment.

Germination screening established moderate salt stress conditions, where proline pretreatment via seed imbibition substantially restored germination rates and seedling vigor. Subsequent in vitro culture experiments applied proline directly to salt-stressed seedlings, revealing an unexpected strategic trade-off: proline-treated plants prioritized photosynthetic protection over structural growth, achieving chlorophyll levels exceeding even non-stressed controls while reducing root biomass. This resource reallocation represents an energy-efficient stress tolerance strategy.

Infrared spectroscopy demonstrated proline incorporation into plant tissues and restoration of structural polysaccharide conformations disrupted by salinity. Metabolomic profiling uncovered fundamental biochemical reorganization: salt stress triggered shifts in primary carbohydrate identity and synthesis of nitrogenous osmolytes, while proline treatment reversed these changes and generated active proline-derived metabolites.

A key finding challenges conventional understanding of stress protection: phenolic antioxidants disappeared under salt stress and were not restored by proline treatment, yet plants showed enhanced tolerance. This suggests proline operates through preemptive metabolic stabilization rather than reactive antioxidant synthesis—a more cost-effective protective mechanism. These results provide practical protocols for enhancing salt tolerance through both seed priming and seedling treatment, with potential application in marginal growing conditions where water quality and soil salinity limit production.

### *5.2. Integrated Nutrient Management for Sustainable Productivity and Profitability of Pigeonpea*

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The excessive and indiscriminate application of chemical fertilizers over the years has resulted in soil degradation, nutrient imbalances, and a gradual decline in overall soil health, which in turn has negatively impacted crop productivity and sustainability. To overcome these challenges, the integration of organic nutrient sources such as vermicompost and farmyard manure (FYM) with chemical fertilizers has been identified as a viable and eco-friendly strategy to restore soil fertility, improve nutrient use efficiency, and sustain agricultural productivity. Vermicomposting originated in the mid-20th century as a sustainable method of organic waste management, utilizing earthworms to convert biodegradable materials into nutrient-rich compost. It gained prominence in countries like the USA and India for improving soil fertility and crop productivity. A field experiment was carried out during the late Rabi season of 2024–2025 at the Instructional Farm of Karunya Institute of Technology and Sciences, Coimbatore. The field trial consisted of eleven treatments comprising various combinations of inorganic fertilizers with vermicompost and FYM under an integrated nutrient management in the cultivation of pigeon pea. The findings revealed that the application of 75% of the recommended dose of fertilizers (RDF) supple-

mented with 25% nitrogen equivalent through vermicompost substantially enhanced plant growth attributes, dry matter accumulation, grain yield, and haulm production compared to the sole application of fertilizers. In terms of economics, the highest net gain and additional cost were achieved with full RDF integrated with FYM, whereas the combination of 75% RDF with vermicompost resulted in higher gross and added returns. These results clearly demonstrate that INM practices not only boost productivity and profitability but also play a crucial role in maintaining long-term soil health and sustainability in crop production systems.

### *5.3. Comparative Effects of a Synthetic Hydrogel and a Bio-Hydrogel on Lettuce (Lactuca sativa) Plants Under Water Stress*

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Water stress keeps increasing considerably due to climate change. Alternative solutions, such as improving soil water retention, have become imperative in order to maintain crop productivity in arid and semi-arid areas. This study focused on the use of two types of hydrogel to improve soil properties and enhance plant tolerance to drought conditions. The first type is a synthetic, commercially available hydrogel based on sodium polyacrylate, while the second is a hydrogel produced in our laboratory from carboxymethylcellulose and sodium alginate (CMC/SA). The two hydrogels were characterized regarding their physicochemical properties, including swelling capacity and biodegradability, and their effect on lettuce plants subjected to water stress was evaluated.

The results showed that the SAP hydrogel has a high swelling capacity (228.5 g/g) compared to CMC/SA (28.1 g/g). As for biodegradability, it was low in the synthetic hydrogel (26.52%) compared to the CMC/SA hydrogel (51.01%). Furthermore, the physiological, biochemical, and morphological parameters of lettuce plants under water stress showed greater improvement following treatment with the CMC/SA hydrogel compared to SAP treatment. These improvements suggest that the bio-hydrogel not only supports better water retention but also enhances the plant's resilience mechanisms.

These findings underscore that bio-hydrogels derived from CMC and SA offer an eco-friendly and efficient strategy to improve plant tolerance to drought stress without adverse environmental impacts. Thus, the use of natural polymer-based hydrogels could represent a sustainable alternative for agricultural practices in water-limited environments.

### *5.4. Comparative Study on the Influence of Liquid Fertilizers on Cabbage Growth and Productivity*

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The growing emphasis on sustainable agriculture in Sri Lanka has increased interest in liquid fertilizers as eco-friendly alternatives to conventional chemical inputs. To evaluate their effectiveness, a pot experiment was conducted from December 2020 to March 2021 at the Agriculture Farm of the University of Jaffna. This study examined the impact of different liquid fertilizers on the growth and yield of cabbage (*Brassica oleracea* var. *capitata*) under insect-proof net house conditions. A Completely Randomized Design (CRD) with ten replicates was used, consisting of four treatments: T1 (control with distilled water), T2 (Nitrobenzene, a chemical growth promoter), T3 (Azolla extract), and T4 (fermented cow urine). Organic treatments were prepared and applied as foliar sprays beginning two weeks

after seeding and continued weekly. Statistical analysis ($p < 0.05$) was performed using SAS software. It revealed that fermented cow urine (T4) significantly enhanced plant height, leaf number, and leaf area, as well as yield attributes such as head diameter, girth, and total yield. Beyond its fertilizing properties, fermented cow urine also acted as a natural pest repellent, contributing to healthier crop growth. These results underscore the potential of fermented cow urine as a cost-effective, eco-friendly alternative for smallholder farmers to improve cabbage production while advancing sustainable farming practices.

### *5.5. Compost Application as a Mitigation Strategy for Water Deficit Stress in Tomato Plants*

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Water scarcity is one of the major constraints in agriculture, particularly affecting crop growth and development in arid and semiarid regions. As climate change intensifies the frequency and severity of drought events, there is a growing need for sustainable strategies to enhance crop resilience under limited water availability. Organic amendments such as compost have gained attention for their potential to improve soil health, water retention, and plant stress tolerance. In this line, this study evaluates, in a pot experiment under controlled conditions, the impact of garden waste compost application on tomato (*Solanum lycopersicum*) growth under varying levels of water deficit (100%, 60%, and 40% of field capacity, FC) in order to simulate optimal, moderate, and severe water stress conditions, respectively. The application of compost significantly enhanced plant growth and biomass accumulation across all the irrigation levels, with the most pronounced benefits observed under moderate water deficit (60% FC). These results suggest that compost amendments can improve plant performance and mitigate the adverse effects of water stress deficit, emphasizing their potential role in promoting water scarcity resilience in sustainable agriculture.

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### *5.6. Deficit Irrigation Strategies (DI and PRD) Effects on Potato (Solanum Tuberosum L.) Yield, Nitrogen Nutrition, NUE and IWUE Under Tunisian Semi-Arid Conditions*

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A reasonable supply of water and nitrogen is a key success factor in potato crop production. Excess or deficiency of these two elements has direct negative impacts on final yield and product quality. In arid and semi-arid regions, the adoption of water deficit irrigation strategies at the farm level is now an obligation to overcome water scarcity and

optimise crop yields. The use of such deficit irrigation strategies also requires studying their impact on crop nitrogen nutrition and use. This work aims to study the impact of deficit irrigation strategies (DI and PRD) on potato nitrogen nutrition and use under specific climate and soil conditions in Tunisia. To achieve this objective, a two-year field trial was set up in 2021 and 2022. The experimental protocol is a complete randomised block design with three irrigation regimes: 1- Full Irrigation (FI) receiving 100% of the crop evapotranspiration (ETc), 2- Deficit Irrigation (DI75) with 75% of the ETc, and 3- Partial Root Zone Drying (PRD50) with 50% of the ETc. Our results showed that the PRD50 slightly decreased potato yield, but not significantly compared to FI and DI75. SPAD-502 values were lower with the PRD regime than with FI and DI75 at 72 and 83 DAP, but the differences were not statistically significant. The total nitrogen content of the plant was significantly affected by the irrigation regime at 70 and 100 DAP. FI had the highest N content, followed by PRD50 and DI75. The Nitrogen Nutrition Index (NNI) was also significantly affected by the irrigation regime, with the FI treatment yielding the highest values, while DI75 and PRD50 induced nitrogen stress at 100 DAP. NUE decreased slightly with the PRD50 regime, but not significantly, while PRD50 and DI75 significantly increased IWUE compared to FI.

### *5.7. Effect of SmartBlock® and 1,4-DMN, Sprout Suppressants, on the Nitrogen Use Efficiency and Growth of Potatoes*

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Postharvest sprouting poses a major challenge for the potato industry, reducing seed quality and causing economic losses. Seed quality is an important factor influencing the yield. SmartBlock® (AMVAC, Newport Beach, CA, USA) and 1,4-DMN are new chemicals used to control sprouting. This study evaluated the effects of these suppressants on the nitrogen use efficiency (NUE) and growth of treated seed potatoes. 'Panamera' and 'Mondial' were treated with 0.100 mL $kg^{-1}$ × 4 dosages of SmartBlock® and 1,4-DMN and stored in the dark. Treated seeds were planted in the field one week after the last application. The trial was arranged in a split–split plot design with 50 and 100% nitrogen as the main block, suppressants as the subplot, and cultivar assigned to plots, and replicated three times, including the control. Emergence percentage and index, leaf area, chlorophyll, stem number, tuber form index, and tuber yield were recorded, and NUE was calculated as yield (kg)/kg N input. 1,4-DMN significantly reduced the emergence percentage and index in 'Panamera' under 100% nitrogen, whereas SmartBlock® increased the emergence index only at 50% nitrogen. SmartBlock® and 1,4-DMN significantly increased stem number in 'Panamera', while 100% nitrogen increased chlorophyll. At 50% nitrogen, SmartBlock® produced oval-shaped tubers, whereas the control produced short-oval tubers. NUE and yield increased in all treatments except SmartBlock® at 50% N. Effects were limited in Mondial. Overall, 1,4-DMN increased NUE and yield under both full and reduced nitrogen application, suggesting its suitability for use by resource-constrained and commercial producers.

### *5.8. Evaluation of Nitrogen Use Efficiency of Vegetables Grown Under Agri-Photovoltaic Systems in North-Central Namibia*

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Agriculture in arid and semiarid regions encounters substantial challenges attributable to climatic variability, limited water resources, and nutrient-deficient soils. Nitrogen (N) is essential for tomato (*Solanum lycopersicum*) growth and affects yield, water efficiency, and fruit quality. Agri-photovoltaic (Agri-PV) systems offer a promising and sustainable solution to land-use competition by concurrently facilitating solar energy generation and horticultural production. This study examined the combined effects of nitrogen application rate and Agri-PV-induced shading on the physiological performance and yield characteristics of tomatoes. The experiments were carried out with tomato seeds planted in an Agrovoltaics experimental field at the School of Agriculture, University of Namibia, Namibia. The split–split plot experimental design featured two nitrogen levels: the recommended rate (150 kg N $ha^{-1}$) and an adaptive rate (120 kg N $ha^{-1}$), combined with three shading conditions: 60% shade (chequered boards), 40% shade (opaque boards), and full sunlight (control). Phosphorus (P) and potassium (K) were applied at the recommended rates of 90 kg P $ha^{-1}$ and 75 kg K $ha^{-1}$. Growth and yield parameters were analysed using SAS 9.4. There were no statistically significant differences in yield between the nitrogen levels; however, shading treatments significantly influenced fruit weight yield, with intermediate shading enhancing production. At harvest, the 40% chequered shade treatment showed the highest values of fresh fruit yield ($kg/m^2$) compared to opaque and with similar values of fruit numbers. These outcomes indicate that Agri-PV systems can control microclimatic conditions, reducing excessive heat and light stress while sustaining or enhancing crop productivity. The integration of Agri-PV with optimised nitrogen management supports both renewable energy generation and sustainable agriculture, offering a viable strategy for climate-smart food production systems.

### *5.9. Genotype-Dependent Effects of Silicon and Arbuscular Mycorrhizal Fungi on Wheat Phenolic Metabolism*

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Silicon (Si) and *arbuscular mycorrhizal fungi* (AMF) have been widely recognized for enhancing plant tolerance to water deficit. However, the combined influence of these factors on the phenolic metabolism of wheat plants grown under water-limited conditions remains unclear. This study evaluated the effects of Si and AMF on the accumulation of phenolic compounds in two wheat genotypes differing in their tolerance to water deficit stress (Tukan-sensitive; Kiron-tolerant). A pot experiment was conducted under two irrigation regimes [90% of water holding capacity (WHC) and 40% WHC], two Si doses (0 or 1000 mg Si $kg^{-1}$ soil), and two AMF levels (−AMF, +AMF). Plants were grown under greenhouse conditions using a randomized factorial design with three replicates per treatment. Data were analyzed by analysis of variance (ANOVA), and treatment differences were determined by the LSD test ($p \leq 0.05$). Plants were harvested at the tillering stage, and individual phenolic compounds were analyzed by HPLC–DAD–ESI-MS/MS. Accordingly, seven flavonoids [*luteolin-hexoside-pentoside I*, *luteolin-hexoside-pentoside II*, *apigenin-pentoside-hexoside I*, *luteolin-hexoside-hexoside*, *apigenin pentoside-hexoside II*, *luteolin 7-(2″-pentosyl-4″*

*-O-hexosyl) hexoside*, *luteolin C-deoxihexosyl-O-hexoside*, *apigenin 8-C-rhamnoside-6-C-glucoside*, and *isoscoparin 2″-O-deoxyhexoside*] were identified in shoots of both wheat genotypes, with apigenin and luteolin derivatives being predominant. In Tukan, higher concentrations of the identified phenolic compounds were detected in plants cultivated under water deficit than in well-watered plants. In contrast, Kiron showed no significant changes across irrigation regimes. Interestingly, the combined application of Si and AMF further increased phenolic accumulation in water-stressed Tukan but reduced phenolic levels in Kiron under the same conditions. Our results reveal that the synergistic action of Si and AMF can either stimulate or decrease phenolic accumulation depending on the wheat genotype. Moreover, these findings highlight the importance of cultivar-specific strategies when combining these beneficial approaches to improve drought tolerance. Acknowledgments: FONDECYT Projects N°1241718, N°11240738 and N°11240769, ANID, Chile.

### *5.10. Growing Lettuce (Lactuca sativa L.) in a Hydroponic Substrate System Under a Range of Saline Waters with the Use of Two Innovative Electronic Devices (MaxGrow and a Generator of Agro-NanoBubbles)*

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Hydroponic systems (soilless plant cultivation) offer a more sustainable solution to many environmental and resource problems, such as salinity, water scarcity, rising fertilizer and pesticide costs, environmental pollution, and soil degradation. Salinity problems affect several physiological, morphological, and biochemical processes in plants, reducing water availability, nutrient uptake, and crop yield. The agricultural sector has taken notice of nanotechnology and nanobubbles, and many important investments have been made to optimize crop yields and eliminate salinity problems. The study took place in the Greenhouse Laboratory of Perrotis College, Thessaloniki, Greece, using three hydroponic substrates (coconut fiber, hydroponic perlite, and Grodan Rockwool), in which two lettuce (*Lactuca sativa* L.) varieties (red oak and Romaine) were grown in 10 different sections. Moreover, the main treatments consisted of five sections utilizing a range of saline irrigation water (E.C.i: 1, 4, 8, 10, and 12 dS/m, replicated three times across substrates), enhanced with Nanobubbles through the use of two innovative electronic devices [MAXGROW (MG) + Agro-NanoBubbles (Agro-NBs)] generator. Additionally, there were another five sections of non-treated saline irrigation water (E.C.i: 1, 4, 8, 10, and 12 dS/m, replicated three times across substrates). The goal of this experiment is to examine the results of the influence of Nanobubbles with the use of two innovative electronic devices on various vegetable agronomic traits (weight and height), plant tissue analysis (macro and micro-nutrients), quality parameters (NDVI, Chlorophyll, etc.), used in high range salinity levels for two lettuce varieties. In addition, environmental conditions inside the greenhouse were recorded [$CO_2$, Temperature (°C), humidity (%), and PAR]. The results showed that red oak and cos lettuce biomass enriched with Nanobubbles were statistically significant and increased (126% and 38%) at high salinity (10 dS/m), compared to non-treated saline irrigation water. In conclusion, coconut fiber has shown the highest yield among the others.

### *5.11. Integrated Zinc and Boron Application Enhances Growth and Yield of Maize (Zea mays L.)*

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Maize (*Zea mays* L.) is a key cereal in India, yet its productivity is often constrained by micronutrient deficiencies, particularly zinc (Zn) and boron (B). These nutrients are critical for photosynthesis, reproductive processes, and the partitioning of assimilates. A field experiment was conducted during the kharif seasons of 2023 and 2024 at IFTM University, Moradabad, to assess the impact of different Zn and B application methods on maize growth and yield. The study followed a randomized block design with eight treatments, including soil application, foliar spraying, and integrated approaches, each replicated three times. Growth attributes—plant height, leaf area index (LAI), dry matter accumulation (DMA), and crop growth rate (CGR)—were recorded, while yield was measured at harvest. Results revealed that integrated Zn and B application through soil and foliar routes significantly enhanced crop performance compared with individual applications and the control. The combined treatment increased plant height by 14–18%, LAI by 20–25%, and DMA by 22–27%. Grain yield reached 6.40 t $ha^{-1}$ in 2024, representing a 28% gain over the control and 12–15% higher than single-nutrient treatments. These findings demonstrate that integrated soil-and-foliar applications of Zn and B improve nutrient uptake, growth, and yield efficiency. This approach offers a practical and scalable strategy for sustainable maize production under irrigated conditions in western Uttar Pradesh.

### *5.12. Nutrient Blend Dashboard Approach to Optimize Fruit Set and Growth of Biloxi Blueberries*

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The present study was conducted to optimise the growth size of the Biloxi blueberry variety by establishing a heuristic dashboard of soil nutrients and monitoring fruit set percentage to maximise the nutrient blend through fertilised water irrigation (10 sets per day over a 90-day harvest period). Blueberries are known as "longevity fruits" due to their high antioxidant capacity against free radicals and reactive species, and they are considered to be one of the greatest sources of antioxidants among all fruits. The time of leaf and floral bud initiation was determined by recording the date of the first leaf and flower to open. Percent fruit set was observed by counting the number of flowers on different selected branches and the number of fruits 15 days after full bloom. Percent fruit set was calculated as follows: Fruit set (%) = (total number of flowers/total number of flowers) × 100. After harvesting, the fruit was analysed for size, weight, and physicochemical properties (total solids, titratable acidity, total sugars, and reducing sugars) using standard procedures. A mixture dashboard was created by blending the acidic: potassium nitrate, magnesium sulphate, monoammonium phosphate, Iron chelate, and phosphoric acid; and non-acidic parts: calcium nitrate, ammonium sulphate, boric acid. After the berry's growth and flowering period (90 days), the increase in size resulting from irrigation with the optimal mixture was maximised at 13 mm, an increase of 2 mm + 0.1 in the measured samples.

### *5.13. Quantifying Tiller Contribution to Yield as a Compensatory and Water Stress Adaptation Mechanism in Sorghum*

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Introduction: Is tillering in sorghum a beneficial adaptive trait or an agronomic burden under water stress? Tillering in sorghum is a highly plastic trait, yet its adaptive value under water-limited conditions remains poorly understood due to contradictory findings.

This study aimed to experimentally quantify the contribution of tillers to grain yield under contrasting water regimes across diverse sorghum cultivars over two growing seasons.

Methods: Field experiments were arranged in a split-plot design with three replications. The main plot factor consisted of three water regimes: full irrigation (FI), deficit irrigation (DI), and rainfed (RF). The subplot factor was four cultivars (Mr Buster, PAN606, Macia, and a local landrace).

Results: Across two seasons, Landrace and Mr Buster consistently produced the highest fertile tiller numbers under RF and DI, though high rainfall during season 2 reduced water × cultivar differences. In season 1, hybrids PAN606 and Mr Buster achieved the highest main stem yields (5.7–6.0 t/ha) under DI and FI. In the second season, Landrace outperformed others in main stem yield under rainfed conditions (4.3 t/ha), while PAN maintained superior main stem productivity (3.6–4.0 t/ha) under DI and FI. When yield was aggregated across stem ranks, Landrace achieved the highest total grain yield (main stem + fertile tillers), reaching 12.4 and 9.8 t/ha in seasons 1 and 2, respectively, under rainfed conditions. Partitioning of these totals showed that the main stem contributed 40.4–40.7%, tiller 1 contributed 30.6–36.2%, tiller 2 added 15.6–19.4%, while tillers 3 and 4 marginally contributed 4.4–7.8% and 1.7%, respectively.

Conclusions: These findings demonstrate that early water stress induces tillering in sorghum as a compensatory drought-adaptation mechanism, with fertile tillers, especially tillers 1 and 2, contributing significantly to enhancing total grain yield under water-limited conditions.

### *5.14. Scaling Crop Water Status Monitoring with a PROSAIL–GPR Hybrid Model on Google Earth Engine*

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Google Earth Engine (GEE) revolutionized agricultural monitoring by providing scientists immediate access to huge satellite archives without requiring heavy local computing. In crop science, this means that water stress and growth conditions can be monitored almost in real time. A critical indicator of plant health is canopy water content (CWC), which reflects leaf hydration and strongly correlates with chlorophyll concentration. Accurate estimation of CWC is essential for timely irrigation management, early detection of crop water stress, and improving overall water-use efficiency. In our research, we developed a hybrid method that couples the PROSAIL radiative transfer model and Gaussian Process Regression (GPR) to directly estimate CWC from Sentinel-2 images. For model training, we utilized field measurements taken at ICAR-IARI, New Delhi, on 23 February 2023, and Sentinel-2 Biophysical Processor data. The model performed well, yielding an $R^2$ of 0.88, an RMSE of 0.0007, and an NRMSE of 7.59% for 155 test plots. To extend our assessment, we deployed the trained model on the GEE platform. This enabled us to scale up water content across the entire IARI location. The GEE-based estimates were very close to the local estimates and had an $R^2$ of 0.96. The results indicate that integrating PROSAIL with GPR and deploying it on GEE provides an efficient, scalable method for crop water status monitoring. This facilitates irrigation scheduling and precision agriculture on a larger regional level.

