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ENLIGHTEN Agriculture

PEER REVIEWED MAGAZINE

CHICKPEA VARIETY NAMED AFTER YOUNG INDIAN AGRICULTURAL SCIENTIST

DR. NUNAVATH ASWINI

WE DEDICATE THIS ISSUE TO HER REMEMBRANCE

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E-MAGAZINE

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EDITORIAL NOTE

It is with a deep sense of honor, reflection, and renewed commitment that we present the second issue of Enlighten Agriculture. This edition is not just another milestone, it is a heartfelt dedication to the memory of Dr. Nunavath Aswini, a brilliant young agricultural scientist whose journey from a humble tribal village to the pinnacle of Indian agricultural science has left an indelible mark on our community.

Dr. Aswini's passion, intellect, and groundbreaking research in chickpea genetics, climate-resilient crops, and molecular breeding continue to inspire students, scientists, and farmers alike. Her legacy now lives on through the newly released chickpea variety "Pusa Aswini", a testament to her enduring contribution to the nation's food security and scientific advancement.

This issue celebrates innovation and resilience across multiple fronts of agriculture. We explore emerging technologies like electronic noses and tongues, delve into genetic resistance against crop diseases, and examine future-ready practices including seed biopriming, atmospheric water harvesting, and climate-smart agriculture. Our authors also spotlight natural farming, interior landscaping, precision livestock farming, and nutritional enrichment in vegetables, reflecting a holistic view of sustainable development in the sector.

The story of From Vision to Victory: The Inspirational Journey of Dr. Nunavath Aswini serves as the emotional centerpiece of this issue, reminding us that the pursuit of knowledge, when guided by integrity and compassion, can transcend even time.

We thank our contributors, reviewers, and readers for being part of this meaningful endeavor. With our newly received ISSN 3049-3293, Enlighten Agriculture is more than a magazine, it is a growing movement to spotlight voices that matter and solutions that endure.

Let us continue to learn, innovate, and grow together.

Warmly,
Editorial Team
Enlighten Agriculture

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EDITORIAL

Carbon, Crisis, and Crops: Toward a Regenerative Future for Global Agri-Food Systems

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The agri-food system, as cross-disciplinary consensus is facing an inflection point of structure. This interaction of climatic volatility, resource degradation, and eventualities of geopolitical instabilities have made the weaknesses of agri-food infrastructures apparent. In addition to episodic shocks, there is systemic stressor that requires reorganization of production architypes, mechanisms of governance, and innovation epistemologies. UN Intergovernmental Panel on Climate Change in their Sixth Assessment Report (IPCC AR6 WGIII, 2023, Ch. 7) have stated that global Agriculture, Forestry and Other Land Use (AFOLU) sector constituted around 22% of anthropogenic global GHG emissions in 2019 with emissions mainly caused by methane and nitrous oxide. The major drivers are livestock systems and rice wetlands along with excessive synthetic nitrogen fertilizers usage. At the same time, the farming is highly susceptible to climate change: production of staple crops like wheat, maize, and rice is expected to fall by 4-10 % per degree of global temperature rise especially under low-latitude conditions (Zhao et al,. 2017; Ray et al., 2019).

Contrary to widespread thoughts, increasing total factor productivity (TFP) is not sufficient to stop the intensifying risks by ecosystem imbalance and external input dependency. According to the Global Agricultural Productivity (GAP) Report 2023, the growth of TFP worldwide has decreased to 1.14 % per year instead of the sustainable level of 1.73 % that is required to feed 9.7 billion people by 2050 (GHI, 2023). The worst slowdowns are being experienced in areas that have already been hit by acute food insecurity, especially the sub-Saharan Africa and South Asia. Moreover, it is visible to be observed that the input-intensive monocultures have reached their agronomic production capacity. Nutrient run-off of excessive nitrogen use has resulted in over 400 reported hypoxic zones world-wide to-date, as reported in the latest updates of the United Nations World Water Development Report 2023.