### *5.15. Soil Revitalization and Yield Gains in Chickpea Cultivation Through Microbial-Enriched Manures and Nano-Biofertilizers*

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Indian agriculture has long depended on chemical fertilizers to sustain food production; however, their continuous, indiscriminate and imbalanced use has caused nutrient depletion, organic carbon loss, and decline in soil microbial activity, jeopardizing long-term productivity. To counter these challenges, integrated nutrient management approaches that combine inorganic fertilizers with organic and biological inputs are gaining importance. Microbial-enriched manures and nano-emulsion biofertilizers, in particular, are promising options for enhancing nutrient availability, stimulating crop growth, and restoring soil health while reducing dependence on synthetic fertilizers. A field study was conducted during the winter (Rabi) season of 2023–2024 at Coimbatore, Tamil Nadu, India, to evaluate the effects of microbial-enriched organic manures and nano-emulsion biofertilizers on soil fertility, microbial dynamics, and chickpea (*Cicer arietinum* L.) productivity under irrigated conditions. The experiment, laid out in a randomized block design with twelve treatments, combined varying levels of recommended fertilizer dose (RDF) with farmyard manure, vermicompost, microbial-enriched amendments, and nano-emulsion formulations. Results revealed that application of 100% RDF + microbial-enriched vermicompost (6 t $ha^{-1}$) significantly improved plant growth, dry matter accumulation, physiological indices, nutrient uptake, and microbial activity, producing a higher grain (1276 kg $ha^{-1}$) and stover yield (2569 kg $ha^{-1}$). Soil analysis confirmed improvements in organic carbon, available nutrients, microbial biomass, and enzymatic activities under this treatment. Economic evaluation showed that, while this combination achieved maximum gross returns (INR 95,700 $ha^{-1}$), the treatment with 75% RDF + nano-emulsion biofertilizer delivered superior net returns (INR 56,785 $ha^{-1}$) and benefit–cost ratio (2.72). The integration of microbial-enriched vermicompost with recommended dose of fertilizers (RDF) significantly improves chickpea yield and soil health, while partial replacement of RDF with nano-emulsion biofertilizers presents a viable, economical, and eco-friendly alternative.

### *5.16. Synergistic Effects of Nano-Emulsion Biofertilizer and Organic Manures on Agronomic Traits of Chickpea*

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Identifying sustainable agricultural practices that simultaneously boost yield from existing farmland and optimize resource use efficiency is critical to meet the growing demands of an expanding population amid dwindling natural resources. Strengthening nutrient management approaches that enhance crop productivity, improve soil health, increase soil organic carbon, and maintain energy balance can promote sustainability in agricultural systems. In this context, chickpea (*Cicer arietinum* L.), distinguished by its comparatively high protein content among pulse crops, serves as an ideal model to evaluate diverse nutrient management strategies. Field investigations were conducted during the Rabi 2023–2024 season in the western part of Tamil Nadu state, India. The treatments were imposed in a factorial randomized block design with two factors: soil

and foliar applications. The soil application consists of S1—100% recommended dose of fertilizer, S2—75% recommended dose of fertilizer + farm yard manure at 10 t $ha^{-1}$, S3—75% recommended dose of fertilizer + vermicompost at 5 t $ha^{-1}$, S4—50% recommended dose of fertilizer + farm yard manure at 10 t $ha^{-1}$, and S5—50% recommended dose of fertilizer + vermicompost at 5 t $ha^{-1}$, while the foliar application includes F1—nano di-ammonium Phosphate (two sprays at 2% at 30 and 45 days after sowing), F2—nano urea (two sprays at 2% at 30 and 45 days after sowing), and F3—nano emulsion biofertilizer (two sprays at 10 mL $L^{-1}$ at 30 and 45 days after sowing). The application of nanoemulsion biofertilizer provided the highest values for growth, physiological, and yield parameters of chickpea at 30, 45, and 60 days after sowing, and at harvest. The grain yield and stover yield were recorded as 1111.60 kg $ha^{-1}$ and 2501.10 kg $ha^{-1}$, respectively. The combined application of the recommended 50% fertilizer dose + vermicompost at 5 t $ha^{-1}$ with nanoemulsion biofertilizer was found to be the most effective for chickpea productivity in the western part of Tamil Nadu, India.

### *5.17. The Impact of Fertilization Systems on Soil Agrochemical Parameters in Green Asparagus Cultivation Under the Conditions of the Left Bank Forest-Steppe of Ukraine*

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The aim of this study was to evaluate the growth, development, and productivity of Argental asparagus plants cultivated using ridge-free technology under drip irrigation in the conditions of the Left Bank Forest-Steppe of Ukraine, under various mineral nutrition systems.

Within the framework of this research, the effectiveness of different fertilization systems was assessed on an eighth-year asparagus plantation: organic (manure), mineral (NPK fertigation), and combined (manure + microbial preparations + complex fertilizers). After the harvest and vegetation season, soil samples were collected and analyzed in laboratory conditions.

The highest concentrations of nitrate nitrogen, available phosphorus, and exchangeable potassium were recorded in variant D4 (combined fertilization): 122.5 mg/kg $NO_3$, 1687.5 mg/kg $P_2O_5$, and 511.0 mg/kg $K_2O$, which exceeded the control (D1) by 84.8%, 11.9%, and 16.7%, respectively. Mineral fertilization (D3) also demonstrated high effectiveness: 108.1 mg/kg $NO_3$ (+63%), 1679.1 mg/kg $P_2O_5$ (+11.4%), and 510.5 mg/kg $K_2O$ (+16.6%) compared to the control. Organic fertilization (D2) resulted in a significant increase only in nitrogen content (+31.4%), while phosphorus and potassium levels remained similar to the control.

Thus, our research established that mineral and combined fertilization systems were the most effective in improving the agrochemical properties of the soil. Their application enhances nutrient availability, which is critically important for the stable growth and development of asparagus plants.

### *5.18. The Response Tuber Quality to Selected Potato Cultivars, Different Mulch, and Fungicide Applications Under Various Localities*

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Potato plays a huge role in addressing food security in lower-income countries; however, smallholder substandard agronomic practices compromise potato tuber quality. This study was conducted in a smallholder setting to determine effective agronomic practices that can improve potato tuber quality. Four potato cultivars (Sababa, Mondial, Electra, and Panamera), two different levels of mulch (no mulch and mulch), and fungicides (sprayed and unsprayed) were laid out in a randomized complete block design under five localities (Mbalenhle, Hlathikhulu, Mbhava, Stezi, and Gobizembe) for two seasons (2022/23 and 2023/24). Tuber quality traits and nutrient reference values were assessed on protein, fat, dry matter, starch carbohydrates, and energy. The results revealed integration of late maturing cultivars (Panamera) with mulch application and fungicide spraying, and Electra with application of mulch and fungicide (for 2023/24 season only) improved dry matter content. Also tubers that had higher dry matter content resulted in higher starch, carbohydrate content, and energy. Sababa has the lowest nutritional profile for all traits across localities. Overall, mulch application was found to have an insignificant effect on the tuber quality. Hence, it can be suggested that farmers can improve potato tuber quality by adopting Electra and Panamera with the application of fungicides; this combination works together to improve plant health and facilitate the uptake of soil nutrients, which boost plant growth and development.

### *5.19. Using a Combination of Innovative Electronic Technologies (MAXGROW and a Generator of Agro-Nanobubbles) for Growing Lettuce (Lactuca sativa L.) in Different Soil Types in Potsunder High Salinity Irrigation Water Management*

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Nowadays, as the population continues to grow, climate change is affecting more and more areas worldwide. One of them is agriculture, and more specifically, salinity not only in irrigation water but also in the soil. The accumulation of salt degrades the quality of the plants and simultaneously reduces soil productivity. Therefore, the goals of the United Nations become more doubtful but, at the same time, more urgent than ever. It is necessary to adopt sustainable methods that improve water quality through innovative irrigation systems to ensure food security for the population in the near future and protect the environment. The objective of this study was to evaluate the use of these two technologies for growing lettuce (Lollo Verde and Lollo Rossa) with high-saline irrigation water (E.C.i = 12 dS/m) in pots filled with five different soil textures. These two innovative electronic technologies were: (i) a generator of Agro-Nanobubbles (Agro-NBs) and (ii) an electronic water treatment system, using low-frequency radiation waves (MAXGROW). More specifically, the main treatments were the following: a. control/regular tap water (E.C.i = 1 dS/m), b. regular tap irrigation water + MAXGROW + Agro-NBs c. saline irrigation water enriched with Agro-NBs, d. saline irrigation water + MAXGROW, and e. saline irrigation water + MAXGROW + Agro-NBs, for each variety. Various vegetable agronomic and quality parameters were measured. In conclusion, the results showed that the vegetable yield was not only not negatively affected, but also increased (5% to 20%), and the plants were improved both in their length (0% up to 14%) and quality (Chlorophyll

fluorescence emission (fv/fm) non-statistical significance). The study demonstrates that, with technological advances, agriculture is well-positioned to address many environmental challenges while promoting sustainability and reducing its ecological footprint.

## 6. Session 5: Crop Biotic Interactions

### *6.1. Agave salmiana and Chinicuil (Comadia redtenbacheri): A Relationship That Promotes the Generation of Bioactive Compounds*

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*Agave salmiana* is a plant of great economic and cultural value in Mexico, whose interaction with the insect chinicuil (*Comadia redtenbacheri*), a phytophagous species that develops in its root system, represents a key example of the plant–insect relationship. The objective of this study was to identify and relate the bioactive compounds present in both *A. salmiana* and the chinicuil to better understand this interaction. Samples were collected from *A. salmiana* free of chinicuil (RSC) and infected by chinicuil (RIC), as well as chinicuils from the infected agave. Both materials were dried, pulverized, and subjected to hydroethanolic extraction (70:30) at a 1:10 $w/v$ ratio. Subsequently, phytochemical screening was performed on the roots and entomochemical screening on the chinicuil. Total polyphenols were quantified using the Folin–Ciocalteu method (GAE mg/g), flavonoids with the AlCl3 method (QE mg/g), and tannins with the Vanillin–HCl method (CE mg/g), followed by statistical analysis with ANOVA and Tukey's test ($p < 0.05$).

The results showed that RIC presented a greater diversity and concentration of compounds compared to RSC, including flavonoids, tannins, terpenes, glycosides, quinones, and coumarins, with up to a fourfold increase in polyphenol, flavonoid, and tannin content. This behavior could be attributed to the plant's activation of metabolite production as an induced defense response to the biotic stress caused by the chinicuil. In contrast, the chinicuil extract showed significant concentrations of polyphenols (14.801 $\pm$ 0.310 mg/g), tannins (53.574 $\pm$ 0.131 mg/g), and flavonoids (21.600 $\pm$ 0.086 mg/g), though lower than in RIC. The screening revealed that the insect performs a selective uptake of metabolites, with low compound accumulation, indicating a detoxification mechanism that allows it to exploit the plant's metabolites without suffering adverse effects. These findings confirm a close biotic relationship, providing valuable insights for the development of functional foods and sustainable agricultural strategies based on ecological interactions.

### *6.2. Evaluation of Phytotoxicity of Manure-Derived Fertilisers Using Seed Germination and Root Elongation Bioassays*

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This study evaluated the phytotoxicity of poultry manure-derived fertilizers. Four composting treatments were obtained from fresh poultry droppings at different initial C/N ratios (12 and 30, P and M, respectively) and oxygenation levels: static pile (S) and

forced aeration (A). Acute toxicity tests were performed on seeds of three plant species (Helianthus annuus, Vigna radiata, and Sinapis alba) using elutriates of fresh poultry droppings (FPDs) and composts (1:10 *w*/*v*) at different concentrations (25, 50, 75 and 100% *v*/*v*). Seeds were disinfected, exposed to elutriates, and monitored for germination and root elongation over 4 days. Relative growth and germination indexes were calculated (RGI and GI, respectively). Toxicity/inhibition thresholds for GI and ICR were 80% (high), 80–100% (low), and >100% (none). Sunflower showed low toxicity effects with composted treatments, either static (MS, PS) or aerated ones (MA, PA), with a mean RGI of 1.07 ± 0.22 and GI of 99.5 ± 18.26 for all concentrations studied. Mungbeans showed high sensitivity to most composting treatments, particularly PA (RGI: 0.7 ± 0.25; GI: 74 ± 23.54) and MS (RGI: 0.62 ± 0.36; GI: 64.24 ± 38.84), while only PS showed low toxicity (RGI: 0.94 ± 0.15; GI: 94.18 ± 13.23). For both sunflower and mungbeans, FPD decreased germination and radicle growth below 70, showing high toxicity in both indexes. Mustard had variable responses, no sensitivity to PS and MA treatments, with average RGI of 1.5 and GI of 147.32, while MS and FPD caused slightly low toxicity, and PA had high toxicity. Root elongation (RGI) was more robust than germination (GI) for detecting phytotoxicity. In general, it was observed that composting poultry droppings, regardless of the aeration or initial C/N, reduced in sensitive species, making it suitable for its use as fertilizer.

### *6.3. An In Vitro Approach to Study Oxidative Stress in Tomato Roots During Root-Knot Nematode Infection*

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Root-knot nematodes (*Meloidogyne* spp.) are among the most economically damaging pests in agriculture, capable of severely impairing crop productivity by disrupting root function and nutrient uptake. These soil-borne phytoparasites manipulate the host plant's root system to form specialized feeding structures, compromising plant vigor and yield. Understanding how crops respond to nematode infection at the physiological level is essential for developing effective control strategies. However, traditional field and greenhouse studies often face challenges due to environmental variability and biological complexity.

In this study, we resorted to in vitro culture systems of tomato transgenic roots to examine host responses to *Meloidogyne incognita* under controlled conditions. Oxidative stress markers were assessed by spectrophotometric analysis, focusing on the accumulation of thiobarbituric acid-reactive substances (TBARS), a proxy for lipid peroxidation, and the activity of the antioxidant enzyme ascorbate peroxidase (APX). Nematode-infected roots exhibited a 25% increase in APX activity, along with higher TBARS levels, indicating a noticeable oxidative response following root infection.

These results suggest that *M. incognita* may alter the redox status of host root tissues, reflecting both a plant defense strategy and/or nematode-induced physiological disruption. Understanding these stress pathways provides valuable insight into the mechanisms underlying crop susceptibility and resilience, offering potential targets for improving resistance and minimizing nematode-related yield losses.

### *6.4. Antimicrobial Activity of Three Pleurotus Species Cultivated in Gujarat, India: A Comparative Study*

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Introduction: Oyster mushrooms are edible mushrooms that belong to the Pleurotaceae family. They contain bioactive compounds with numerous nutritional and health benefits. Studies of their antimicrobial activities have highlighted their natural role in biological control. Methods: Fresh oyster mushroom samples of Pleurotus ostreatus, Pleurotus florida, and Pleurotus sajor caju were collected from growers in Gujarat, India. They were sun-dried for four days and powdered. Ten grams of powder from each species were extracted with 300 mL of double-distilled water, methanol, and ethanol (70%) using a Soxhlet apparatus, depending on the boiling point of each solvent. Antimicrobial activity was evaluated by agar well diffusion against *Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Candida albicans*, and *Candida parapsilosis* using extracts prepared at a concentration of 100 mg/mL, and tested in volumes of 25, 50, and 100 µL. Results: Methanol and ethanol extracts of oyster mushrooms exhibited inhibition zones ranging from 3.9 to 4.8 mm, whereas the aqueous (double-distilled water) extracts showed comparatively lower activity. Alcoholic extracts produced the largest overall bacterial inhibition zones, ranging from 22 to 23 mm at the highest concentration. Among the tested bacteria, *Staphylococcus aureus* and *Pseudomonas aeruginosa* were the most sensitive. In contrast, the fungal strains showed smaller inhibition zones, with Candida albicans and Candida parapsilosis exhibiting zones of 12–13 mm. Among the tested species, the alcoholic extract of *Pleurotus florida* demonstrated slightly higher antibacterial activity than those of *P. ostreatus* and *P. sajor caju*. In contrast, the methanol extract of *P. sajor caju* exhibited the most potent overall antimicrobial effect. Conclusion: The choice of solvent significantly influences the antimicrobial activity of oyster mushrooms. Oyster mushrooms are natural antimicrobial agents with applications in nutrition, medicine, and agriculture.

### *6.5. Biotic Interactions Modulating Stress Tolerance in Lablab purpureus*

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Climate change is increasing the incidence of abiotic stresses such as salinity and drought, which threaten both biodiversity and crop production, leading to economic losses and undermining food security. In this context, promoting sustainable agriculture requires not only the evaluation of stress-tolerant crops but also the identification of beneficial microorganisms capable of enhancing resilience, soil health, and productivity while reducing reliance on agrochemicals.

In this study, we evaluated whether nodule-associated bacteria, isolated from two Mediterranean ecosystems, modulate the response of *Lablab purpureus*—an underutilised legume with high nutraceutical potential—to salinity and drought. Three salt-tolerant strains (CJND1, LN1RA and LN3BA) were selected, and phenological parameters,

biomass and root architecture, photosynthetic pigments, osmolytes, ionic content ($Na^+$, $Cl^-$, $K^+$, $Ca^{2+}$), oxidative stress markers, antioxidant compounds, and antioxidant enzyme activies were assessed.

The inoculated strains exhibited distinct effects. CJND1 and LN3BA promoted root elongation, with LN3BA additionally increasing root surface area and enhancing $K^+$ accumulation in leaves. LN1RA increased the chlorophyll a/b ratio and improved nodulation under drought conditions. Overall, bacterial inoculation positively influenced root traits. Salinity reduced biomass, increased proline content, and promoted $Na^+$ and $Ca^{2+}$ accumulation in roots while restricting $Na^+$ translocation to the shoots. Moreover, salinity tended to increase catalase and superoxide dismutase activities, whereas drought significantly induced glutathione reductase activity and also slightly increased superoxide dismutase activity.

In conclusion, local microbiota, particularly nodule-associated bacteria tolerant to salinity and drought, may represent a valuable tool for the introduction of new agronomic crops such as *L. purpureus*. Their application could contribute to more sustainable production systems and help safeguard food security in regions such as the Mediterranean, where climate-driven threats are expected to reduce crop yields and water availability.

### *6.6. Genome-Wide Association Mapping for Striga Resistance, Secondary Metabolites and Nutritional Composition Related Traits in Sorghum*

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*Striga hermonthica* infestation and recurrent drought are major constraints to sorghum production in sub-Saharan Africa, significantly reducing both grain yield and nutritional quality. Developing sorghum varieties that combine resistance to Striga with enhanced nutritional traits is therefore a priority for food security and sustainable agriculture. This study investigated the genetic basis of Striga resistance and nutritional composition in 75 diverse sorghum genotypes, including advanced breeding lines and released varieties from Zimbabwe and South Africa. Whole-genome sequencing of genomic DNA from these genotypes was performed to identify single-nucleotide polymorphisms (SNPs) associated with secondary metabolites and macronutrient traits. SNPs linked to the biosynthesis of key phenolic acids—including hydroxybenzoic, gallic, ferulic, cinnamic, p-coumaric, caffeic, protocatechuic, and syringic acids—were distributed across multiple chromosomes, with chromosome 1 exhibiting the highest density of associated SNPs. Manhattan plot analyses highlighted significant associations for caffeic acid on chromosomes 1 and 9, protocatechuic acid on chromosomes 2, 3, 4, 5, and 10, and syringic acid on chromosomes 3, 5, 8, 9, and 10. Similarly, SNPs associated with macronutrient composition—including ash, carbohydrate, fat, fibre, and protein—were identified on chromosomes 1, 3, 4, 8, and 9. Several genomic regions were found to potentially exert pleiotropic effects, influencing both Striga resistance and nutritional traits, indicating co-localized genetic control. These findings provide a detailed map of key genomic regions underlying resilience and dietary quality in sorghum. The identified SNP markers can serve as valuable tools for marker-assisted selection, enabling the development of sorghum varieties that are both Striga-tolerant and nutritionally enhanced. By integrating resistance and nutritional profiling at the genomic level, this study contributes to the advancement of sorghum breeding strategies aimed at improving food security and nutritional outcomes in stress-prone environments of sub-Saharan Africa.

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### *6.7. Insect Dynamics in Sunflower Agroecosystems: Between Pest Pressure and Beneficial Insects*

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Sunflower (*Helianthus annuus* L.), as an allogamous and entomophilous species, plays a dual role in agroecosystems: it serves as a host that supports diverse insect populations, including pests, while simultaneously providing essential resources that sustain pollinators and natural enemies. Understanding this balance is key factor for sustainable crop management. This study was conducted in Cuautitlán Izcalli, State of Mexico, to analyze the population dynamics of diurnal insect visitors to sunflower. Over a 79-day monitoring period, 2986 individuals from 20 species were recorded. *Hemiptera* was the most abundant order, dominated by *Aphididae* (>1600 individuals), alongside other significant pests such as *Sphenarium purpurascens Charpentier* (*Orthoptera: Pyrgomorphidae*) and *Bemisia tabaci Gennadius* (*Hemiptera: Aleyrodidae*). Importantly, sunflower also attracted a wide range of beneficial insects. The most frequent natural enemies were *Hippodamia convergens Guérin-Méneville* (*Coleoptera: Coccinellidae*), a key predator of aphids, while *Apis mellifera* L. (*Hymenoptera: Apidae*) represented the dominant pollinator species. Population peaks occurred mainly in September, coinciding with favorable environmental conditions and the onset of flowering, which enhanced both pest and beneficial insect activity. These results highlight sunflower's ecological importance not only as a host of major pest species but also as a critical reservoir for pollinators and natural enemies. Recognizing this dual function is fundamental for integrated pest management strategies that seek to reduce pesticide use and strengthen ecosystem services in sunflower-based systems.

### *6.8. Interaction Effect of Foliar Fertilisation and Precision Drip Irrigation on Cob-Related Yield Components in Maize Hybrids*

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Maize hybrid selection depends on several traits, including cob parameters. Hybrids respond differently to agronomic inputs, namely irrigation and fertilisation. Our study was conducted at Látókép Crop Production Experimental Site, University of Debrecen, Hungary, in 2023. The evaluation of the interaction effect of foliar fertilisation and precision drip irrigation on cob diameter, cob length, cob weight, and number of rows per cob in four maize hybrids (FAO390, FAO420, FAO430, FAO490) was performed under a randomised

split-plot field experiment. Foliar fertiliser was applied at the 8th leaf stage when the plant's leaves had fully developed with enough leaf surface area to absorb nutrients such as nitrogen (10 g/L), zinc (8 g/L), $K_2O$ (8.5 g/L), $P_2O_5$ (0.83 g/L), and sulphur (8.93 g/L). Surface drip irrigation lines fixed at each row delivered 3 litres of water per hour, managed by the HydraWise app. Data were analysed by ANOVA using Genstat (18th edition) software. Cob diameter and cob weight had significant differences ($p < 0.01$) between hybrids. FAO430 recorded the largest cob diameter (52.8 mm) and cob weight (31.5 g). Thus, the least performing hybrid, FAO420, exhibited a 10–15% difference, with a cob diameter of 47.9 mm and a cob weight of 23.7 g. Both cob length and number of rows per cob showed no significant differences ($p > 0.05$) among hybrids. FAO390 had a longer cob (19.7 cm) compared to FAO430 (18.4 cm). Irrigation had a significant effect on cob length ($p < 0.001$) and cob diameter ($p < 0.05$). Irrigated cobs had a 7.8% (cob length) and 2.1% (cob diameter) difference compared to non-irrigated cobs. Foliar fertilisation alone increased mean cob weight by 7% but no statistical significance across all traits. The interaction between foliar fertilisation and precision drip irrigation showed a positive effect on cob diameter ($p < 0.001$) and cob weight ($p < 0.05$) across all hybrids. Combined input application enhanced yield components compared to single-factor effects. Therefore, the interaction among hybrid type, precision drip irrigation, and foliar fertilisation has a profound effect on cob-related yield components.

### *6.9. Metabolomic and Transcriptomic Insights into Root Exudate-Driven Recruitment of Beneficial Microbes Under Pathogen Stress in Tomato and Citrus*

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Root exudates play a crucial role in shaping the rhizosphere microbiome, influencing plant health and resilience against biotic stress. These exudates, composed of sugars, organic acids, amino acids, and secondary metabolites, act as chemical signals that modulate microbial recruitment, fostering beneficial interactions while suppressing pathogens. This study investigates the dynamic role of root exudates in regulating microbial communities and enhancing disease resistance in tomato (*Solanum lycopersicum*) and citrus (*Citrus* spp.) under pathogen stress caused by *Pseudomonas syringae*, *P. viridiflava*, and *Bacillus cereus*. Using metabolomics and microbiome sequencing, we analyzed root exudate composition and its influence on rhizosphere microbial diversity. Results indicate that plants under pathogen attack upregulate the secretion of flavonoids, phenolics, and organic acids, thereby significantly enhancing the abundance of beneficial bacteria, including non-pathogenic strains of Pseudomonas and Bacillus spp. while suppressing pathogenic counterparts. Furthermore, transcriptomic analysis reveals the activation of genes associated with exudate biosynthesis and microbial recognition pathways. Inoculation with selected beneficial rhizobacteria further amplified systemic resistance, reducing disease severity through induced systemic resistance (ISR) and competitive exclusion of pathogens. These findings underscore the

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critical role of root exudates in engineering beneficial microbial consortia, offering potential applications for sustainable crop protection. Harnessing this plant-microbe interaction could lead to the development of microbiome-based biocontrol strategies, reducing reliance on chemical pesticides and improving crop resilience against emerging pathogens. Future research should focus on optimizing root exudate-mediated microbial recruitment to enhance agricultural sustainability.

### *6.10. MicroRNAs from Pear Stigma Exudates—The Next Generation of Anti-Fire Blight Agents?*

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Introduction: Fire blight is a devastating disease, which threatens global fruit production in pear, apple, and other Rosaceae family members. The disease is caused by *Erwinia amylovora* bacteria, which colonize the stigma surface and grows rapidly prior to floral infection. Current strategies for controlling fire blight are insufficient; thus, alternative solutions must be sought.

Liquid excretions from different flower stigmas can interact with the stigma inhabitants including pollen grains and various microorganisms. Recently, our lab analyzed stigma exudates of several pear species and discovered extracellular RNAs (exRNAs) including microRNAs. Plant exRNAs modes of action are still poorly understood, yet recent studies have shown that plant extracellular small RNAs can be transmitted to cells from various kingdoms including mammalian and microorganisms and interfere with their transcriptional regulation.

Methods: The possibility that the pear stigma exudate microRNAs might have targets in the *E. amylovora* genome was explored via bioinformatic prediction of RNA–RNA interactions incorporating both the accessibility of interacting sites as well as the existence of a user-definable seed interaction. The two target prediction tools used were "TargetRNA2" and "IntraRNA2.0". Target prediction was performed with the threshold set up to $p < 0.05$ against "Erwinia amylovora CFBP1430 chromosome" with all the parameters set at the default values.

Results: The bioinformatic target prediction analysis identified 370 *E. amylovora* genes that are potentially targeted by the pear stigma miRs. Moreover, molecular categorization analysis of these genes revealed that several of them are known bacterial virulent factors, while many others are differentially expressed in *E. amylovora* during several infection stages on apple trees.

Conclusions: Our results indicate the possible involvement of the pear stigmatic microRNAs in host–pathogen interactions and suppression of *E. amylovora* pathogenicity genes. Moreover, our findings can potentially lead to the development of novel bio-control microRNA-based strategies against fire blight.

## 7. Session 6: Basic Plant Science

### *7.1. Effects of Waterlogging on Fe, Mn, and Al Profiles in Green and Senescent Leaves of Bread Wheat Genotypes with Different Genetic Backgrounds*

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Waterlogging is a major abiotic stress affecting wheat (*Triticum aestivum* L.) productivity worldwide, yet the dynamics of micronutrient accumulation and redistribution under this stress remain poorly understood. This study evaluated Fe, Mn, and Al concentrations in green and senescent leaves of 23 bread wheat genotypes exposed to 14 days of waterlogging at the tillering stage. Responses to waterlogging were compared across Portuguese landraces, Italian-derived varieties, CIMMYT-derived lines, advanced Portuguese breeding lines, and Australian varieties, allowing a broad comparison of genetic pools. Leaf samples were collected at the end of the stress period and at 7 and 14 days after stress release, under well-drained conditions. Micronutrient concentrations were measured in dried tissues using X-ray fluorescence (XRF).

Results highlighted both leaf stage– and genotype-dependent responses. In green leaves, Fe concentrations showed minor changes, whereas senescent leaves exhibited consistent Fe increases across genotypes, both under stress and throughout the recovery phase. Waterlogging further promoted transient accumulation of Mn and Al in green leaves, whereas more pronounced and frequent accumulations were observed in senescent leaves. Taken together, these findings indicate that waterlogging triggers micronutrient remobilization and accumulation that are age-dependent. Such differential partitioning between green and senescent leaves may influence the timing of leaf senescence and the capacity of wheat plants to recover following stress release, offering new insights into genotype-specific resilience mechanisms.

### *7.2. Antimicrobial Potential of Crop-Derived Extracts of Echinacea purpurea and Chenopodium formosanum Against Oral Pathogens*

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Antimicrobial resistance has emerged as one of the most pressing global health threats, reducing the effectiveness of conventional antibiotics and increasing the prevalence of untreatable infections. In response, researchers are turning to natural sources, particularly crop plants or their by-products, known for their antimicrobial potential. Exploring these crop-derived compounds not only addresses the urgent need for novel therapeutic options but also contributes to the valorization of agricultural resources for human health applications. This study investigated the in vitro antimicrobial activity of methanolic extracts prepared from *Echinacea purpurea* flowers and *Chenopodium formosanum* (djulis) seed husks against major human oral pathogens. Plant materials were macerated in 100% methanol, filtered, and concentrated by rotary evaporation. Antimicrobial activity was assessed using

the disk diffusion method, with ampicillin and ketoconazole serving as positive controls for bacteria and fungi, respectively. Triplicate experiments were analyzed by one-way ANOVA and Tukey's post hoc test. The methanolic extract of *C. formosanum* husk (CFH) demonstrated stronger antibacterial activity than the *E. purpurea* flower (EPF). At full strength (100%), both extracts produced the largest inhibition zones, with *Staphylococcus aureus* being the most susceptible (EPF: 21.6 $\pm$ 0.49 mm; CFH: 24.2 $\pm$ 0.85 mm). *Escherichia coli* and *Porphyromonas gingivalis* showed no inhibition at 25% EPF, whereas concentrations $\geq$ 50% of both extracts significantly inhibited *E. coli*, *Streptococcus mutans*, and *P. gingivalis*. Candida albicans exhibited marked resistance to both extracts. Statistical analysis confirmed significant ($p < 0.05$) differences in antimicrobial effects depending on extract type, microbial strain, and concentration. These results highlight the potential of crop-derived methanolic extracts as promising natural antimicrobial agents, contributing to sustainable approaches for managing microbial infections.

### *7.3. Antioxidant Properties of California poppy (Eschscholzia californica Cham) Plants Biofortified with Iodine*

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Iodine is a trace element whose deficiency impacts human health. Iodine's function is participation in the synthesis of thyroid hormones. It also has therapeutic potential to counteract oxidative stress by increasing antioxidant capacity. Biofortification is one of the most promising methods for enriching plants with this element.

The study aimed to determine the effect of biofortification with mineral (KI) and organic forms of iodine: 5-iodosalicylic acid (5-ISA) and 3,5-diiodosalicylic acid (3,5-diISA) on the antioxidant properties of Eschscholzia californica grown in a hydroponic system. The following combinations were tested: (1) Control; (2) KI; (3) 5-ISA; (4) 3,5-diISA.

For the determination of antioxidant activity, ethanol extracts (80% $v/v$) of California poppy plants were prepared. These parameters were determined using the DPPH radical, ABTS radical, FRAP, and CUPRAC methods. Absorbance was measured 10 min after the addition of solutions at 516, 734, 595, and 450 nm, respectively.

No significant differences were observed using the DPPH, ABTS, or CUPRAC methods. The only statistically significant differences between the combinations were observed with the FRAP method. The greatest increase in potential was observed after use of 5-ISA (approx. 17.5%), while a lower increase was observed for KI (approx. 9.0%). The increase in activity after the use of 3,5-diISA was not statistically significant.

In this study, the lack of an increase in oxidative potential in response to the treatments applied can be attributed to the lack of stress, which potentially could be induced in plants by poorly selected concentrations of iodine compounds.

### *7.4. Chlorophyll Content Assessment in Black Ginger (Kaempferia parviflora) Across Different Leaf Development Stages*

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Chlorophyll content is a critical indicator of photosynthetic efficiency and plant vigour. Black Ginger (*Kaempferia parviflora*) is a new medicinal crop that is gaining popularity in Malaysia. This study aimed to evaluate the effects of different extraction methods and leaf developmental stages on chlorophyll content in Black Ginger (*Kaempferia parviflora*). Two extraction methods (dissolved and grinder) and three leaf stages (old, mature, and young) were tested, and chlorophyll a, chlorophyll b, and total chlorophyll (a + b) contents were determined. Results revealed that extraction methods significantly influenced chlorophyll a content ($p < 0.0001$), with the grinder method producing higher concentrations ($1.5786 \pm 0.0309$ mg $g^{-1}$) compared to the dissolved method ($1.1288 \pm 0.0454$ mg $g^{-1}$). In contrast, chlorophyll b content was not significantly affected by the extraction method ($p = 0.46$). Leaf developmental stages showed a strong effect on both chlorophyll a and total chlorophyll contents ($p < 0.0001$ and $p = 0.0002$, respectively), with young leaves recording the highest total chlorophyll content ($3.3158 \pm 0.1186$ mg $g^{-1}$). Significant interactions between extraction methods and leaf stages were observed for chlorophyll a ($p < 0.0001$) and total chlorophyll ($p = 0.01$), highlighting the combined influence of methodological and physiological factors. These findings suggest that both extraction technique and leaf maturity must be considered for accurate chlorophyll determination in Black Ginger, with implications for optimizing physiological assessments and future studies on plant growth and bioactive compound evaluation.

### *7.5. Content of Selected Essential and Toxic Metals in Adaptogenic Plants Supporting Post-COVID-19 Recovery*

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Introduction: The COVID-19 pandemic, which began in late 2019, has drawn global attention to natural methods of supporting health during recovery. Adaptogens—plant-derived substances enhancing resilience to stress and boosting immunity—may play a vital role in post-infection rehabilitation. This study aimed to determine the content of essential (Mn, Mg, Cu, K, Na, Fe) and toxic (Cr, Cd, Pb, Sr) elements in selected adaptogenic plants used in recovery after SARS-CoV-2 infection.

Methods: Six plant materials—*Withania somnifera* (ashwagandha), *Centella asiatica* (gotu kola), *Schisandra chinensis* (schisandra), *Lycium barbarum* (goji berries), *Lepidium meyenii* (maca), and *Glycyrrhiza glabra* (licorice root)—were analyzed. Elemental concentrations were determined using atomic absorption spectroscopy (ContrAA 700, Analytik Jena). Results were compared with literature data and international safety limits for heavy metals in herbal products.

Results: Gotu kola exhibited the highest concentrations of most elements, including Fe (1274.76 mg/kg), Mn (251.95 mg/kg), K (21,866.10 mg/kg), Na (2895.86 mg/kg), Cu (12.35 mg/kg), and Cr (29.09 mg/kg). Licorice root showed the highest Sr content (68.90 mg/kg). Cd levels slightly exceeded the permissible limit (1 mg/kg) in gotu kola (1.735 mg/kg) and maca (1.023 mg/kg). Pb concentrations in all plants were below 3.0 mg/kg. The lowest Fe content was found in goji berries (39.61 mg/kg), while schisandra had the lowest Na (25.12 mg/kg) and Sr (2.42 mg/kg) levels.

Conclusions: The elemental analysis confirmed notable variability among the tested adaptogens, reflecting differences in their origin, cultivation conditions, and possible environmental exposure. Although Cd concentrations in gotu kola and maca slightly exceeded regulatory thresholds, overall heavy metal levels remained within safe limits for human consumption when adhering to recommended dosages. The high mineral content in certain species, particularly gotu kola, indicates their potential contribution to dietary mineral intake

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during convalescence. These findings highlight the importance of monitoring elemental composition in medicinal plants to ensure both safety and therapeutic effectiveness.

### *7.6. Control of Senecio vulgaris L. in Carrot Seed Crop with Pyridate Tank-Mixes—Its Potential, Efficacy, and Selectivity*

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The field experiment was conducted during the fall-spring period of the 2024/2025 growing season, at the experimental field of the Institute of Vegetable Crops Smederevska Palanka in Smederevska Palanka, Serbia. Carrot (*Daucus carota* L.) variety Nantes SP-80 was sown on 2 October 2025, after which pendimethalin at 1137.5 g ha$^{-1}$ of a.i. was applied.

Three different herbicide treatments were applied on 24 March 2025, all including pyridate: (1) pyridate 900 g ha$^{-1}$ + clopyralid 100 g ha$^{-1}$, (2) pyridate 900 g ha$^{-1}$ + flumioxazin 30.6 g ha$^{-1}$, and (3) pyridate 900 g ha$^{-1}$ + clomazone 96 g ha$^{-1}$. All herbicides were applied with 200 L ha$^{-1}$ of water by using Lechler IDK12002 nozzles. A period of 21 days after application (DAA), crop injury, weed density, and aboveground biomass of weeds and carrots were sampled, and these were then oven-dried for 72 h at 75 °C. Data was analyzed with IBM SPSS Statistics software, version 26.0, by running Tukey's test ($\alpha = 0.05$).

The most dominant weed species was *Senecio vulgaris* L. The highest dry biomass reduction of *Senecio vulgaris* L. was obtained in treatment with clomazone (89.09%), followed by treatments with clopyralid (55.67%) and flumioxazin (52.38%). The dry biomass reduction of carrots was highest in treatments with flumioxazin (63.53%), followed by clomazone (46.99%) and clopyralid (22.98%), respectively, whereby visual crop injury was 10, 30, and 20%, respectively. By adding flumioxazin, leaves were burned more, which is why the percent of dry biomass reduction was higher than visual rates, compared to treatments with clomazone, where, due to the synergism, visual crop injury was the highest of all three treatments.

All treatments caused crop injury, whereby flumioxazin caused the highest dry biomass reduction of carrots, but did not control *Senecio vulgaris* L., compared to treatment with clomazone where crop biomass reduction was less, but *Senecio vulgaris* L. biomass was highest.

### *7.7. Ecophysiology of Olea europaea in Semi-Arid Urban Environments in Morocco: Characterization of Functional Traits and Assessment of Ecosystem Services (Case Study of Marrakech)*

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This study elucidates the ecophysiological mechanisms of olive trees (*Olea europaea*), using the historic Menara Garden in Marrakech as a case study, and highlights their central role in the resilience of semi-arid urban agroecosystems. By integrating hyperspectral remote sensing, bioeconomic modeling (via i-Tree Eco software), and biophysical analysis results, we comprehensively quantify the ecosystem services provided by this urban park (spanning 100 ha and hosting over 10,000 trees).

The findings demonstrate optimized microclimate regulation, with evapotranspiration accounting for 53.21% of the local water balance, thereby mitigating the urban heat island effect. This park sequesters 0.2264 t of $CO_2$, 5.130909 t of $O_3$, 0.34 t of $NO_2$, 0.0282727 t of $SO_2$, and 1.28 t of atmospheric particulate matter ($PM_{2.5}$–$PM_{10}$) annually, while stabilizing soils through a deep root system (up to 6 m). Additionally, biomass flow analysis reveals a circular valorization of 268 tons per year into renewable energy, illustrating the integration of circular economy principles. These functions stem from adaptive functional traits: adjustable stomatal conductance (50–150 mmol $H_2O$ $m^{-2}$ $s^{-1}$), a moderate leaf area index (2.5–4.0), and high phenotypic plasticity under water stress. Hydraulic simulations reveal exceptional optimization of water fluxes ($\Psi_{max} = -4.2$ MPa), resulting in water savings of $35 \pm 5\%$ without significant yield reduction (*$p$* > 0.05).

This study presents a conceptual and empirical framework that integrates plant physiology, ecosystem services, and the Sustainable Development Goals (SDGs), highlighting the need to reorient urban policies around green infrastructure as pillars of sustainability. The results advocate for agroecological management of urban parks that combine climate mitigation, economic circularity, and biodiversity preservation in semi-arid and dry environments.

### *7.8. Effect of Light Intensity on Growth of Tomato Rootstocks in Controlled Environments*

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Rootstock vigor is strongly influenced by environmental conditions during the early growth phase. Light intensity plays a critical role in determining the vigor and physiological performance of plants under controlled environments. The aim of this study was to evaluate the effect of light intensity on the growth and root system of two tomato rootstocks. The present study evaluated the biometric responses of two commercial tomato rootstocks, Auroch and Ficus, to three light intensities, i.e., 150 µmol $m^{-2}$ $s^{-1}$, 250 µmol $m^{-2}$ $s^{-1}$, and 350 µmol $m^{-2}$ $s^{-1}$. Biometric parameters, including plant height, root length, stem diameter, leaf area, and fresh biomass, were measured and analyzed statistically. The results indicated that light intensity had a significant effect ($p$ value < 0.05) on all growth parameters. The tomato rootstock Auroch performed best at 250 µmol $m^{-2}$ $s^{-1}$, where leaf area expanded to 118 $cm^2$ compared with 41 $cm^2$ at 150 µmol $m^{-2}$ $s^{-1}$, and shoot biomass increased from 1.0 g to 3.7 g. In contrast, Ficus responded more positively at 350 µmol $m^{-2}$ $s^{-1}$, where root biomass increased from 0.19 g at 250 µmol $m^{-2}$ $s^{-1}$ to 0.65 g and root length exceeded 25 cm, compared with 11.7 cm at 150 µmol $m^{-2}$ $s^{-1}$. The initial findings indicate that light intensities exert a differential effect on tomato rootstock growth. Auroch favored moderate irradiance for balanced shoot and leaf development, whereas Ficus performed optimally under elevated irradiance with stronger root growth. These findings refine our understanding of tailoring light management strategies for different rootstocks to improve seedling quality and sustainable tomato production.

### *7.9. Estimation of Ascophyllum nodosum Extract and Mineral Fertilizer Potential to Improve Yield, Morphological Traits, and Physiological Parameters of Petroselinum hortense var. foliosum*

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Parsley (flat-leaf parsley, *Petroselinum hortense* var. *foliosum*) is a plant that belongs to the Apiaceae family. It has no special requirements for soil chemical composition so that it can grow well on all soil types. However, it responds very well to moisture during the germination phase, with a very good response to fertilization, particularly nitrogen. The present study aimed to evaluate the level of significance in effects of soil mineral (NPK) fertilization solely and combined with foliar use of a brown seaweed *Ascophyllum nodosum* extract (ANE) in 2, 4 and 6 mL per liter, on the yield, morphological traits (stem length, number of leaves per stem, root length) and physiological parameters (nitrogen balance index, chlorophyll, flavonoids, anthocyanins) of parsley plants, comparing the treatments and in relation to the control. The trial was conducted in greenhouse conditions in pots from the first week of April to the fourth week of June 2025, using Eutric Cambisol soil, characterized as a clay loam with a very acidic reaction. Physiological parameters were measured using a Dualex leaf clip sensor. The obtained data revealed significant effects ($p < 0.05$) of all applied treatments on the physiological parameters of parsley, except for anthocyanin content, for which treatments had no significant effect ($p > 0.05$). All morphological traits did not differ significantly between treatments ($p > 0.05$), but showed values noticeably higher than those of the control. Statistically significant differences ($p < 0.05$) in the yield of parsley were most pronounced in the NPK + ANE (4 mL) treatment in relation to other treatments and the control. In conclusion, the best results were obtained with NPK + ANE (4 mL) across all tested parameters, suggesting it as the optimal fertilization treatment for flat-leaf parsley cultivation based on this study.

### *7.10. Evaluation of Peroxidase Activity and Proline Content as Indicators of a Particular Light Duration Tolerance Mechanism in Ginger Plant (Zingiber officinale R.)*

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Introduction: Ginger (*Zingiber officinale Roscoe*) is a medicinal crop indigenous to China. As for conservation, propagation, and enhanced crop growth rate under a protected environment, understanding the mechanisms of abiotic stress tolerance plays an integral role in enhancing medicinal properties in the herb's subsequent growth stages.

Methods: The effects of three different light durations (15, 30, and 45 days) represented by 50% shade levels in 3 times harvesting (every 15, 30 and 45 days shading in each harvesting time durations combined with three water levels in greenhouse condition on plant growth parameters, including the level of peroxidase activity and proline content in the root and shoot of 2 month-old seedling plants, were investigated. The two-factor experiment was laid out in a split-plot design based on RCBD with three replications. The proline concentration was measured spectrophotometrically employing the method of Bates et al. (1973). Peroxidase (POX) activity was measured according to the method of Herzog and Fahimi (1973).

Results: Both peroxidase activity and proline content were increased in the inappropriate light duration condition. Peroxidase (POX) in roots increased sharply, reaching 68.3% and 50% in 15 and full-time shading days, respectively, at each harvest after months of treatment, compared to the 30-day shaded condition. Meanwhile, lower proline levels were recorded after 30 days of shading in each harvest; while the height ratio in root and shoot (58% and 40%, respectively) was higher after 15 days of shading compared to 30 days of shading.

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Conclusions: In the case of POX and proline, there were increasing trends in terms of shortened shading duration compared with the other two shade durations. Peroxidase plays an essential role in plant growth and development. Proline content of under- and above-ground plant organs augmented upon exposure to the shortest and longest shade durations.

### *7.11. Hormonal Modulation of Growth and Metabolite Dynamics in Saffron (Crocus sativus) Under Innovative Cultivation System*

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Saffron (*Crocus sativus* L.) production is limited by land availability and climatic conditions, highlighting the need for innovative cultivation systems. The effects of three plant growth regulators, i.e., kinetin (1 ppm), gibberellic acid ($GA_3$, 50 ppm), and abscisic acid (ABA, 1.5 ppm), were assessed in controlled cultivation systems over two seasons (2022–2023) at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, India, with field-grown controls from Pampore (Kashmir) and Kishtwar. Key parameters were grouped into vegetative growth (leaf number and plant height), floral yield (flower fresh weight and dry stigma yield per 100 corms), and quality indices. Secondary metabolites were evaluated both qualitatively and quantitatively: crocin and picrocrocin contents were determined using UV–visible spectrophotometry at their respective absorption maxima, while antioxidant activity was estimated by the DPPH radical scavenging assay ($IC_{50}$ values). Kinetin performed comparably to or better than field controls in leaf production (21.0 vs. 22.2–23.0), stigma yield (7.65 g vs. 6.63–6.67 g), and crocin content (17.4% vs. 14.7–16.5%), while $GA_3$ enhanced shoot length (23.7 cm vs. 24.9–27.1 cm) and flower weight (404.6 mg vs. 391.7–427.5 mg). ABA was ineffective or inhibitory for most parameters. Principal component analysis grouped kinetin and $GA_3$ treatments with high-performing field controls, confirming their effectiveness in promoting both growth and quality. These results indicate that kinetin (1 ppm) enhances saffron quality through improved metabolite accumulation, while $GA_3$ (50 ppm) optimizes growth and yield. This study demonstrates that hormonal modulation in innovative cultivation systems can enable high-value, year-round saffron production in non-traditional areas, contributing to climate-resilient crop production.

### *7.12. Improving the Nutritional Value and Growth of Eschscholzia californica Cham. Through Iodine Biofortification*

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*Eschscholzia californica Cham.* (California poppy, *Papaveraceae*) is a plant native to North America. Although it is primarily an ornamental plant, it also has potential applications in herbal medicine. Extracts of *E. californica* are used for its sedative and sleep-inducing properties. One way to increase the pro-health and nutritional value of plants, as well as accelerating their growth, is enriched fertilization. This practice is known as biofortification. Of particular interest is the iodine enrichment of crops, which serves to introduce this element into the human diet. It is an alternative to the iodisation of table salt, the excessive use of which poses risks to human health. *E. californica* plants were grown hydroponically

in a greenhouse. The plants were watered with a standard nutrient solution enriched with the following: (1) potassium iodide (KI), (2) 5-iodosalicylic acid (5I-SA), and (3) 3,5-diiodosalicylic acid (3,5-diISA). The control group was watered with a nutrient solution that did not contain iodine compounds. The concentrations of vitamins and sugars in plants from the experimental groups were compared to those in the control one. Cultivation with KI and 5I-SA resulted in higher mean fresh shoot weights. Plants fertilized with KI and 3,5-diISA showed an increase in the mean total sugar concentration. Importantly, increases in the mean concentrations of vitamins B2 and B7 were noted in the KI group, whereas an increase in vitamin B1 was observed in the 5I-SA and 3,5-diISA combinations. These results demonstrate that iodine compounds can have a beneficial effect on nutritional and health-promoting properties of *E. californica* plants as well as on accelerating its growth.

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### *7.13. In Silico Evolutionary Analysis of Plant Alpha Amylase from Monocot to Dicot: A Plausible Explanation for Stability and Diversity*

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Alpha-amylase is an essential enzyme in plants that hydrolyses starch into sugars that the growing seedling uses for energy, especially during seed germination. Alpha-amylase also contributes to starch synthesis during seed maturation and in other plant tissues for energy storage and utilisation. In this study, an in silico initiative has been undertaken to characterize the sequences and structures of alpha-amylase in monocot (*Oryza sativa* subsp. *japonica*) and dicot (*Arabidopsis thaliana*) plants. An unavailability structure of dicot alpha-amylase was created through Python homology modelling, along with the structural validations. The results revealed that the sequences of monocot were highly occupied by charged polar and nonpolar amino acids, whereas the dicots mostly increased their uncharged polar amino acids. The alpha-amylase of dicot was more hydrophilic than that of monocot. The instability index and aliphatic index indicate that the alpha-amylase of monocots was more thermostable. The secondary structure assessment of both proteins showed some significant structural differences. The higher formations of different intra-protein interactions significantly increased the stability of monocot alpha-amylase. The molecular dynamics simulations with a run time of 100 ns comparatively disclosed the higher stability, fluctuations, rigidity, and compactness of monocot alpha-amylase. This study will help in understanding how evolution had a marked impact on monocots to dicots. It is also helpful for protein engineering to enzyme synthesis.

### *7.14. Iodine Biofortification of Eschscholzia californica Cham. and Its Effect on the Mineral Composition of Plants*

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One of the greatest challenges facing global health policy is the burden of chronic non-communicable diseases caused by nutrient deficiencies. Plants' biofortification has

been proposed as a method of introducing essential nutrients into the human diet. An increased level of one element can affect the content of others in the plant and, thus, the health-promoting properties of plant materials.

The study aimed to determine the effect of biofortification with mineral (KI) and organic forms of iodine: 5-iodosalicylic acid (5-ISA) and 3,5-diiodosalicylic acid (3,5-diISA) on the mineral composition of Eschscholzia californica plants grown in a hydroponic system. The following combinations were tested: (1) Control; (2) KI; (3) 5-ISA; (4) 3,5-diISA.

To determine the content of macro- and microelements (P, K, Ca, Mg, S, Al, Ba, B, Be, Bi, Co, Cr, Cu, Fe, Li, Mn, Mo, Na, Ni, Zn) using an ICP-OES spectrometer, plant samples were digested in $HNO_3$.

Control plants had the highest macronutrient accumulation. Particularly significant decreases were observed for K and Mg. The use of 5-ISA and 3,5-diISA resulted in a greater decrease in macronutrient content than KI, especially for P, K, and Mg. The concentrations of Be, Cr, and Fe did not differ significantly from those of the control group. The lowest concentrations of B, Ba, Li, Na, Al, Bi, Co, and Cu were observed after the use of mineral iodine. The content of most micronutrients was higher after the use of 5-ISA than after the use of 3,5-diISA. For Ni, all enrichment treatments increased the concentration of this element in the series 3,5-diISA > 5-ISA > KI, whereas KI and 5-ISA increased Zn concentration. The use of 5-ISA increased Al levels in the plant compared to the control group.

### *7.15. Iodine Biofortification of Eschscholzia californica Cham. Plants with the Use of Various Iodine Compounds and Their Effect on the Biosynthesis of Selected Alkaloids*

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The biofortification of medicinal plants has been proposed as a novel approach to introduce essential mineral nutrients into the human diet. Yet, its increased levels may affect the synthesis of secondary metabolites and the health-promoting properties of these plants. California poppy (*Eschscholzia californica Cham.*) has been widely used in traditional medicine for analgesic and sedative purposes due to the presence of alkaloids such as californidine, protopine, allocryptopine, and sanguinarine. The study evaluated the effects of inorganic and organic iodine compounds on the growth and accumulation of iodine and selected alkaloids in California poppy grown in a hydroponic system. ICP-MS was used to analyse the total iodine content in plants after TMAH extraction. The levels of selected alkaloids in leaves were determined by the LC-MS/MS technique after ultrasound-assisted sample extraction in 50 mM HCl in MeOH. Iodine content in plants increased in all tested combinations, with the highest levels noted for 5-iodosalicylic acid (5-ISA). An increase in whole-plant biomass after the application of potassium iodide (KI) and 5-ISA suggests a possible growth-promoting effect on *Eschscholzia* plants. Leaf-level sanguinarine increased across all iodine combinations, with the highest level observed with 5-ISA. Berberine content increased only after 5-ISA application, while protopine content increased after KI treatment. The leaf levels of allocryptopine, californidine, chelerythrine, coptisine, corydaline, dehydrocorydaline, and reticuline tended to be higher in the KI combination, but the observed changes were not statistically significant. The observed modifications in the alkaloid profile suggest that iodine is involved in regulating its biosynthesis. Further

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studies are required to monitor changes in root alkaloid levels to fully evaluate the effect of iodine on the production and distribution of these metabolites in Eschscholzia plants.

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### *7.16. Phytochemical Profiling of Baby Leafy Greens from Different Swiss chard (Beta vulgaris L.) Varieties Cultivated Under Indoor Conditions*

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As consumer interest in functional foods increases, so does the demand for nutrient-dense and visually appealing vegetables. Swiss chard (*Beta vulgaris* subsp. *cicla*), recognized for its colorful petioles and nutritional richness, stands as a promising candidate. This study aimed to evaluate the phytochemical composition of baby leafy greens from four Swiss chard varieties (white, yellow, pink, and orange) cultivated using a soilless system under semi-controlled indoor conditions. Plants were grown in a walk-in growth chamber equipped with LED lighting. Seeds were sown in vermiculite-filled trays, kept in darkness for four days to induce germination, and irrigated with a 3:1:6 NPK nutrient solution. Seven days after sowing, uniform and healthy seedlings from each variety were transplanted into individual rockwool cubes and cultivated under a 14/10 h light/dark photoperiod, with temperatures ranging from 20 to 25 °C and relative humidity around 60%. After 27 days of growth post-transplantation, baby leafy greens were harvested for phytochemical analysis using high-performance liquid chromatography with diode array detection and electrospray ionization mass spectrometry. In total, up to 11 phenolic compounds, 4 betalains, and 10 saponins were identified among the different varieties. Pink Swiss chard baby greens exhibited the highest phenolic compound content (12.15 mg/g dw). The white variety was the only one in which betalains were detected (1.99 mg/g dw), comprising one betacyanin and three betaxanthins. The yellow variety presented the highest saponin concentrations (911.1 μg/g dw). These findings reveal distinct phytochemical profiles among Swiss chard baby leaf varieties, emphasizing their chemical diversity and supporting their potential as functional foods rich in bioactive compounds.

### *7.17. Reactive Oxygen Species at the Crossroads of Stress and Sustainability in Plants*

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Introduction: Climate change is intensifying abiotic and biotic stresses such as drought, salinity, heat waves, and emerging pathogens, threatening global food security. Reactive oxygen species (ROS) have emerged as central regulators of plant adaptation to these stresses. While uncontrolled ROS accumulation induces oxidative damage, controlled ROS signaling modulates growth, defense, and survival under adverse conditions. Deciphering ROS homeostasis is, therefore, crucial for developing climate-smart crop improvement strategies.

Methods: A comprehensive synthesis of experimental evidence was undertaken, covering ROS generation sites (chloroplasts, mitochondria, peroxisomes, and plasma membrane NADPH oxidases), their quantification under stress, and their interplay with enzymatic (SOD, CAT, APX, and GPX) and non-enzymatic (ascorbate, glutathione, and phenolics)

antioxidants. Recent omics-based studies, mutant analyses, and transgenic approaches were reviewed to highlight advances in understanding ROS-mediated stress regulation.

Results: Evidence indicates that moderate ROS bursts act as critical secondary messengers, activating MAPK cascades, transcription factors (NAC, WRKY, and MYB), and stress-responsive genes. ROS interact synergistically with phytohormones (ABA, ethylene, and salicylic acid) and redox regulators to orchestrate adaptive responses, including stomatal regulation, osmolyte accumulation, and improved water-use efficiency. Climate-resilient genotypes and genetically engineered lines with enhanced antioxidant capacity show superior tolerance to combined stresses, validating ROS management as a breeding target.

Conclusions: ROS act as pivotal modulators of plant stress responses, mediating a fine balance between oxidative damage and adaptive signaling. Precise regulation of ROS production and scavenging is essential for sustaining cellular homeostasis under drought, salinity, and temperature extremes. Advances in CRISPR/Cas-mediated editing of ROS-related genes, overexpression of antioxidant enzymes (e.g., SOD, APX, and CAT), and application of redox-active biostimulants have demonstrated significant improvements in plant resilience and yield stability under combined stresses. Future climate-smart breeding programs should integrate ROS-signaling markers, antioxidant enzyme profiles, and redox transcriptomic data to accelerate the development of stress-tolerant cultivars tailored for variable environments.

### *7.18. The Content of Flavonoids in Hemp Seedlings*

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Hemp (*Cannabis sativa* L.) seedlings do not contain cannabinoids, which are the species' typical active compounds, but synthesize flavonoids, including the anti-inflammatory compounds cannflavin A and B. The aim of this study was to analyse the content of flavonoids in different commercial hemp cultivars, Fibrol, Finola, Epsilon 68, Secuieni Jubileum, Fedora, Henola, Uso 31, Earlina 8FC, Kompoliti, and Lipko, using the HPLC-MS/MS method. The plants were grown in pots at temperature of 25 °C (±2 °C) under a 16-h photoperiod with 80–100 μmol $m^{-2}$ $s^{-1}$ fluorescent daylight. Fifteen days after germination, the aerial parts were collected, weighed, and dried. The catechin, vitexin, cannflavins (A and B), quercetin, isovitexin, apigenin, orientin, naringenin, luteolin, and myricetin content was determined in the isopropanol extracts. The chromatographic analysis was performed using a Shimadzu 8040 LC-MS chromatograph and Zorbax SB-C18 column (3.0 mm × 150 mm 3.5 μm). Mobile phase A consisted of acetonitrile and formic acid solution in water 0.1% (*v*/*v*), both HPLC grade. Mobile phase B consisted of water and formic acid at a concentration of 0.1% (*v*/*v*). The analysis was performed in negative ion charge, using multiple reaction monitoring (MRM) for qualitative and quantitative analyses. The analysis was performed in triplicate (3 n). Statistical significance was determined applying Duncan's post hoc (*p* value of 0.05). Significant variation in flavonoid content was found. The Kompolti cultivar had the most diverse flavonoid profile (cannflavin A and B, isovitexin, vitexin, and apigenin). The highest concentrations of cannflavin A were recorded for the Epsilon 68 (18.3 ± 1.1 μg/g) and Fibrol (18.2 ± 4.3 μg/g) cultivars. The content of cannflavin B was much lower and ranged from 1.2 to 2.5 μg/g. Genotypes such as Kompolti, Epsilon 68, and Fibrol are potential sources of valuable flavonoids and can be used as parental material in further breeding work.

### *7.19. The Effect of the Moringa oleifera Agrisilviculture System and Fertilizer Application on Vegetable Productivity and Soil Fertility*

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Rising food demand alongside shrinking arable land and resources necessitates more efficient and resilient cultivation methods. In agrisilviculture, trees are grown with crops, promoting ecological and economic interactions. Moringa oleifera Lam. is grown for its nutritional and medicinal values to both humans and animals. Intercropping *M. oleifera* with vegetables can reduce pest pressure, lowering the need for chemical pesticides and supporting ecological balance. The aim of the study was to evaluate the performance of vegetable crops in an agrisilviculture system and fertilizer application. The experiment consists of three treatments (sole vegetable, *M. oleifera* + vegetable, and vegetable with fertilizer) laid out in a Randomized complete block design with five replications. Parameters collected include plant height, leaf area, stem diameter, chlorophyll content, number of branches, plant vigour, Radiation Use Efficiency (RUE) and fresh biomass. All studied parameters were found to be statistically significant ($p < 0.05$). For spinach, chlorophyll content, plant vigour, plant height, biomass and radiation use efficiency were positively influenced by the fertilizer application as they obtained greater values of 31.02 µ/mol, 56.08%, 25.4 $cm^2$, 340.47 g and 3.072 g/MJ, respectively. On the other hand, for butternut, leaf area, biomass, stem diameter, number of branches and radiation use efficiency were observed to be high in fertilized plots with values of 73.54 $cm^2$, 239.3 g, 51.726 mm, 5.2 and 2.5603 g/MJ, respectively. *M. oleifera*-based agrisilviculture improved soil fertility, with vegetables under the moringa canopy showing the highest nutrient concentrations (B, Ca, Cu, Fe, K, Mg, Mn, $NH_4$, P, Zn). Soil moisture was also the highest in agrisilvicultural plots, reaching 15.25% in butternut and 15.27% in spinach. Thus, tree-crop interaction enhances crop resilience by providing shade, improving soil fertility, and conserving water, making it a sustainable option for small-scale farmers.

## 8. Session 7: Precision and Digital Agriculture

### *8.1. Pocket Agronomist: Smart Card-Based Precision Farming System*

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Introduction: Smallholder farmers face challenges in adopting precision agriculture due to high costs, lack of digital literacy, and limited access to advanced technologies. Existing solutions such as drones, IoT devices, and satellite imaging are effective but remain impractical in resource-limited settings. This project introduces a low-cost, farmer-friendly smart card system that delivers personalized precision agronomy advice through shared community kiosks.

Methodology: (1) Each farmer receives a Smart Agronomy Card, storing soil, land, and crop data. (2) Farmers insert the card into a solar-powered kiosk/device. (3) The device integrates the following: (4) soil data, (5) satellite weather information, and (6) AI crop growth models. (7) Weekly recommendations are delivered via text, audio (local language), or printed slips. (8) The data are then aggregated to build a digital agronomy map for community-level insights.

Tools: Smart Agronomy Cards, solar-powered shared kiosks/devices, AI-based advisory software, cloud database for soil and crop records, and weather data integration APIs (Application Programming Interfaces) are all utilized in this study.

Budget (Approximately): (1) Smart card per farmer: $2–3. (2) Shared solar-powered kiosk: $250–300 per village. (3) Software and AI integration: $2000–3000 (one-time purchase). (4) Maintenance and training: minimal (community-managed).

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Benefit for Farmers: Personalized advice without the need for smartphones or internet, reduced fertilizer and water costs (20–30% savings), improved crop yield, reduced pest/disease losses, accessible in their local languages (which leads to trust and easy adoption), and the community model reduces individual cost burden. One kiosk can serve 50–100 hectares of farmland. For example, a village with 200 smallholder farmers (each with 0.2–0.5 ha) can all use one kiosk.

Problems: (A) Farmer literacy and digital skills. (B) Limited access to kiosks. (C) Data accuracy and reliability. (D) Infrastructure challenges. (E) Farmer trust and adoption. (F) Maintenance and technical support. (G) Scalability.

Time: Prototype development: 6–8 months. Field testing: 1 cropping season (4–6 months). Full deployment in a region: 1–2 years.

Results: (1) Increased input efficiency and crop yield. (2) Lower production costs for smallholder farmers. (3) Creation of a digital agronomy network at grassroots level. (4) Scalable model for national and international adoption.

### *8.2. A Transformer-CNN Hybrid Autoencoder for Semi-Supervised Plant Disease Detection*

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Plant diseases represent a persistent challenge to global food security, causing an estimated 16% annual loss in crop yield and quality. As global food demand is projected to rise by 70% by 2050, developing reliable and scalable detection systems has become increasingly critical. Traditional disease identification methods based on manual inspection are labor-intensive, subjective, and impractical for large-scale agricultural monitoring. Early automated systems that relied on handcrafted features and classical classifiers achieved only limited success because they were unable to adapt to complex, variable field environments. Although deep learning, particularly convolutional neural networks (CNNs), has significantly improved detection performance by learning discriminative features directly from images, these models depend heavily on large, annotated datasets collected under controlled conditions—restricting their generalization to real-world settings. Furthermore, the scarcity of labeled data for rare or emerging diseases limits the scalability of supervised approaches.

Anomaly detection offers a promising solution by training models solely on healthy plant samples and identifying diseases as deviations from normal patterns. However, CNN-based autoencoders used for this task often struggle to capture the long-range dependencies required to recognize subtle or spatially distributed disease symptoms. To address this limitation, we propose a semi-supervised anomaly detection framework built upon a hybrid autoencoder with a Vision Transformer (ViT) encoder backbone. By leveraging the ViT's self-attention mechanism, our model learns rich global representations of healthy foliage and detects anomalies through reconstruction errors. Experimental evaluations on multiple plant disease datasets demonstrate that our framework achieves an F1-score of 80%, representing a 7% improvement over the state-of-the-art anomaly detection methods. These results highlight the framework's potential for robust, scalable, and early detection of plant diseases across diverse agricultural environments.

### *8.3. AI Driven Paddy (Oryza sativa) Yield Forecasting Using Open Satellite Data, Weather APIs and Historical Data for Sri Lankan Agro Zones*

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Paddy, *Oryza sativa*, is a widely consumed staple food worldwide, feeding over 50% of the global population and Sri Lanka has been producing paddy for centuries. Because of the rapid increase in population, forecasting paddy yield has become essential. This research aims to predict Sri Lankan district wise paddy yield with openly available data: CHIRPS 2.0, NASA POWER APIs, Sri Lankan Rice Research and Development Institute's PH and Salinity Maps, Paddy Statistics from the Department of Census and Statistics—Sri Lanka for local agro zones using an XGB regressor-based stacked ensemble learning framework. For the three major agro-climatic zones and 25 administrative districts, data from 2004 to 2024 were collected for the two harvesting seasons "Yala" and "Maha", with the specific target being the total paddy production per district (in metric tons) with the range (185, 530,356) MT. lowest recorded for "Mannar" district in 2006 "Yala" season and highest "Anuradhapura" district in 2019–2020 "Maha" season. The crop calendar template provided by the Department of Agriculture—Sri Lanka was used to simulate end-to-end crop harvesting patterns for the selected time span as the foundation for dataset construction. By combining harvesting simulations with climate variables, soil properties and historical yield records, we created 12 heterogeneous datasets. These datasets were used to train 12 base models, whose out-of-fold predictions were subsequently integrated into two intermediate meta models. Finally, the outputs of the intermediate meta models were stacked for the final meta model to evaluate predictive performance, showcasing RMSE of 3535 MT and $R^2$ of 0.9986 on the validation set with a NRMSE of 0.76%, indicating that the model can predict district level seasonal paddy yield with high accuracy. These results highlight the potential of integrating openly available data to support reliable, data driven decision making for sustainable paddy production in Sri Lanka.

### *8.4. AI-Powered Robotic System for Precision Irrigation and Pesticide Application in Sustainable Tomato*

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A robotic system that efficiently uses water and pesticides for tomato cultivation is not widely available in sustainable agriculture practice. This study proposes a design for a new AI-powered robot that automates pesticide and irrigation applications on small- to medium-sized tomato farms. The system operates based on water and pesticide requirements, turning on weekly to follow a predefined zigzag path in the field to reach every plant. The robot uses ultrasonic sensors and small reflective markers on the plant support sticks to accurately identify each tomato plant. The system then takes a picture of the plant and runs the data through a pretrained YOLOv8-based disease classifier, which helps find plants that need treatment. The robot skips plants that are healthy, which saves pesticides, resources, and the environment. The robot sprays pesticides on the affected area and, simultaneously, applies irrigation water. The irrigation water demand is calculated based on crop water needs and the amount of water that evaporates from the air, ensuring efficient water use. The system hasn't been tested in the field yet, but an early estimate of the development cost is USD 300, suggesting a low initial price for small- to medium-sized farms. The combination of plant-level monitoring, selective treatment, and combined irrigation will help lower input costs, have less impact on the environment, and enable farmers to use more sustainable methods.

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### *8.5. Early Detection and Prediction of Rice Crop Diseases Using Deep Learning and Multi-Sensor Satellite Imagery in Rosso, Mauritania*

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Rice cultivation in Rosso, Mauritania, a critical agricultural hub along the Senegal River, is threatened by diseases such as rice blast, bacterial leaf blight, and sheath blight, exacerbated by climate variability and limited ground monitoring. This study develops a novel deep learning (DL) framework for early disease detection and prediction using multi-source satellite imagery to enhance crop health management in resource-constrained regions. Using Google Earth Engine, we analyzed Sentinel-1 (SAR), Sentinel-2 (10 m resolution), and Landsat 8/9 (30 m) imagery from January to August 2025, identifying May–June as optimal for vegetation indices due to peak rice growth. Thirteen indices (NDVI, SAVI, NDWI, GNDVI, NDRE, MCARI, EVI, VARI, ARVI, MSI, NBR, CIgreen, CIrededge) were computed, and TIFF images were exported and labeled in QGIS for rice vs. non-rice classification. DeepLabV3 and U-Net++ models achieved 95% accuracy in segmenting rice fields. Pre-trained ResNet and MobileNet models classified disease types using indices and ~300 geo-referenced samples from public datasets (e.g., PlantVillage). An LSTM model forecasted disease risk with >85% accuracy. Strong correlations (Pearson $r > 0.78$) between DL predictions and indices, enhanced by SAR's rainy-season capability, enabled precise disease hotspot mapping. This proof-of-concept integrates open-source DL and satellite data, offering scalable solutions for West African rice farming. Future work should focus on field validation and the development of farmer-accessible mobile tools.

### *8.6. Enhancing Water Efficiency and Sustainability in Morocco's Citrus Orchards Using Soil Moisture Sensors and Plastic Mulch*

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Water scarcity represents a significant challenge to citrus production in Morocco, a situation worsened by climate change. To secure the long-term sustainability and productivity of this essential agricultural sector, it is vital to implement innovative and integrated water management strategies. This study focuses on a six-year-old citrus orchard situated in a Mediterranean climate zone (Kenitra, Morocco). The orchard was equipped with LoRaWAN-enabled soil moisture sensors (TerraPrima Ladybird) and covered with geotextile black plastic mulch. The sensors, placed at depths of 20, 40, and 60 cm within the root zone, continuously monitored volumetric water content under a drip irrigation system. The data was incorporated into a daily water balance model to optimize irrigation scheduling. Concurrently, the use of plastic mulch decreased surface evaporation while improving soil moisture retention. The integrated strategy of using sensor-based irrigation management alongside soil mulching increased soil moisture levels by up to 30%, translating into an additional storage capacity of 20 to 180 $m^3$/ha of water within the root zone. As a result, the mulch effectively reduced evaporation rates, allowing longer intervals between irrigation cycles as determined by the soil moisture sensors. This strategy not only minimized water and energy consumption but also significantly boosted fruit yields by up to 57%, along with notable improvements in fruit size and overall orchard health and efficiency. This later increased by 25%. The integration of soil moisture sensors, plastic mulch, and a Water-

Energy-Food-Ecosystem nexus approach represents a promising strategy for enhancing water efficiency and overall sustainability of citrus orchards. This comprehensive approach addressed the pressing challenge of water scarcity while also promoting the long-term environmental and economic viability of the citrus industry amid evolving climate and trade dynamics.

### *8.7. Monitoring Drought Impacts on Rainfed Olive Orchards in the Iberian Peninsula Using Satellite-Derived Vegetation Indices*

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Olive growing plays an important socioeconomic role in Mediterranean agriculture, particularly in the Iberian Peninsula (IP), where rainfed systems are increasingly vulnerable to drought under climate change. This study investigates the spatial and temporal responses of olive orchards to drought in two traditional production regions: the Trás-os-Montes (TM) agrarian region in Portugal and the Badajoz (BA) province in Spain. Satellite-based multispectral data were used to compute vegetation indices from the Harmonized Landsat Sentinel-2 dataset (HLSL30), specifically the Soil-Adjusted Vegetation Index (SAVI) and the Normalized Difference Moisture Index (NDMI), which were analysed over the 2015–2023 period. Drought intensity was assessed using the Mediterranean Palmer Drought Severity Index (MedPDSI), specifically adapted for olive ecosystems. Correlation and lag analyses were performed to explore drought–vegetation relationships and temporal responses.

Results revealed regional differences, with the BA region experiencing more intense and prolonged drought episodes, stronger negative correlations between MedPDSI and vegetation indices ($r = -0.72$, $p < 0.05$), and a lagged vegetation response of approximately 2 months. On the other hand, the TM region showed milder drought conditions and a more stable vegetation response, suggesting slightly higher resilience. Both SAVI and NDMI detected vegetation stress during the severe drought years of 2017 and 2022, confirming their sensitivity to variations in soil moisture and canopy greenness.

This approach demonstrates the potential of combining satellite-based vegetation indices with drought indicators to monitor stress in perennial crops. Although spatial resolution and cloud cover may introduce some uncertainty for constant real-time monitoring, the results provide valuable perspectives for early drought detection and adaptive water management. The proposed framework supports the development of sustainable strategies to improve the resilience and productivity of olive orchards in Mediterranean environments.

### *8.8. Mushroom Kothi: An IoT-Enabled Climate Control Chamber for Precision Oyster Mushroom Cultivation*

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Mushroom production in India is typically restricted to cooler months due to the difficulty of maintaining stable environmental conditions in open or low-cost setups. We developed and field-tested Mushroom Kothi, an IoT-enabled chamber designed to deliver real-time climate control and monitoring for smallholder mushroom farmers. Across three agro-climatic sites and two seasons, replicated trials compared Oyster mushroom (*Pleurotus ostreatus*) production in Mushroom Kothi versus conventional farmer practice. Continuous sensor logging of temperature, relative humidity, $CO_2$, light, and substrate moisture enabled automated misting and ventilation adjustments through a cloud-connected ESP32-based system. Preliminary results indicate yield gains of 15–25%, reduction in water use by 30–35%, and improved uniformity of fruit body size. Time-to-harvest was shortened by 1–3 days, while the productive window extended beyond conventional seasonal limits. Statistical analyses (two-way ANOVA, Tukey HSD) confirmed significant treatment effects ($p < 0.05$) across sites. In addition to production benefits, the system achieved high reliability with >95% data transmission success and reduced manual interventions, demonstrating ease of adoption in low-resource settings. By combining continuous digital monitoring with automated environmental control, Mushroom Kothi provides an affordable precision agriculture tool that enhances productivity, reduces input waste, and improves the resilience of mushroom farming. Future work will integrate predictive analytics to further support farmer decision-making.

### *8.9. Plant Disease Detection Using Transformer-Based NLP Model from Sensor-Generated Descriptions*

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Abstract: Introduction: Early detection of plant stress is critical for sustainable agriculture. Conventional techniques, including threshold-based sensors and image recognition, face limitations such as environmental interference, high costs, and dependency on visual data. To address these challenges, we propose a novel sensor-to-text approach that leverages natural language processing (NLP) for plant health monitoring. Methods: A dataset containing soil properties, environmental variables, and nutrient concentrations was prepared with labels (Healthy, Moderate Stress, High Stress). A rule-based algorithm generated descriptive symptom statements from sensor readings (e.g., "Soil is too dry, risk of dehydration"). These narratives were processed using two pipelines: (i) TF-IDF with Random Forest and Support Vector Machine classifiers, and (ii) a transformer-based DistilBERT model fine-tuned for multi-class classification. Results: Baseline models with TF-IDF and traditional classifiers achieved 85–88% accuracy, with an average F1-score of 0.86. In comparison, the DistilBERT model significantly outperformed them, reaching 95% accuracy, with precision 0.94, recall 0.95, and F1-score 0.94. The transformer approach also showed particular strength in distinguishing subtle differences between moderate and high stress conditions. Conclusions: This study presents a novel pipeline that converts agricultural sensor data into natural language descriptions for classification using transformer-based NLP. The results highlight the potential of this method to improve plant disease detection, provide interpretable feedback, and support scalable AI-driven advisory systems for farmers.

### *8.10. Research Progress and Prospects of Fruit Recognition and Positioning Technology Based on an Unmanned Aerial Vehicle Platform*

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Fruit identification and location technology plays a significant role in modern agriculture, especially in smart agriculture and automated picking systems. Due to factors such as irregular fruit distribution, branch and leaf obstruction, and environmental light, traditional manual or ground positioning methods face many challenges in large orchards. Through current research on the phased achievements of fruit recognition and positioning based on unmanned aerial vehicles, the key technologies of fruit recognition and positioning are deeply analyzed.

Fruit identification and location technology is a key link in smart orchards. The positioning technology based on unmanned aerial vehicles (UAVs) significantly improves the positioning accuracy in complex environments through high flexibility and multi-sensor fusion. Research shows that machine vision and multi-sensor fusion models have made progress in the positioning of fruits such as citrus and strawberries, thanks to the three-dimensional spatial flexibility of multi-rotor platforms, the efficiency of cluster operations, and their adaptability to orchards. However, this technology still faces many technical bottlenecks in practical applications: the complex orchard environment has a significant impact on the flight stability of unmanned aerial vehicles and the accuracy of sensors, and the humid climate also shortens the service life of the equipment. The positioning accuracy and real-time performance of existing algorithms are difficult to balance in scenarios with severe fruit occlusion and dense overlap, and there is a contradiction between lightweight models and high-precision requirements. Meanwhile, the equipment cost is high, the cluster control and data fusion technology is still not mature, and the standardization degree of orchard planting is insufficient. Enhancing environmental adaptability through multi-sensor fusion and intelligent algorithm optimization, developing lightweight and modular recognition models, ensuring positioning efficiency, and promoting the standardization of orchard planting will be the key directions for breakthroughs in fruit positioning technology based on unmanned aerial vehicle (UAV) platforms.

### *8.11. Spatio-Temporal Analysis of Agricultural Sugarcane Areas in La Granja, La Carlota, Negros Occidental, Philippines During Different Phenological Stages*

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The study investigated the spatiotemporal variations of agricultural sugarcane areas in La Granja, La Carlota, Negros Occidental, from 2020 to 2024. Data on agricultural areas were delineated from Sentinel-2 satellite imagery and were cloud-masked. NDVI was computed and analyzed across sugarcane's five (5) phenological stages: germination, tillering, stalk elongation, growth, and maturation, following the Philippine cropping calendar. Variations in NDVI have been observed across years during different phenological stages, with values ranging from −0.06 to 0.91 during the germination stage, −0.08 to 0.92 during the tillering stage, −0.08 to 0.97 during the stalk elongation stage, −0.1 to 0.99 during the grand growth stage, and −0.06 to 0.91 during the maturation stage. NDVI values were consistently

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high during stalk elongation and grain growth, while low values were evident during the germination and tillering periods.

Differences in values are evident across agricultural areas at each phenological stage. Area A generally exhibited higher NDVI during germination and grand growth. Area D showed higher NDVI during tillering and elongation, reflecting optimal canopy development, while Area B displayed persistently lower NDVI throughout all stages, suggesting delayed or stressed growth. Area C often shifted earlier to lower NDVI values during the maturation stage, suggesting early senescence or harvest.

Cloud cover affected the amount of data available for each timeframe. In addition, some variabilities in the time series of NDVI calculation across different phenological stages may be attributed to varied planting dates among farmers, because sugarcane establishment does not occur uniformly across agricultural areas; some farms may already be advancing to the next stage, while others remain in earlier stages, resulting in overlapping NDVI signatures. This underscores the importance of integrating cropping calendar variations into remote sensing assessments to better align spectral observations with ground conditions.

### *8.12. Spatiotemporal Dynamics of Ecological Health in Punjab (2001–2023): Integrated Remote Sensing Approach for Sustainable Paddy Cultivation*

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Monitoring ecological health at regional scales is crucial for guiding sustainable agricultural practices under increasing climatic and anthropogenic pressures. This study employs the Remote Sensing Ecological Index (RSEI), integrating NDVI, Land Surface Temperature (LST), Normalized Difference Built-up and Soil Index (NDBSI), and wetness, to assess ecological condition during the Kharif season from 2001 to 2023 using MODIS imagery across Punjab. Each indicator was normalized (0–1) and processed through Principal Component Analysis (PCA), with PCA1 utilized to construct the composite RSEI. Spatiotemporal analyses reveal a predominance of moderate ecological quality (37–45%), while the "Good" category declined from 19.11% in 2001 to 14.40% in 2023, reflecting ecological stagnation under urbanization and thermal stress. Vegetation (NDVI) contributed most strongly to RSEI (0.72–0.81), followed by wetness (0.12–0.18), whereas NDBSI and LST, though lower in weight, strongly influenced localized ecological degradation. Temporal fluctuations highlight stress years (2020 with elevated LST and reduced NDVI) and partial recovery in 2023. Rainfall analysis underscores the dominance of monsoon variability, with July–September contributing >70% of annual totals, directly shaping vegetation health and wetness. Correlation analysis demonstrates that RSEI negatively associates with NDVI (−0.74), wetness (−0.84), and paddy yield (−0.23), while positively linking with NDBSI (0.715), confirming the ecological and agronomic costs of built-up expansion and climate stress. These findings underscore the utility of RSEI as a robust, spatially explicit indicator of ecosystem quality, offering actionable insights for precision agriculture and sustainable land-use planning in water-intensive crop regions.

### *8.13. Sustainable Mango Production Through Innovative and Community-Based Management: The Mango Tayo! Model*

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The Philippine mango sector experienced a steady decline from 2000 to 2022 across all industry performance metrics, including productive area, production volume, yield per unit area, and yield per tree. In addition, mango exports are not performing as well as they did in previous decades. Low farm-gate prices, inadequate induction and flowering intensity, a lack of farm-to-market routes, and a lack of pest control, nutrition management, and weather factors are additional issues that many farmers, particularly small-scale farmers, face. Responding to these issues, the Davao del Sur State College proposed and approved a college-funded program that developed an AI-based Smart application and IoT-based devices for the management of mango production, employing cutting-edge technologies in smart and sustainable agriculture. Thus, the program developed the following technologies: an AI-based Mobile Application to manage, the Soil Macro Nutrient Analyzer, and the Micro-weather Station. As a result of these developments, community involvement and activities were carried out to enable women and men mango farmers of Digos City, Davao del Sur, Philippines, to use the developed technologies. The program achieved its goals, including providing community partners with access to advanced farming technologies. Moreover, this program contributes to Sustainable Development Goal 2, which seeks to eradicate hunger by empowering small-scale farmers to increase agricultural output.

### *8.14. Unsupervised Learning and Geostatistics for Vineyard Management Zone Delineation: Integrating PCA, Clustering, and Kriging in Chile's Maule Valleys*

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Powdery mildew (*Erysiphe necator* (*Schw.*) *Burr.*) is a pathogen that threatens vineyard sustainability and profitability. This study presents a reproducible framework that integrates unsupervised machine learning with geostatistics to delineate risk and management zones in *Vitis vinifera* L. vineyards in Chile's Maule Region. The workflow comprises (i) data preprocessing; (ii) dimensionality reduction via rotated principal component analysis (PCA) to synthesize multisource attributes; (iii) segmentation and dominance assessment from rotated scores to identify key agronomic factors (e.g., vigor and yield); (iv) spatial validation through factor-wise grouping and cross-validation; (v) geostatistical modeling—empirical isotropic and directional variograms, weighted least-squares fitting to extended models, model selection by cross-validation—followed by kriging of principal components and their variances; (vi) clustering-based delineation of management zones projected onto a spatial grid; and (vii) spatial interpolation and fusion to produce discretized backgrounds with contours of the dominant component. Across seasons, retained components explained at least 70% of the total variance. Silhouette coefficients of 0.47–0.56 indicated moderate-to-good separation and stable dominance patterns. Moran's I was significant in the first two seasons, evidencing spatial dependence and interannual variation. Cross-validated isotropic ranges typically spanned 25–90 m, reaching ~170 m depending on season and component; directional analysis revealed anisotropy with predominant NE–SW (≈45°) continuity. The framework yields continuous severity/incidence maps and coherent management zones, supporting site-specific management and reduced pesticide use in precision viticulture.

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### *8.15. VitiN et—An Open-Set Framework for OOD-Robust Grape Leaf Disease Classification*

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Grape leaf diseases threaten viticulture by reducing yield and quality, while manual scouting remains inconsistent and can drive unnecessary chemical use. Although deep learning enables automated diagnosis, standard models trained on curated datasets are computationally heavy and prone to overconfident errors on out-of-distribution (OOD) vineyard imagery. We present VitiNet, a lightweight, OOD-aware grape leaf disease classifier built on a ResNet18 backbone and optimized through staged fine-tuning, an engineered 'Other' class for explicit OOD rejection, and a risk-mitigating dual-threshold deployment protocol. Evaluated on a challenging, OOD-skewed test set, VitiNet achieved 98.2% accuracy and a 0.982 weighted F1-score, with exceptional OOD performance (99.6% precision for the 'Other' class). The primary limitation of this model was found to be the confusion between Bacterial_rot and OOD images (Bacterial_rot F1 = 0.807). Grad-CAM analyses showed that the model focuses on symptomatic regions but can be overly sensitive to necrotic textures that resemble Bacterial_rot in non-disease images. To ensure safe and reliable operation, we suggested a dual-threshold policy for deployment: T-disease = 0.96 (chosen to achieve approximately 95% recall for disease detection) and T-other = 0.99, directing ambiguous predictions to human review. VitiNet delivers fast, accurate, and non-invasive decision support for grape growers and provides a robust foundation for future domain adaptation with real-world field data, including eventual on-device deployment for in-field use.

## 9. Session 8: Sustainable Farming Systems and Soil Management

### *9.1. Spent Pleurotus Substrate Effects on Soil Fertility and Enzymatic Activity in Baby Leaf Lettuce Cultivation*

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Among edible mushrooms, *Pleurotus* spp. is widely cultivated, and interest is growing in reusing its spent substrate (SPS). SPS shows promise as an organic fertilizer to enhance soil fertility and physical properties; however, its impact on soil microbial activity remains underexplored. This study assessed raw SPS as an organic fertilizer for baby leaf lettuce, focusing on yield, nutritional quality, soil fertility, and soil enzymatic activity. The trial took place in a tunnel greenhouse across two crop cycles (Cycle 1: October–December; Cycle 2: January–March) using two lettuce varieties: Doge and Imperiale. Five fertilization treatments were applied: T0 (no fertilization), TMIN (mineral fertilizer NPK 35-7-4, 75 kg $ha^{-1}$), T100 + 50 (35 kg $ha^{-1}$ N via SPS + 17.5 kg $ha^{-1}$ mineral N), T200 (70 kg $ha^{-1}$ N via SPS), and T200 + 50 (70 kg $ha^{-1}$ N via SPS + 17.5 kg $ha^{-1}$ mineral N). At harvest, aerial biomass and soil samples were collected to assess yield, plant mineral content, soil nutrients, and enzymatic activities (BGA, ArS, AcP, and AlkP). Fertilization significantly influenced yield: T0 and TMIN produced the highest yields (2.6 and 2.3 kg $m^{-2}$), while T100 + 50 yielded the most among SPS treatments (2.0 kg $m^{-2}$). T200 and T200 + 50 improved all enzymatic activities. Mineral profiles differed by variety: Imperiale had higher P, K, S, and Ca and the highest nitrate content under TMIN (37,232 mg $kg^{-1}$), while Doge absorbed more nitrates under SPS treatments (29,943 mg $kg^{-1}$).

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SPS did not affect soil P or K due to the short crop cycle. Overall, raw SPS enhanced soil enzyme activity and lettuce nutrient content, with T100 + 50 offering the best trade-off between soil health and yield. Future research will evaluate SPS use in other baby leaf crops.

### *9.2. Biowaste-Based Solutions to Water Pollution: Dragon Fruit Peel as a Green Adsorbent*

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Water pollution has become an escalating global threat, driven by industrialization, agricultural runoff, and improper waste disposal. Contaminants such as heavy metals, synthetic dyes, and organic pollutants are increasingly polluting freshwater sources, posing serious risks to ecosystems and human health. There is an urgent need for eco-friendly and cost-effective solutions to mitigate this issue. One sustainable approach gaining attention is the valorization of agricultural waste, particularly from fruit crops like dragon fruit (*Hylocereus* spp.), to develop natural adsorbents for water purification. This review explores the potential of dragon fruit peel and other waste parts as bio-adsorbents for treating polluted water. Rich in cellulose, pectin, hemicellulose, and phenolic compounds, dragon fruit peel exhibits high surface area and active functional groups capable of binding and removing various pollutants. Studies have shown its efficiency in adsorbing heavy metals like lead ($Pb^{2+}$), cadmium ($Cd^{2+}$), and chromium ($Cr^{6+}$), as well as synthetic dyes such as methylene blue and malachite green, through mechanisms including ion exchange, hydrogen bonding, and surface complexation. By converting agricultural waste into a valuable resource for water remediation, dragon fruit waste offers an environmentally sustainable and low-cost solution. This approach supports circular economy practices while reducing dependency on synthetic and non-biodegradable adsorbents. In conclusion, dragon fruit waste has significant potential in reducing water pollution, and further research into optimization, scalability, and real-world applications can enhance its role in sustainable water management systems.

### *9.3. Evaluating the Plant-Growth-Promoting Endophytes for the Reclamation of Saline Soils in Coastal Agriculture*

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Soil salinization is a major threat to food security in the coastal regions of Pakistan, necessitating innovative and sustainable reclamation strategies. This study investigated the efficacy of indigenous plant-growth-promoting endophytes (PGPEs), isolated from native halophytes of the Indus Delta, to enhance wheat (*Triticum aestivum*) resilience and rehabilitate saline soils in Sindh province. A consortium of three potent endophytic strains, selected for high salt tolerance and multifunctional PGP traits (including phosphate solubilization and indole-3-acetic acid production), was developed. A field trial was conducted in naturally saline soils near Thatta using a randomized complete block design with four treatments: an untreated control, chemical fertilizer alone, PGPE inoculation alone, and a combined PGPE and reduced fertilizer application. Inoculation with the PGPE consortium significantly improved soil health, reducing electrical conductivity by 18% and increasing soil organic matter content by 22% compared to the control. Wheat plants treated with PGPEs exhibited superior growth, with a 35% increase in root length and a 28% increase in shoot biomass, attributable to enhanced nutrient acquisition and water use efficiency. The combined treatment (PGPE + fertilizer) yielded the highest grain production, surpassing the control by 42%. Biochemical analyses confirmed elevated proline content and antioxidant enzyme activities, indicating robust induced systemic tolerance to salinity stress. This research provides

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compelling evidence that locally sourced PGPE consortia are a highly effective, sustainable, and economically viable bio-strategy for mitigating salt stress and improving productivity in saline agroecosystems, with significant potential for global application.

### *9.4. Influence of Zoocompost Application on Macromineral Content in Honeysuckle (Lonicera caerulea L.) Leaves*

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With growing interest in the broader use of medicinal and nutritionally valuable plant parts, attention is expanding beyond the fruit of honeysuckle (*Lonicera caerulea* L.) to include other organs such as leaves. These leaves constitute a valuable source of bioactive substances and essential minerals. This study aimed to evaluate the effect of zoocompost derived from black soldier fly (*Hermetia illucens* L.) larvae on the macrominerals of honeysuckle leaves.

A field experiment was conducted in the Alytus district of Lithuania, involving three cultivars: 'Zojka', 'Wojtek', and 'Indigo Yum'. Plots were arranged in a randomized design with four replicates. Zoocompost was applied at 0 (control), 1000, 1500, and 2000 kg $ha^{-1}$ at the end of March. Leaf samples were collected in mid-July, freeze-dried, and analyzed for nitrogen (N) using the Kjeldahl method. Phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined by means of inductively coupled plasma atomic emission spectrometry (ICP-AES). Soil samples collected in June were analyzed for available $P_2O_5$, $K_2O$, mineral nitrogen, and pH.

The leaf sample results showed that N content was significantly highest in 'Zojka' leaves treated with 1500 kg $ha^{-1}$ of zoocompost, while the highest P content was recorded in the same cultivar at the 2000 kg $ha^{-1}$ application rate. The 'Indigo Yum' treated with 2000 kg $ha^{-1}$ showed significantly increased Ca content but significantly lower K content. The lowest Ca content was observed in 'Zojka' leaves under the 2000 kg $ha^{-1}$ treatment. No significant effect was found on Mg levels. Application of zoocompost at the highest fertilization rate significantly increased the contents of available $P_2O_5$, $K_2O$, and mineral nitrogen in the soil. Fertilization did not have a significant effect on soil pH.

The results of this study demonstrate that zoocompost can effectively improve both the macromineral composition of honeysuckle leaves and soil fertility by increasing the availability of key nutrients.

### *9.5. A Local Spectral Library from the Kopaida Plain, Greece, for Rapid Soil Property*

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Monitoring soil is essential for understanding and maintaining soil health, ensuring agricultural productivity, and addressing environmental challenges such as land degradation and climate change. Conventional methods for evaluating soil properties, although precise, are often labor-intensive, time-consuming, and unsuitable for large-scale or near real-time applications. This has created a strong demand for innovative, cost-effective, and scalable techniques to characterize soils. Hyperspectral sensing—using both point-based and imaging sensors—has emerged as a powerful solution, capable of capturing detailed spectral signatures that reveal a wide array of soil attributes, including soil organic carbon

(SOC), texture, carbonates, and moisture content. A key element in advancing these techniques is the creation of spectral libraries—comprehensive datasets of soil spectra—that enable robust modelling and prediction of soil properties in various environments. This study aims to demonstrate preliminary modelling results for soil property estimation using a local soil spectral library from Kopaida plain, central Greece, for soil property assessment, with a focus on estimating SOC and calcium carbonate content. Standard laboratory procedures were applied to determine soil chemical and physical properties, with SOC quantified via wet oxidation, and calcium carbonate percentage was estimated using Bernard test. Several statistical modelling approaches—Partial Least Squares Regression (PLSR), Random Forest (RF) and Ridge regression—were tested. Modelling accuracy was assessed using Root Mean Square Error (RMSE), the coefficient of determination ($R^2$), and the Ratio of Performance to Interquartile Range (RPIQ). The findings highlight the considerable potential of the developed spectral library for accurately estimating soil properties and contribute to sustainable land management. By capitalizing on the strengths of hyperspectral sensing, this method offers a rapid, scalable, and precise means of monitoring soil conditions across diverse landscapes. Such advancements are crucial for promoting soil sustainability, enabling targeted conservation actions, and supporting agricultural productivity under the pressures of climate change.

### *9.6. Analysis of the Effect of Different Planting Dates and Varieties on the Growth and Yield of Potatoes (Solanum tuberosum L.) in Northern Central Namibia*

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Potatoes are highly valued worldwide for their high yield, nutrition, versatility, and income potential. Potatoes are the leading non-cereal food crop, ranking third in human consumption after rice and wheat. In Africa, potatoes are the second most cultivated crop and are commonly used as a staple food after maize. Potatoes are a promising crop to address global poverty and hunger, potentially improving food security and boosting farm returns for smallholders. Recent years saw high temperatures and droughts affecting crops globally. Namibia has the potential to increase potato production and diversity. The study aims to identify how planting date and varieties affect potato growth and yield across cultivars and seasons. Three planting phases (6 March, 6 April, 6 May) and four varieties (Barcelona, Rainbow, Spunta, Montreal) were arranged in a randomized complete block design with four replications. Twelve treatments were organized into four varieties, each with three phases. Data on growth and yield parameters were analyzed using SAS 9.4. The maximum plant height of 32.76 cm was recorded from phase 1 in Barcelona, and the minimum of 9.12 cm from phase 3 in Rainbow. The highest total tuber number (33) was recorded from 06 April in Spunta, with the lowest (13) in Montreal from the third planting date. The highest total tuber weight (21.40 t/ha) was recorded in Rainbow from the second planting date, and the least (6.78 t/ha) was Montreal in phase 3. The study indicates that 06 April is the best planting date for all varieties, considering overall performance and tuber yield, with phase 1 and phase 3 showing poorer results. The best planting date is phase 2, as Barcelona and Rainbow outperform Spunta and Montreal in marketable tubers.

### *9.7. Assessment of Soil Electrical Conductivity and Yield Responses of Maize Hybrids Under Different Plant Densities*

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Different maize hybrids vary in nutrient uptake efficiency. Plant density influences nutrient absorption, which affects yield at different growth stages such as germination, tasselling, and kernel development. Few studies have examined the relationship between soil electrical conductivity (EC) and maize yield under varying plant densities. This research aimed to identify optimal hybrid–density combinations for improved productivity and resource use efficiency. The experiment was conducted in 2024 at the Látókép Experimental Station (Debrecen, Hungary) under strip tillage on non-irrigated chernozem soil. Three maize hybrids (Merida, Fidencio, and P9985) were cultivated at two plant densities (60,000 and 80,000 plants $ha^{-1}$) with a fertiliser rate of 80 kg Nitrogen $ha^{-1}$ plus basal Phosphorus and Potassium. Soil EC was measured monthly with a portable sensor from planting to cob formation, and grain yield was determined at harvest. Data were aggregated by hybrid–plant density and statistically analysed using SPSS Software (IBM v20), with significance evaluation at $p \leq 0.05$. Results revealed no significant correlations among hybrid, EC, plant density, and yield. This shows that neither EC nor plant density reliably predicts yield, suggesting other factors, such as soil moisture and fertility, that may exert stronger influence. Future studies should examine interactions between EC and other factors affecting maize productivity. Moreover, long-term studies across multiple seasons and diverse soil types could clarify EC patterns under varying environmental conditions, tillage systems, and irrigation regimes.

### *9.8. Complexation of Molybdenum(VI) with Humic Substances from Greek Leonardite: Spectroscopic Insights and Implications for Soil Bioavailability*

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Humic substances (HSs), derived from organic matter degradation in terrestrial and aquatic systems, play critical roles in nutrient cycling, metal complexation, and soil fertility. Their ability to bind trace elements, including molybdenum, is of particular agricultural importance since Mo is an essential micronutrient regulating nitrogen fixation and assimilation. Despite Mo's pivotal role, its solubility and bioavailability in soils remain limited, often leading to deficiencies in plants. Understanding Mo–HS interactions is therefore crucial for developing sustainable strategies to improve nutrient availability.

HS samples obtained from Greek leonardite were studied for their interaction with Mo(VI). Solutions of HS were titrated with Mo(VI) and analyzed. Mo concentrations in supernatants were determined via atomic emission spectroscopy. Solid residues containing Mo–HS complexes were characterized using UV–Vis spectroscopy and FTIR spectroscopy.

The addition of Mo(VI) to HS solutions decreased pH, consistent with proton-releasing complexation reactions. UV–Vis spectra revealed charge-transfer processes indicative of Mo–HS associations without Mo reduction. FTIR analyses confirmed the involvement of functional groups—primarily carboxylic, with additional contributions from phenolic and

alcoholic moieties—in Mo binding. Shifts and intensity changes in COO–, C=O, and O–H vibrations substantiated the formation of stable complexes.

This study demonstrates that HSs effectively complex Mo(VI), enhancing its solubility and potential bioavailability in soils, highlighting the agronomic potential of humic-rich materials, such as leonardite, as natural Mo carriers for improving crop nutrition. These findings contribute to the broader understanding of HS-mediated trace element dynamics and their role in sustainable agriculture.

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### *9.9. Conservation Agriculture as a Global Sustainable Pathway*

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Conservation Agriculture (CA) has achieved global recognition as a sustainable land-use concept grounded in three basic principles: minimal soil disturbance, permanent soil cover, and planting diversity. Its global expansion is a response to concerns with soil degradation, tillage erosion, climate change, and food insecurity, and in 2019, CA was adopted on more than 205 million hectares overall. In North America, the United States championed the expression of CA due to the Dust Bowl crisis and made soil conservation a federal commitment. Today, the United States still leads the way in no-till systems, cover crops, and precision agriculture through ongoing federal research and policy initiatives. South America also implemented CA on a large scale in Brazil, Argentina, and Paraguay, which has impacted their soybean-maize systems, reducing erosion and contributing to soil carbon. In Africa, South Africa and Morocco have also incorporated and adapted CA to local conditions to improve drought resistance and increase the stability of production through their cereal systems. In Asia, a zero-till wheat production system in India has expanded productivity and resource-use efficiency through government and international collaboration. In Australia, CA innovations in machinery and water management have sustained yields in systems during drought years, with lower input costs. Europe (Spain, France) has also more closely integrated CA with agroecological goals and soil carbon, with CA being more widely discussed and further positioned into climate-smart farming. Despite its proven benefits, CA adoption remains constrained by technical, socio-economic, and policy barriers. Overcoming these requires integrated strategies—financial incentives, adaptive extension services, and stronger alignment with agroecology and circular economy principles. CA thus represents a scalable, climate-resilient pathway to sustainable, regenerative food systems worldwide.

### *9.10. Delineation of Management Zones in Citrus Orchards Using Geostatistics and Clustering Techniques in Central India*

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Soil nutrient management in citrus orchards across central India still largely follows traditional, uniform guidelines that overlook the spatial variability of environmental conditions. This often results in unbalanced blanket fertilization, inconsistent yields, and reduced fruit quality, ultimately affecting farmers' profitability. This study aimed to assess the spatial variability of soil properties in citrus orchards on the Malwa Plateau in central India using geostatistical techniques and to delineate potential management zones through principal component analysis and fuzzy c-means clustering. A total of 104 orchards were selected in the citrus-growing areas of the Rajgarh region, Madhya Pradesh. Surface soil samples (0–20 cm depth) were collected in 2022 to analyze pH, electrical conductivity (EC), organic matter, and levels of primary, secondary, and micronutrients. The data were subjected to descriptive and geostatistical analyses. Management zones were delineated using clustering methods, with the optimal number of zones determined by the Fuzziness Performance Index and Fuzzy Partition Entropy.

Results revealed significant spatial variability in soil properties, with three distinct management zones identified as optimal for citrus orchards. Most soil attributes varied significantly across these zones. Based on these delineated zones, preliminary zone-specific nutrient management guidelines were developed, suggesting differentiated fertilizer rates and organic matter inputs tailored to each zone's fertility status. The developed recommendations system optimizes nutrient application, uses efficiency, further integrates the Diagnosis and Recommendation Integrated System (DRIS), and develops a nutrient management zone. The validity is better than blanket fertilizer recommendations, which further improve fruit yield and quality and provide practical decision-support tools for farmers and extension services.

This study provides a foundation for implementing site-specific nutrient management. It supports broader adoption of precision agriculture in central India, contributing to more sustainable, resilient citrus production systems.

### *9.11. Design and Fabrication of a Mould Suitable for Traditional Sweetener (Mazankwaila), in Kaduna State, Nigeria*

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Traditional food processing preserves indigenous knowledge and supports sustainable agriculture. In northern Nigeria, Mazankwaila is a cube-shaped sweetener made from sugarcane juice, commonly used as a sugar substitute in tea. Amid rising refined sugar prices, low-income households increasingly struggle with affordability. This study aimed to design and fabricate a standardized mould to enhance Mazankwaila production, improving both quality and accessibility while preserving traditional methods. Fieldwork was conducted in Dan Damisa village, Kaduna State, using observation and interviews with local producers. Bulk density measurements of Mazankwaila averaged 591.93 kg/m$^3$, enabling precise conversion of sweetener mass into volume. This informed the design of a mould measuring 75 cm $\times$ 75 cm $\times$ 3 cm, with a batch capacity of 16.875 L—aligned with the volume needed for standardized cube production. Daily output was tracked over five production shifts, each yielding 100 L, for a total of 500 L per day. The mould was fabricated using a combination of traditional craftsmanship and engineering calculations to ensure durability, ease of use, and consistency in cube sizing. Producers reported improved efficiency, reduced product waste, and enhanced uniformity, without compromising traditional preparation methods. This integration of empirical data with indigenous practices demonstrates a practical, scalable approach to artisanal sweetener production. The

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standardized mould offers a cost-effective alternative to refined sugar, supporting rural livelihoods, food security, and local agribusiness development.

### *9.12. Effect of Herbicide-Treated Soil Inoculum on Nodulation in Cowpea (Vigna unguiculata L. Walp.) and Soybean (Glycine max L. Merr.) Planted Under Glasshouse Conditions*

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The application of herbicides in agricultural systems raises concerns regarding their non-target effects on soil microbial communities, particularly symbiotic nitrogen-fixing rhizobia. This study investigated the effect of herbicide-treated soil inoculum on rhizobia nodulation in cowpea and soybean. A glasshouse experiment was conducted with herbicide-treated and 15 untreated soils collected from farmers' fields. Seeds were surface-sterilized (70% ethanol and sodium hypochlorite) and sown at 2–3 cm depth. Seedlings were inoculated with soil suspensions (5–10 g soil in 300 mL distilled water; 100 mL per pot), with three replicates per treatment. Plants were irrigated with nitrogen-free nutrient solution and harvested at flowering (65 days after planting, DAP). Nodulation and growth parameters—including nodule number, nodule DM, shoots DM, and roots—were quantified to assess herbicide-induced effects. The results revealed significant ($p \leq 0.05$) differences in nodulation, plant growth, and nitrogen fixation in herbicide-treated soils compared to untreated controls, with variability influenced by crop species and soil origin. Untreated soils increased whole-plant dry matter (DM), particularly in cowpea, at locations Nator (6.05 g/plant) and McCoy (5.87 g/plant). Soybean exhibited notable nodule reduction in herbicide-treated soils, except in Dapuori, suggesting potential herbicide tolerance in local rhizobial strains. Conversely, untreated soil from Lambussie recorded an increase in soybean nodulation (19.00 nodules/plant). Cowpea exhibited greater sensitivity to herbicide residues, with pronounced declines in nodule formation, while soybean demonstrated moderate resilience. These findings underscore that herbicides significantly impair nodulation, with cowpea being more adversely affected than soybean. Untreated soil inoculum promoted superior nodulation and biomass, emphasizing the necessity for herbicide selection based on soil-microbe compatibility. Site-specific variations suggest the existence of herbicide-tolerant rhizobial strains in certain soils. Prolonged herbicide use may compromise soil fertility and sustainable crop production, warranting further investigation into microbial adaptation strategies.

### *9.13. Effect of Supplemental Irrigation and No Tillage on Bread Wheat: A Global Meta-Analysis Approach*

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A global meta-analysis was conducted to assess how various abiotic factors influence grain yield (GY) and grain protein content (GPC) of bread wheat. For this purpose, forty peer-reviewed papers published between 1986 and 2024 were analyzed. The results showed that the application of supplemental irrigation had significant effects on GY and GPC depending on the climate. In a semi-arid climate, supplemental irrigation had a positive effect on the yield, increasing it by 1154.08 kg $ha^{-1}$, and a negative effect on GPC, decreasing by 2.09%. However, in a sub-humid climate, a yield decrease of 499.25 kg ha-1 was observed. In addition, GY and GPC responses to supplemental irrigation were significant according to soil textures ($p < 0.0001$). When irrigation was applied, the highest GY increase was observed in coarse- and fine-textured soils (1507.41 kg $ha^{-1}$ and 1826.18 kg $ha^{-1}$, respectively). However, the medium-textured soils indicated negative responses (MD = $-1811.63$ kg $ha^{-1}$). Indeed, the beneficial effect of supplemental irrigation on GPC was demonstrated in fine-textured soils (MD = 0.91%). However, a negative response of irrigation was observed in coarse- (MD = $-1.67$%) and medium-textured (MD = $-1.60$%) soils. When no tillage was implemented, GY response was positive in both sub-humid and humid climates, leading to an increase by 1660.41 kg $ha^{-1}$ and 1650.02 kg $ha^{-1}$, respectively. In contrast, no tillage led to a decreased GY (by 499.25 kg $ha^{-1}$) in the semi-arid climate. Although no tillage had no significant impact on GPC alone, GY and GPC showed positive responses, leading to an increase by 201.36 kg $ha^{-1}$ and 0.13% in coarse-textured soils and 1390.57 kg $ha^{-1}$ and 1.11% in medium ones, respectively. However, a negative response to no tillage was observed in fine-textured soils (MD = $-0.45$%).

### *9.14. Enhancing Seasonal Resilience and Resource Efficiency in Button Mushroom Production Through the Mushroom Kothi System*

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Button mushroom (*Agaricus bisporus*) cultivation in India remains highly seasonal, with farmers facing yield losses and quality decline in warmer months. To address these limitations, we evaluated Mushroom Kothi, a low-cost IoT-enabled cultivation chamber, across three agro-climatic zones and multiple growing seasons. The system integrates temperature, humidity, and $CO_2$ sensors with automated misting and ventilation, ensuring a stable microclimate independent of external fluctuations. Comparative trials between Mushroom Kothi units and farmer-managed controls (n = 30 per season) revealed that the device extended productive cultivation by up to two additional months beyond the conventional season. Yield improvements averaged 20%, with water-use efficiency gains of 35–40% and crop loss reduction of nearly one-third. Post-harvest shelf life improved by 1–2 days due to reduced disease incidence and more uniform fruiting. Beyond production, operational data showed fewer manual interventions and lower labor time, confirming usability for smallholders with limited resources. Resource-use metrics (liters of water and watt-hours per kilogram yield) confirmed the significantly higher efficiency in Mushroom Kothi systems, supporting sustainable intensification goals. These results highlight the potential of digitally assisted chambers to provide stable year-round income, reduce environmental footprint, and strengthen smallholder resilience. Future research will extend the trials to additional regions and test integration with renewable energy to further improve sustainability.

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### *9.15. Evaluating Corn Yield and Plant and Soil Nutrient Concentrations Under Application of Synthetic Fertilizer and Dairy Manure*

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Manure application in field corn can sustain corn yields and reduce nutrient losses in the soil profile. A field trial was conducted to evaluate the impact of applying manure and synthetic fertilizer on nutrient concentrations in plants and soil, and on field corn yield. Experimental treatments included applications of synthetic fertilizer (NPK) and dairy manure at 5, 10, and 15 tons acre$^{-1}$ in addition to a non-fertilized control. All the manure was applied before planting, whereas synthetic fertilizer was applied in splits during the crop growth season. Corn was manually harvested, and plants were separated into leaves, stems, and cobs to determine dry weights. Post-harvest soil sampling was performed at 0–30, 30–60, and 60–90 cm soil depths. Results indicated that in-season leaf nutrient concentrations differed significantly among applied treatments. Application of synthetic fertilizer resulted in the highest plant height (116 in) and the highest corn yield (45.5 tons acre$^{-1}$) compared to the control and dairy manure application. Application of manure at 5 tons acre-1 produced a higher corn yield (35.5 tons acre$^{-1}$) compared to manure application at 10 (25.9 tons acre$^{-1}$) and 15 tons acre$^{-1}$ (26.1 tons acre$^{-1}$). A similar trend was observed for the fresh and dry weights of leaves, stems, and cobs. Nutrient recovery was higher with synthetic fertilizer application, followed by manure at 5 tons acre$^{-1}$. Soil nutrient analysis indicated no significant differences in N, P, K, and S concentrations among treatments, except for $NH^{4+}$–N. However, nutrient concentrations across depths significantly differ. Results suggest that a combination of synthetic fertilizer application and manure might be a practical approach for balanced nutrient supply for field corn. Findings of this study establish a framework for improving manure-based nutrient management, with future work expanding its application across production systems.

### *9.16. Evaluation of the Phenolic Profile of Two Consecutive Prunings of Different Varieties of Vitis vinifera from the Same Region*

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In the context of sustainable viticulture and circular bioeconomy, this study investigated the valorization potential of vineyard pruning by-products (leaves), gathered during two seasonal defoliation events across eight Vitis vinifera varieties (Vinhão, Touriga Nacional, Padeiro de Basto, Alvarinho, Sauvignon Blanc, Loureiro, Moscatel Galigo Branco and Arinto).

Removing leaves from plants before they naturally dry out and fall is a useful winegrowing practice for controlling yield and improving grape quality. This technique can reduce the number and compactness of bunches and improve the cold resistance and composition of grapes. However, the time of year and the amount of defoliation are crucial, since excessive leaf removal can negatively affect vine performance.

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This study aimed to evaluate the polyphenolic composition of two defoliation timings (May and June) from hydroalcoholic extracts of dried leaves.

Identification and quantification of catechin, epigallocatechin gallate (EGCG), gallic acid, quercetin, rutin, ellagic acid and 3-O-methylellagic acid (3-MEA) were performed using high-performance liquid chromatography (HPLC) with a diode array detector (DAD).

Based on the obtained results, the 50% ethanol solution resulted in a higher content of phenolic compounds for vine leaves in the second defoliation. In the leaves of the early defoliation, the phenolic composition showed the main accumulation of gallic acid and catechin, while the content of quercetin and 3-MEA was higher in the second defoliation.

Higher contents of quercetin were obtained in leaf extracts from the Vinhão variety (53 mg/100 g). 3-MEA, an ellagic acid derivative, was found exclusively in leaves collected during the second defoliation, revealing significant differences between cultivars.

This research provides information about the phenolic profile evolution of vineyard pruning by-products (leaves), contributing to a more environmentally friendly and waste-reducing food system. Valorization of this pruning waste presents a possible alternative to disposal, in line with sustainable and health-promoting food innovation goals and enhancing a circular economy.

### *9.17. Flood Stress and Growth Management for Plants in Arable Soils Using Cocopeat-Plant Growth Promoting Rhizobacteria Formulation*

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This research formulated and evaluated the efficiency of a biofertilizer, cocopeat encapsulated plant growth-promoting rhizobacteria (cocopeat-PGPR), in the management of flood stress and the growth of Zea mays (maize) seeds cultivated under flood conditions. Rhizobacteria were isolated from a weed (*Phyllanthus amarus*) and screened for plant growth-promoting (PGP) traits; Indole-3-acetic acid (IAA) production and phosphate solubilization. Rhizobacteria were further tested for PGP activity using a seed germination bioassay, and those with superior performance were used for formulation and a pot experiment. Formulations were prepared by homogenizing 20 mL of each PGPR standardized inoculum with 2 g of oven-dried cocopeat and 24 g of starch gel, pelleted, and dried at room temperature. The efficiency of the formulations was evaluated in a pot experiment by measuring plant height (PH), shoot length (SL), and root length (RL) of the treated maize seeds weekly. Two sets of treatments were performed: seeding with one cocopeat-PGPR pellet/pot and four cocopeat-PGPR pellets/pot. Controls were without the cocopeat-PGPR formulation. Flood conditions were simulated by waterlogging the treatments without drainage. Five rhizobacterial isolates were obtained; two tested positive for phosphate solubilization (CE and C), and two tested positive for IAA production (CE and PP). These isolates also demonstrated superior growth performance during the seed germination bioassay. At day 7 of the pot experiment, no growth was recorded for maize seeds treated with a single cocopeat-PGPR pellet or for the control. However, at day 7, in treatments with four cocopeat-PGPR pellets, only cocopeat-CE supported maize seed growth and sustained growth. The mean SL, RL, and PH recorded for the seeds were 2.4 cm, 3.1 cm, and 15.7 cm, respectively. Before day 14, the maize seeds withered. The PGPR (CE) was identified by 16S rDNA sequencing as Priestia flexa. This study, therefore, examines the potential of cocopeat (*Priestia flexa*) to mitigate flood stress and promote growth in maize plants.

### *9.18. Four Bacteria, One Mission: Degradation of the Persistent Herbicide Diflufenican*

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Diflufenican is a widely used herbicide characterized by extreme environmental persistence, with a $DT_{90}$ of up to 1900 days. Its accumulation in agricultural soils poses ecological risks and requires the development of efficient bioremediation strategies. While microbial degradation is a promising approach, no previous studies have demonstrated the potential for diflufenican removal using soil bacterial isolates.

Agricultural soil from a diflufenican-treated field in Poland was screened for degradative microorganisms using enrichment culture techniques in mineral salt medium (MSM) supplemented with the herbicide. Four isolates with the highest biodegradation potential were identified via 16S rRNA sequencing as *Pseudomonas* sp. 10Kp8—A1, *Pseudomonas chlororaphis* subsp. *aureofaciens* B19—A2, *Pseudomonas* baetica JZY4-9—C1, and *Streptomyces atratus* ROA017—D1. Biodegradation efficiency was assessed in MSM and sterile horticultural soil, comparing individual strains with a quadruple consortium. Herbicide residues and selected diflufenican metabolites were quantified by GC-MS/MS.

In MSM, the D1 strain achieved 70% degradation after 21 days, while the consortium reached 74%. In soil, D1 removed 79% of herbicide and the consortium 82% within 28 days. The metabolite, 2-(3-trifluoromethylphenoxy) nicotinic acid, was detected in all MSM and soil samples analyzed.

This study presents the first evidence of diflufenican biodegradation by bacteria, highlighting both the D1 strain and a consortium as promising candidates for bioremediation. The superior performance of the consortium suggests synergistic interactions enhance degradation. Given their safety profile and the existing agricultural uses of related strains, these isolates have strong potential for integration into sustainable soil remediation practices.

### *9.19. Green Synthesis of Lawsonia inermis-Mediated Silver Nanoparticles and Their Effect on Seed Germination of Chickpea*

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The development of eco-friendly nanomaterials through plant-mediated synthesis has gained wide attention in recent years due to its sustainability and biocompatibility. In the present study, silver nanoparticles (AgNPs) were synthesized using aqueous leaf extract of *Lawsonia inermis* (henna), a plant rich in bioactive phytochemicals that act as reducing and stabilizing agents. The green synthesis approach eliminates the need for hazardous chemicals, aligning with the principles of green technology. The formation of AgNPs was confirmed by characteristic surface plasmon resonance in UV–Vis spectroscopy and further validated by means of complementary analytical techniques. The biosynthesized nanoparticles were evaluated for their effect on seed germination and early seedling growth of chickpea (*Cicer arietinum*), an important pulse crop. Different concentrations of AgNPs (10, 20, 30, 40, 50, 60, 70, 80 ppm), were applied to assess their influence on germination percentage, root and shoot elongation, and seedling vigor index. The results revealed that lower concentrations of *L. inermis*-mediated AgNPs enhanced germination rate, stimulated root development, and improved overall seedling vigor when compared with control treatments. However, higher concentrations exhibited inhibitory effects, indicating a dose-dependent response. The observed stimulatory effect at optimum levels may be attributed to the antimicrobial properties of AgNPs, which reduce pathogenic interference during germination, as well as their potential role in modulating physiological processes in seeds. These findings highlight the dual advantage of green synthesized AgNPs as both an eco-friendly nanomaterial and a seed priming agent. This study emphasizes the potential

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application of *L. inermis*-derived AgNPs in sustainable agriculture, offering an alternative to synthetic agrochemicals for enhancing crop establishment and productivity.

### *9.20. Impact of the Nutrient Relay Principle in Multi-Cropping Systems on Soil Structural Properties*

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Intensive agricultural practices contribute to soil erosion, compaction, and the depletion of soil organic carbon and essential nutrients. There is a growing demand for sustainable practices that enable efficient crop production while minimizing environmental impact. Among these, multi-cropping has emerged as a promising strategy to address major agroecosystem challenges such as biodiversity loss, declining soil fertility, and increased greenhouse gas emissions. Prior studies have shown that crop interactions and interspecific competition in multi-cropping systems enhance root development and improve soil structural stability. Balandaitė et al. (2024) noted that multi-cropping is becoming a promising technique in agriculture.

A stationary field experiment was established in 2024 at the Experimental Station of Vytautas Magnus University Agriculture Academy (Lithuania; 54°53′ N, 23°50′ E), on Endocalcaric Amphistagnic Luvisol. The study aims to evaluate the effects of multi-cropping and nutrient relay on soil physical properties, crop development, and environmental indicators across two full crop rotation cycles.

Soil aggregate structure, stability, electrical conductivity, and greenhouse gas emissions were assessed before sowing and after harvest. Biomass samples were collected following the final cut. Preliminary results indicate that aggregate stability in multi-cropping systems is higher compared to monoculture spring barley, with a greater proportion of macroaggregates observed. These findings align with previous research showing that post-harvest residues from systems combining barley and red clover provide higher nutrient retention than monocultures. Additional results on biomass nutrient content are forthcoming.

In conclusion, multi-cropping positively influenced soil structure and stability in both the first and second crop rotations. The impact of nutrient relay will be further evaluated through subsequent assessments of the diagnostic crop. Ongoing observations across the full rotation cycles aim to provide insights supporting regenerative agriculture and alignment with the EU Green Deal objectives.

### *9.21. Influence of Municipal Refuse Waste Used as Fertilizer Material on Soil Physical and Chemical Properties*

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This study examined the effects of Municipal Refuse Waste (MRW) used as fertilizer on soil physical and chemical properties in three Local Government Areas of Kano State, Nigeria, where MRW mainly contained decomposed organic matter, food residues, ash, and limited inert materials, with variable composition that may influence soil and environmental outcomes. Nine farmlands applying MRW and three control sites without MRW were selected. Each site was stratified, and five surface (0–15 cm, because the cultivated arable crops obtain most nutrients within the rhizosphere zone) soil samples were randomly collected per stratum and composited. However, further work will consider 15–30 cm layers to assess nutrient and metal leaching. Samples were analyzed for texture, fertility, and metal content using standard laboratory methods.

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Results revealed loamy-sand textures across all soils, with MRW-treated soils showing lower sand (77.22–78.55%) and higher silt (15.00–17.67%) and clay (4.89–7.78%) fractions than the control (82.77% sand, 13.23% silt, 4.00% clay). Soil pH (6.05–6.32) slightly decreased compared with the control (6.40). Fertility parameters, including organic carbon (up to 0.79%), likely due to organic matter decomposition, total nitrogen (0.10–0.17%), available phosphorus (up to 30.81 mg $kg^{-1}$), and exchangeable bases such as calcium (2.32–3.33 cmol $kg^{-1}$) and magnesium (2.03–2.77 cmol $kg^{-1}$), were significantly enhanced.

Heavy-metal concentrations were determined using mild acid extraction (0.5 M HCl + 0.012 M $H_2SO_4$) and Atomic Absorption Spectrophotometry, which measures available fractions (bioavailable). Iron ranged from 11.29–12.10 mg $kg^{-1}$, manganese 18.77–26.25 mg $kg^{-1}$, zinc 10.05–38.94 mg $kg^{-1}$, and chromium 0.0387–0.0518 mg $kg^{-1}$. Lead levels exceeded safety limits in some sites, notably Ungogo. Although MRW improved soil fertility, variation in its composition and elevated metal levels highlight the need for cautious use and deeper assessments to evaluate long-term environmental and food-safety implications.

### *9.22. Interactions Between Far-Red Light and Blue–Red Spectra on Growth, Pigment Content, and Mineral Composition of Hydroponic Lettuce Cultivated in a Vertical Farming System*

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The blue–red spectrum, widely used in vertical farming due to its alignment with chlorophyll absorption and its role in regulating secondary metabolism, can be supplemented with wavelengths such as far-red to improve cultivation in fully controlled environments. The aim of this research was to determine the impact of adding FR light to the blue (B), red (R), and blue–red (BR) spectra on the growth, pigment content, and mineral profile of green- and purple-leaf lettuce grown hydroponically in a vertical farm. Plants were cultivated under B, R, and BR spectra with or without FR addition (total PPFD ~150 μmol $m^{-2}$ $s^{-1}$; 16 h light). The addition of FR light, particularly to the red spectrum (R + FR), significantly increased fresh weight, between 36.6% and 141.5% in green lettuce and between 13.1% and 104.9% in purple lettuce compared to other treatments, due to the higher relative growth rate. Moreover, this treatment also caused a reduction in the percentage of dry matter, which ranged from 7.88% to 20.7% in green lettuce and from 8.43% to 24.8% in purple lettuce, compared to other treatments. In green lettuce, chlorophylls (Chl) a and b increased independently under BR and with FR addition. In purple lettuce, Chl a rose with B, while Chl b improved with the B + FR interaction. In green lettuce, carotenoid levels increased significantly with the BR-FR interaction, while in purple lettuce, they augmented significantly with B, and in the absence of FR, independently. Finally, anthocyanin content increased significantly with the B-FR interaction, followed by BR-FR. Although the intensity of these responses varied among cultivars, the results highlight the importance of adapting light spectra to maximize both yield and nutritional value in indoor growing systems. This knowledge lays the foundation for designing precise lighting protocols that respond to different production objectives in vertical farming with different lettuce cultivars.

### *9.23. Interactive Effects of Plant Density and Sowing Method on Growth and Productivity of Quinoa*

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Quinoa (*Chenopodium quinoa Willd*.) has gained increasing global relevance due to its exceptional nutritional value and ability to thrive in diverse and marginal environments. However, despite the expansion of its cultivated area, yields remain suboptimal, often constrained by inadequate agronomic practices. Among the key determinants of productivity, crop structure—shaped by plant density and sowing method—plays a decisive role in resource allocation, competition, and yield formation. This study assessed the effects of four plant densities (8, 10, 15, and 20 plants $m^{-2}$) and three establishment methods (continuous row sowing, hill seeding, and transplanting) on quinoa growth dynamics and yield performance under field conditions at the La Argelia Experimental Station, Universidad Nacional de Loja, Ecuador. A completely randomized factorial design was implemented, with 6 $m^2$ plots and 0.5 m row spacing. Both plant density and establishment method significantly influenced most growth and yield traits. Transplanting improved establishment efficiency but delayed physiological maturity, reduced plant height, and decreased aboveground biomass, likely due to post-transplant stress. In contrast, hill seeding at high plant density promoted greater plant height (2.28 m), aboveground biomass (2414 g $m^{-2}$), and grain number (235,415 grains $m^{-2}$). The highest yield (600 g $m^{-2}$) was achieved at 20 plants $m^{-2}$, exceeding the lowest density by more than 30%, mainly through increased grain number per unit area and enhanced biomass production. These results underscore the importance of optimizing plant density and establishment method to maximize quinoa productivity and provide practical guidelines for improving resource-use efficiency under Andean growing conditions.

### *9.24. Linking Soil Health and Human Wellness Through Organic Approaches to Tomato Nutrition and Safety*

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Introduction: Food security is increasingly challenged by climate change, soil degradation, and water scarcity. Although chemical fertilizers have boosted agricultural productivity, their excessive use can degrade soil fertility, contaminate water resources, and leave residues in crops, thereby raising concerns for food quality and safety. In this context, sustainable organic inputs provide an alternative strategy that not only improves soil health but also enhances the nutritional and functional properties of agricultural products. Tomatoes, being among the most consumed vegetables and a major source of antioxidants and vitamins, offer an ideal model to study the link between soil management and food quality.

Materials and Methods: A field experiment was carried out under semi-arid conditions. Tomato plants were grown under two controlled water-stress regimes and amended with locally produced organic inputs derived from horse manure vermicompost, applied at two concentration levels. Soil physicochemical characteristics, plant physiological responses, and fruit quality traits were assessed, with a focus on bioactive compounds and indicators relevant to nutritional value and food safety.

Results: Organic amendments improved soil fertility and water retention capacity, along with enhanced microbial activity. At the physiological level, plants showed better

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leaf relative water content (RWC) and stronger responses to drought stress. Fruit analysis revealed significant increases in lycopene, ascorbic acid, protein content, enhanced antioxidant capacity (DPPH), and extended shelf life. Notably, higher organic inputs achieved the most consistent improvements across these parameters.

Conclusions: This study highlights the close connection between soil management and food quality. By enhancing soil fertility and improving the nutritional and postharvest traits of tomatoes, organic approaches represent a promising pathway to produce safe, nutritious food while contributing to sustainable food security under climate challenges.

### *9.25. Organic Amendments for Sustainable Agriculture: Unlocking Soil Potential and Crop Performance*

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Soil degradation and nutrient depletion remain pressing threats to sustainable agriculture, particularly in highly weathered volcanic soils where phosphorus (P) retention and structural fragility constrain productivity. This study evaluated the long-term impact of organic amendments (ORG) compared to inorganic fertilization (INORG) across five pasture sites in southern Chile. A comprehensive set of soil health indicators, including physical, chemical, and biological parameters, was assessed alongside plant nutrient status and productivity. Results demonstrated that ORG management significantly improved soil physical structure, reducing bulk density and increasing porosity, water retention, and plant-available water. Chemically, soils under ORG exhibited higher soil organic matter, total carbon, and nitrogen, as well as a 30–40% increase in labile and organic P fractions. Biologically, microbial biomass carbon, nitrogen, and phosphorus increased up to tenfold under ORG, coupled with a 15–50% rise in acid phosphatase activity, indicating enhanced microbial functionality and nutrient cycling. Plant responses mirrored these improvements. ORG-treated pastures produced 25–60% more biomass than INORG-managed sites and showed higher concentrations of N, P, and K in shoots and roots. In addition, elevated chlorophylls and carotenoids supported improved photosynthetic efficiency, while oxidative stress indicators decreased by more than 40%, suggesting greater resilience to environmental stressors. Principal component analysis confirmed that plant vigor, nutrient uptake, and biomass production were strongly associated with organic management, whereas oxidative damage clustered with inorganic fertilization. Overall, these findings provide robust field evidence that organic amendments foster soil resilience and enhance plant performance in temperate pastures. By improving nutrient availability, microbial ac-

tivity, and water regulation, ORG management emerges as a viable pathway to strengthen agroecosystem sustainability under current and future climate pressures.

*9.26. Organic and Conventional Production Systems: Estimated Daily Intake of Essential Elements from Selected Grains*

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Macro- and microelements, together with trace elements, are essential components of human nutrition. The chemical composition of cereals and soybean can vary depending on geographical origin and cultivation system. This study evaluated the estimated theoretical daily intake (%RDI) of selected macroelements through consumption of 100 g of organic and conventional maize, soybean, and spelt grains. Seed samples were grown and collected at three locations in 2017 year: (1) Maize Research Institute, Zemun Polje (Belgrade): organic and conventional maize (Rumenka hybrid) and organic spelt (Nirvana hybrid); (2) Institute of Field and Vegetable Crops, Novi Sad: organic and conventional soybean (Kaća hybrid); and (3) Nova Varoš: conventional spelt. Determination of macroelements was performed by Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES). Concentrations were expressed in μg/g and converted to mg/100 g, and contributions were made to recommended daily intake (RDI). Soybean showed the highest nutritional potential, particularly in Ca (up to 20% RDI), Mg (≈47% RDI), K (≈32% RDI), and S (over 200% RDI). Both soybean and spelt were rich in Fe and Mn, with conventional soybean contributing more than 40% RDI of Fe and spelt exceeding 200% RDI of Mn. Spelt was also a relevant source of Zn, providing more than 200% RDI per 100 g. In contrast, maize generally contributed lower percentages of daily requirements, although it was a notable source of Mg (≈30% RDI) and Zn (≈160–185% RDI). Na content in all grains was very low (0.5% RDI), which is favorable from a public health perspective. Comparison between organic and conventional samples indicated only minor quantitative differences in mineral composition, without altering overall distribution patterns. These findings suggest that maize, soybean, and spelt significantly contribute to dietary intake of essential elements, with soybean and spelt standing out as particularly valuable sources of minerals in human nutrition.

*9.27. Revalorization of Vineyard Pruning By-Products from Different Vitis vinifera Varieties: Evaluation of the Phenolic Profile Across Two Defoliation Seasons*

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In the context of sustainable viticulture and circular bioeconomy, this study investigated the valorization potential of vineyard pruning by-products (leaves), gathered during two seasonal defoliation events across eight *Vitis vinifera* varieties (Vinhão, Touriga Na-

cional, Padeiro de Basto, Alvarinho, Sauvignon Blanc, Loureiro, Moscatel Galigo Branco, and Arinto). This study aimed to evaluate the influence of different defoliation timings (May and June, respectively) on the polyphenolic composition in hydroalcoholic extracts from dried leaves. Identification and quantification of catechin, epigallocatechin gallate (EGCG), gallic acid, quercetin, rutin, ellagic, and 3-O-methylellagic acid (3-MEA) were performed using high-performance liquid chromatography (HPLC) with an ultraviolet multi-diode detector (DAD). Based on the results obtained, it was determined that 50% ethanol solution resulted in a higher content of phenolic compounds for vine leaves in second defoliation. Early defoliation influenced the phenolic composition of leaves by promoting the accumulation of gallic acid and catechin, while the content of quercetin and 3-MEA was higher in second defoliation. Catechin was the most abundant polyphenol identified in the stems, ranging from 32.0 to 345 mg/100 g in the first defoliation and from 24.6 to 309 mg/100 g in the second defoliation. Higher contents of quercetin were obtained in leaf extracts collected from second harvest, particularly in the Vinhão variety (53 mg/100 g). Thus, the contents of 3-MEA, an ellagic acid derivative and a prospective medication for cancer treatment, were found exclusively in leaves collected during the second defoliation, revealing significant differences between cultivars. As a result, these findings allow the optimization of bioactive extraction from vineyard waste for use in functional ingredients, so contributing to a more environmentally friendly and waste-reducing food system. Valorization of this pruning waste presents a possible alternative to disposal, in line with sustainable and health-promoting food innovation goals and enhancing a circular economy.

### *9.28. Scaling Successional Agroforestry Systems to Build Resilient Food Systems in Mozambique*

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Mozambique, especially the coastal Zambézia Province, faces serious challenges from climate change, soil degradation, food insecurity, and rural poverty. ICEI has promoted Successional Agroforestry Systems (SAFS) as a sustainable solution to restore soil health, enhance biodiversity, and improve food security.

This case study, conducted within the three-year Ethaka project (2023–2025), assesses the potential of SAFS to strengthen sustainable food systems in eight rural communities across Maganja da Costa and Namacurra districts. It focuses on the impacts on food security, women's livelihoods, agrobiodiversity, and soil quality.

The SAFS model is based on a holistic, science-informed, and community-led approach. Key components include soil restoration, multi-layered cropping for year-round food availability, high-frequency yields (3–4 harvests per year), integrated livelihoods (e.g., beekeeping and fish farming), strong community involvement, local knowledge transfer, and continuous training through Farmer Field Schools. Nutrition education complemented the agricultural interventions.

The findings reveal strong improvements across all indicators. Women's dietary diversity (MDD-W) increased significantly—from 8% to 23% in Zambézia and up to 43% in Maganja da Costa. Severe child malnutrition was eliminated, and crop diversity rose from 13–15 to 20–26 species per farm. Average crop yields increased by 16% in Namacurra and 87% in Maganja da Costa. Women's income grew by over 120%. Soil fertility improved with pH levels moving closer to neutral, higher organic matter, and better moisture and nutrient retention.

The study concludes that SAFS offer a technically sound, regenerative, and socially inclusive model that is scalable for building resilient food systems in Sub-Saharan Africa. SAFS contribute meaningfully to Sustainable Development Goals (SDGs) 2 (Zero Hunger),

13 (Climate Action), and 15 (Life on Land). Long-term success will require supportive policies, investment in capacity building, and integration into national agricultural strategies.

### *9.29. Seed Quality and Crop Sustainability: The Influence of Stem Rank and Genotype Selection in Sorghum Under Traditional Seed Systems*

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Introduction: Traditional seed systems in sub-Saharan Africa depend largely on farmer-saved sorghum seeds, which play a vital role in food security, seed sovereignty, and maintaining on-farm biodiversity in low-input farming systems. However, limited information exists on how stem rank (mainstem vs. tiller-derived) influences subsequent seed quality, seedling establishment, and yield performance. This study evaluated the interaction between genotype and stem rank harvesting source on subsequent physiological seed quality and field performance under traditional seed systems.

Materials and Methods: Seeds were collected during the 2023/24 season from four sorghum types: two hybrids differing in tillering ability, one open-pollinated variety (OPV), and a landrace grown at the University of Limpopo Experimental Farm. A 4 × 3 factorial design tested the effects of cultivar and stem rank (mainstem, tillers 1–2). Seed viability and vigour were analyzed using R statistical software with an unbalanced two-way ANOVA under a completely randomized design (CRD). Post hoc mean separation was conducted using the Bonferroni–Sadik test at the 5% probability level via the agricolae package. Field performance was analyzed using a two-way ANOVA under a randomized complete block design (RCBD) in GenStat® Version 20, with mean comparisons performed using the Bonferroni test.

Results: Germination exceeded 80% across all genotypes and stem ranks, with no significant differences ($p < 0.05$). However, mainstem and tiller 1 seeds exhibited superior membrane integrity (25 $\mu S \cdot cm^{-1} \cdot g^{-1}$), metabolic activity, and seedling vigour, while tiller 2 seeds showed delayed maturation and reduced vigour, particularly in hybrid Mr. Buster. Field performance mirrored these trends, with yields above 3 $t \cdot ha^{-1}$ but reduced yield in Mr. Buster tiller 2.

Conclusions: All seed sources maintained high viability and yield potential, but prioritizing mainstem, tiller 1 and tiller 2 seeds especially in resilient genotypes such as Macia, PAN606, and the landrace can sustain subsequent seed vigour and productivity in traditional sorghum seed systems across sub-Saharan Africa.

### *9.30. Short-Term Nutrient Dynamics in Conservation Agricultural Practices on a Cambisol in a Semi-Arid Region of South Africa*

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Conventional agricultural practices such as intensive tillage and monoculture have accelerated soil degradation and reduced fertility in South Africa's grain-producing regions, thereby constraining crop yields. Conservation agriculture (CA), which integrates reduced

tillage, crop rotation, and cover cropping, is promoted to restore soil fertility by improving nutrient cycling. However, the mechanisms through which CA influences soil nutrient dynamics in semi-arid environments remain poorly understood. This study evaluated short-term nutrient responses to CA after three years of implementation at the Kenilworth Experimental Farm, Bloemfontein, South Africa. A randomised split-plot design was established with tillage (conventional vs. no-till) as main plots and cropping systems (maize monoculture, fallow–cereal rotation, maize–cover crop rotation, and legume–cover crop rotation) as subplots, replicated three times. Composite soil samples (0–30 cm) were collected at crop maturity and analyzed for phosphorus (P), copper (Cu), and manganese (Mn). Significant interactions between tillage and cropping systems were observed. No-till combined with a wheat–fallow rotation decreased Mn content by 24% compared to conventional tillage and wheat–fallow–maize systems, due to declines in effective cation exchange capacity. Compared to conventional tillage and maize monoculture systems, no-till maize monoculture increased Cu content by 22%, associated with elevated soil pH. Compared with maize monoculture, the maize–cover crop system decreased available P by 27%, likely due to P immobilisation in cover crop biomass. Overall, the results demonstrate that short-term adoption of CA in semi-arid regions generates divergent nutrient responses: some practices enhance micronutrient availability, while others constrain macronutrient supply. These findings highlight the complexity of nutrient cycling under CA and emphasise the need for system-specific nutrient management. The study provides mechanistic insights to refine CA practices for sustaining soil fertility and crop productivity in semi-arid South Africa.

### *9.31. Soil Quality Assessment of an Experimental Plot at University of Ibadan, Nigeria*

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This study aimed to describe, classify, and provide baseline data for assessing soil quality at the Organo Mineral Fertilizer Plant experimental plot, Barth Road, University of Ibadan. Objectives included evaluating the soils for agricultural use, mapping their spatial distribution, and determining soil quality ratings of the identified units.

A detailed soil survey was conducted on the 1.05 ha plot using a rigid grid method. Auger examinations at 10 m intervals revealed three mapping units, with one profile pit excavated in each. Soil samples from various horizons were air-dried, crushed, and sieved before undergoing physical, chemical, and biological analyses.

Three soil series were identified: Balogun (Typic Kanhaplausalf/Haplic Lixisol), Egbeda (Chromic Kandiustalf/Chromic Lixisol), and Ibadan (Typic Kandiustalf/Manganiferric Lixisol). Textures ranged from sandy to sandy clay loam. The Balogun series graded from sandy at the surface to sandy loam beneath. Soil pH values (6.20–7.07) indicated slight acidity to near-neutrality. Organic carbon content was moderate to high, with the Ibadan series recording the highest value (17.56 g/kg). Total nitrogen was moderate (4.38–6.32 g/kg). Although calcium, magnesium, potassium, and sodium were low, micronutrients such as manganese, iron, copper, and zinc were abundant.

All soils showed high base saturation (>50%) and well-developed horizons, confirming their classification as Alfisols. They were slightly acidic to slightly alkaline, with medium to high organic carbon levels, making them suitable for crop production. Based on the soil quality index, IND_B and IND_A performed best (1.00 and 0.90, respectively), while IND_C (SQI 0.90) remained suitable for farming. To enhance productivity, exchangeable bases should be supplemented through organic and inorganic fertilizers. Overall, the soils are suitable for sustainable agricultural management and productivity improvement.

*9.32. Soil Quality Enhancement Through Integrated Farming Systems*

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Sustainable agricultural productivity depends on soil quality and management practices. Integrated crop–livestock systems offer a promising pathway to enhance agri-food system resilience through soil quality improvement. This study evaluates soil quality dynamics under varying integration levels in a Mexican agricultural region characterized by conventional monoculture maize production, addressing critical gaps in sustainable transition strategies. Four farming systems were compared, FS1 (low-integration system: maize monoculture, no grazing) and three medium–high-integrated systems, all of them including grazing: FS2 (grass + legume), FS3 (grass + maize + cover crop), and FS4 (grass + maize + legume). Soil samples were collected at the beginning and end of two crop cycles, with physical and chemical properties analyzed. Key soil quality indicators were identified via Principal Component Analysis (PCA) and aggregated into a Soil Quality Index (SQI) for each farming system. Monoculture maize (FS1) exhibited a significant decline ($p = 0.001$) in SQI (13.8) compared to higher-integrated systems (average SQI = 17.7) by the end of the evaluation period. Legume integration (FS2 and FS4) consistently improved SQI, underscoring its role in soil health. PCA identified organic matter, nitrogen, and bulk density as primary drivers of soil quality differentiation. Higher-integrated farming systems significantly mitigate soil degradation compared to monocultures, with legume inclusion offering additional benefits. SQI provides a robust tool for monitoring management practices and guiding sustainable transitions. These findings advocate policy and practitioner prioritization of diversified systems to reconcile productivity with environmental sustainability in farming systems. Acknowledgements: The authors wish to thank the UNAM (Project: CI 2454) for providing financial and institutional support for this study.

*9.33. Supplementary Red LED Lighting for Concurrent Disease Suppression and Yield Gains in New Zealand Glasshouse Production*

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Greenhouse production systems in New Zealand face dual challenges of limited light availability during winter and high pathogen pressure, both of which restrict productivity. Conventional responses rely on agrochemical inputs, yet these approaches are increasingly unsustainable. Recent advances in controlled-environment photobiology suggest that supplementary monochromatic red LED light can simultaneously stimulate growth and activate defence mechanisms, offering a sustainable alternative. Red light is perceived by phytochromes, triggering downstream transcriptional changes that regulate salicylic acid signalling, antioxidant enzyme activity, and secondary metabolite biosynthesis—pathways known to enhance resistance against necrotrophic pathogens such as Botrytis cinerea.

To test these effects, a glasshouse experiment was conducted at Lincoln University using lettuce as a model crop. Plants were grown under two conditions: supplementary

red LED light (250 μmol $m^{-2}$ $s^{-1}$ for 5 h daily) and an untreated control, for ten weeks. Growth performance was evaluated by measuring shoot fresh weight (SFW) and dry weight (DW). Chlorophyll content was quantified spectrophotometrically using acetone-extracted pigments following Lichtenthaler (1987). Total phenolic content and antioxidant activity (DPPH assay) were also determined. Plants were subsequently inoculated with *B. cinerea* spores to assess disease severity.

Red-light supplementation increased SFW by 45% and significantly increased total chlorophyll, phenolic content, and antioxidant activity compared with controls. Disease severity was markedly reduced in red-light–treated plants: three days after inoculation, lesion length averaged 40 mm compared with 70 mm in controls, and lesion width averaged 18 mm compared with 30 mm. These findings indicate that red-light exposure not only promotes biomass accumulation but also enhances biochemical defences against *B. cinerea* infection.

This work underscores the potential of targeted spectral manipulation as a dual strategy for yield enhancement and disease resistance in glasshouse crops. Such findings contribute to the mechanistic understanding of light-mediated defence and provide a framework for scaling sustainable lighting strategies in controlled-environment agriculture.

### *9.34. Sustainable Citrus Farming Through Aromatic Alley Cropping: Agronomic and Market Benefits*

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To strengthen the positive role of agriculture in ecosystems, Best Management Practices (BMPs) have been developed to enhance sustainability through water conservation, reduced pesticide use, and crop diversification. Among them, alley cropping systems—the deliberate association of annual crops with rows of perennial woody species—have emerged as a promising alternative to intensive monocultures, with the potential to improve both soil health and crop performance.

This study evaluated the agronomic and economic viability of alley cropping applied to lemon cultivation (*Citrus* × *limon*, cv. Fino) in the Region of Murcia, Spain. Two complementary approaches were adopted: (i) surveys with farmers and consumers to assess their willingness to support sustainable practices despite potential additional costs, and (ii) a ten-month field experiment comparing two treatments: lemon trees bordered with Mediterranean aromatic plants (*Rosmarinus officinalis* L. and *Lavandula dentata* L.) versus a control without aromatics, both using black plastic mulch.

The aromatic alley cropping system significantly improved soil moisture and mineral content, enhanced photosynthesis and vegetative growth, and increased yield. Notably, it advanced the first lemon harvest by one month, enabling earlier access to high-value markets.

In conclusion, integrating aromatic plants into citrus orchards through alley cropping proved to be agronomically beneficial, economically viable, and environmentally sound. Beyond the local context, this strategy represents a scalable approach to foster climate-resilient and sustainable agriculture in Mediterranean and semi-arid regions.

### *9.35. Sustainable Maize Crop Management: A Multifactorial Long-Term Field Experiment in Hungary*

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This study presents a multifactorial long-term field experiment designed to evaluate the combined effects of fertilizers, hybrid varieties, planting density, tillage practices, and crop rotation on sustainable crop management. The treatments included three tillage systems (Ripping tillage, Strip tillage, Winter plowing), three levels of NPK fertilizer (0, 80, 160 t/ha), three maize hybrids (Merida, Fiednico, and P9985), two plant densities (60,000 and 80,000 plants per hectare), three types of tillage, crop rotation (winter wheat, maize) and irrigation (irrigated –non irrigated). The study was conducted in 2024 at the Látókép Experimental Station (Debrecen, Hungary). The experiment was established to address the need for integrated agricultural practices that optimize crop yield, soil health, and resource use efficiency over extended periods. The long-term experiment has a split-plot design. The main plot treatments are tillage and irrigation, with no replication. Data were collected following standardized protocols and statistically analysed using Genstat 12th edition. Results demonstrate significant interactions among the factors. The three hybrid treatments evaluated: Merida hybrid had the highest average yield (11.02 t/ha), followed by Fiedncio and P998510.67-10.51 t/ha, respectively. Interaction between hybrids, fertilizer, and tillage did not show a significant difference in yield, as determined by the Duncan multiple-range test at the 5% significance level. It could suggest using a low amount of fertilizer with any type of hybrid and tillage. Irrigated plots consistently outperformed non-irrigated counterparts. All hybrids with ripping tillage had the highest yields, and Merida yielded significantly more with ripping tillage ($p < 0.05$). This suggests that Merida is a promising variety for cultivation, making it a preferred choice for farmers looking to maximize output. This research provides valuable insights into balancing productivity with sustainability, offering a framework for developing resilient cropping systems that can adapt to evolving agricultural challenges. The findings support the adoption of diverse management practices to enhance both economic and ecological outcomes in long-term crop production.

### *9.36. Sustainable Use of Organic and Industrial Waste Amendments to Enhance Durum Wheat Productivity and Soil Fertility Under Water Scarcity in the Mediterranean Region*

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Water scarcity severely limits crop productivity in arid and semi-arid regions, highlighting the need for innovative soil management strategies to enhance plant performance

and maintain soil health under limited water. However, field-based evidence combining mineral-rich by-products with biodegradable organic amendments remains limited, especially in cereal systems under drought stress. A two-year field experiment (S1 and S2) was conducted using a randomized design with three replicates per treatment, each plot covering 1.2 $m^2$. Five treatments were evaluated: Control (T-), recommended NPK, steel slag (S, 700 kg $ha^{-1}$), green waste compost (OA, 4000 kg $ha^{-1}$), and their combination (S_OA), under well-watered (100% ETc) and drought stress (30% ETc) conditions. Application rates were previously optimized in greenhouse trials. Compost, derived from plant residues, contained 20% organic carbon, 700 ppm available phosphorus, 1.5% total nitrogen, and 0.5% potassium, while steel slag from a Moroccan steel industry contained 0.37% $P_2O_5$, 30.6% CaO, and 8% $SiO_2$. A two-way ANOVA was used to assess treatment effects. Under drought, the combined application (S_OA) significantly improved soil fertility, increasing organic matter (by 183% in S1 and 111% in S2), total nitrogen (by 69% in S1 and 96% in S2), and available phosphorus (by 103% in S1 and 94% in S2) compared with the control. Durum wheat exhibited enhanced drought tolerance, with higher photosynthetic efficiency (+5.13% in 2023 and +4.78% in 2024), relative water content (+24% in S1 and +27% in S2), and grain yield (+68% in S1 and +59% in S2). Grain protein and nitrogen contents increased by 51% and 35% in S1 and 42% and 35% in S2, respectively. Heavy metal analysis in grains showed no significant differences between untreated and treated plants, confirming the environmental safety of the amendment. Nonetheless, further studies are needed to evaluate long-term metal accumulation in soil and economic feasibility at larger scales.

### *9.37. Vermicomposting of Two-Phase Olive Mill Waste with Eisenia fetida to Reduce the Environmental Impact of Olive Oil Production and Produce a High-Quality Soil Amendment*

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Olive oil production is integral to Mediterranean culture and economy. Yet, the disposal of olive mill waste (OMW) poses major environmental risks due to its phenolic content, low biodegradability, and phytotoxicity. Vermicomposting using *Eisenia fetida* offers a sustainable method to convert two-phase OMW into a nutrient-rich soil amendment, while reducing its toxicity. This study evaluated the feasibility of vermicomposting OMW mixed with dairy cow manure to produce a high-quality soil amendment without impairing earthworm performance.

A completely randomized design with four treatments and four replicates was used, testing OMW-to-manure ratios of 0:100 (control), 33:67, 50:50, and 67:33 as a feedstock in 20 × 20 × 9 cm plastic containers. Each container received ten mature *E. fetida* earthworms and was incubated for one month at 21 °C and 75% moisture. Parameters monitored included electrical conductivity (EC) and pH, while phytotoxicity was assessed by germination of lettuce seeds exposed to extracts of the resulting vermicompost.

Vermicompost pH was 7.7 across treatments, while EC increased with increasing OMW concentrations, ranging from 685 µS/cm (control) to 1062 µS/cm (OMW-67%). Earthworm biomass increased in all OMW treatments relative to the control. However, cocoon production declined with higher OMW content, suggesting temporary reproductive inhibition. During a subsequent recovery phase in which earthworms were transferred to dairy manure, biomass remained similar across treatments, and cocoon production increased above control levels, demonstrating a temporary rather than permanent reduction in reproductive activity. Lettuce seed germination exceeded 90% in all treatments (91–93%), indicating low residual phytotoxicity.

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These findings indicate that OMW can be effectively converted into a high-quality soil amendment through vermicomposting when mixed with cow manure, while maintaining viable, reproductively active earthworm populations. This process offers a practical and environmentally sound approach to managing a major agro-industrial byproduct in Mediterranean regions, supporting circular economy practices and sustainable agricultural development.

### *9.38. Vermicomposting Spent Coffee Grounds with Eisenia fetida: Effects on Earthworm Performance and Compost Quality*

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Coffee production generates large volumes of spent coffee grounds (SCGs) as a nutrient-rich residue. Despite this potential, the direct use of SCGs as a fertilizer is limited by their acidity and secondary metabolites such as caffeine, tannins, and polyphenols, which can inhibit plant growth. This study assessed the feasibility of combining SCGs with raw cow manure as a feedstock for vermicomposting by examining their effects on the growth and reproduction of *Eisenia fetida* and the phytotoxicity of the resulting compost.

Four treatments and four replicates were used in a completely randomized design, testing SCG-to-dairy manure ratios of 0:100 (control), 33:67, 50:50, and 67:33. Each $20 \times 20 \times 9$ cm container was stocked with ten mature *E. fetida* earthworms and maintained for one month at 21 °C and 75% moisture. Parameters monitored included pH and electrical conductivity (EC). Phytotoxicity was assessed using aqueous extracts of the vermicompost in a lettuce germination bioassay.

Vermicompost pH was 7.5 across treatments, while EC decreased with higher SCG content, ranging from 674 µS/cm in the control to 383 µS/cm in the 67% SCG treatment. Increase in earthworm biomass was higher in the 33% SCG but lower in the 50% and 67% treatments relative to the control. Cocoon production decreased with increasing SCG content. In a subsequent recovery phase, where earthworms were transferred to a manure-only environment, biomass stabilized across all groups, and cocoon production increased relative to the control, suggesting that reproductive inhibition under higher SCG levels was reversible. In the lettuce seed test, the germination rate was above 90% for all treatments (92–93%).

Overall, the results demonstrate that a 33:67 SCG-to-manure ratio provides optimal conditions for vermicomposting, enabling efficient processing of SCGs while supporting earthworm performance and producing a phytotoxin-free organic soil amendment. This highlights the potential of integrating SCGs into circular bioeconomy practices in sustainable agriculture.

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