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There is still much undone to turn this funding into agroecological transformation and regenerate the soils and carbon-neutral innovation. It also should be noted that such constructive phenomena as "climate-smart agriculture" (CSA), "nature-based solutions" (NBS) and rational subsidies based on the payment for ecosystem services should be re-adjusted. The growth of new perspective "Carbon for soils, not soils for carbon" highlights, a classic change in the management of soil system and carbon sequestration questioning will be witnessed. Traditionally, the soils were considered as the carbon storehouses whose main contribution has been to climate-change mitigation. Rather than the wider set of benefits that are produced by resilient soil ecosystems, which must take centre stage (Moinet et al., 2023). There are too few CSA frameworks that pay proper attention to labor rights, gender equity, or land tenure, in the context of smallholders, pastoralists, or Indigenous communities who control over 80 % of the global biodiversity hotspots (FAO, 2021; Garnett et al., 2020). This fact emphasizes an idea that the agricultural sector needs to be reshaped and rethought not just as a productivity project but also as an ecological unit and even as a sociopolitical one. Indeed, agricultural science must shift from optimizing the status quo towards driving structural reimagination. Minor changes won't suffice – **we need a solid transformative and systemic change. Let's think globally and act locally to revolutionize the future of agriculture!**

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From Vision to Victory: The Inspirational Journey of Dr. Nunavath Aswini

"A PEN FROM ASWINI'S FAMILY"

Dr. Nunavath Aswini's life story is a radiant tribute to brilliance, resilience, and an unyielding pursuit of purpose. Born on January 7, 1996, in the humble village of Gangaram, Khammam district, Telangana, Aswini grew up in a household rooted in simplicity and hard work. Her father, Shri Nunavath Mothilal, a dedicated farmer, and her mother, Smt. Nunavath Neja, who balanced household duties and farming, instilled in her the core values of determination and discipline. A pillar of support throughout her journey was her brother, Nunavath Ashok Kumar, who encouraged her ambitions and believed in her potential. Aswini's academic brilliance emerged early. She excelled in her school years, scoring 91.67% in Matriculation (2011) and 94.60% in Higher Secondary (2013). These achievements laid the foundation for her journey into agricultural sciences. She pursued a B.Sc. Agriculture at the College of Agriculture, Aswaraopet, under PJTAU, graduating in 2018 with a stellar CGPA of 9.27/10 and 10 University Gold Medals—a rare academic feat. Her aspiration to serve Indian agriculture drove her to secure All India Rank 26 (Rank 2 in Cat) in the ICAR-JRF (Plant Sciences) exam, which led her to the Division of Genetics at IARI, New Delhi. At the heart of India's Green Revolution, she conducted groundbreaking research on chickpea genetics under Dr. V.S. Hegde, earning the IARI Merit Gold Medal (2020).

Alongside, she mentored JRF aspirants, showing early signs of leadership. Her scientific curiosity was just as sharp during her M.Sc. studies, where she characterized a different RIL population for pod and seed traits. Her work validated SSR markers like TA64, which showed strong potential for marker-assisted selection (MAS). One of her lines, ToFRIL-214, combined early flowering with high yield, offering a tangible genetic solution to the age-old challenge of achieving early maturity without compromising productivity.

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Dr. Aswini qualified Joint CSIR-UGC NET (Life Sciences) in 2019, with rank 153, the ICAR NET in Genetics and Plant Breeding in 2021 with an impressive score of 87.33%, and later cleared the UGC NET in Environmental Sciences in 2022. Her next academic milestone came with topping the PJTSAU Ph.D. entrance, securing Overall Rank 1 (Crop Sciences-I). She pursued her Ph.D. in Genetics and Plant Breeding at PJTSAU in collaboration with ICRISAT, under Dr. C.V. Sameer.

Her PhD thesis was a pioneering study that combined advanced genetics with applied breeding. Using a RIL population developed through speed breeding, she identified 19 QTLs related to stem growth, flowering, and maturity—especially three major QTLs governing stem determinacy, crucial for mechanical harvesting. Her candidate gene analysis and promising lines like RIL 183 and RIL 173 demonstrated both scientific rigor and practical relevance. Her academic journey reached its pinnacle with a remarkable and historic achievement: securing All India Rank 1 in the Agricultural Research Service (ARS) examination for Genetics & Plant Breeding, one of the most fiercely competitive and prestigious scientific assessments in India.

This unparalleled accomplishment solidified her position as a foremost expert in the field of agricultural science. In 2023, Dr. Aswini's immense talent and dedication led her to a prestigious role as a Scientist at the ICAR–National Institute of Biotic Stress Management (NIBSM), Raipur to develop climate-resilient varieties for global sustainability. Her scientific curiosity spanned crops and disciplines. She authored more than 13 peer-reviewed research papers, with several

more under review at this early stage. Her studies covered QTL mapping, gene expression under stress, transcription factors, and pre-breeding in chickpea, and sugarcane. A standout among these was her work on Cytochrome P450 gene expression under oxidative stress in sugarcane, offering insights into climate-resilient breeding. Aswini was also a prolific science communicator. She published over 10 popular articles in English and Hindi to educate farmers on emerging genetic tools. Her 10 book chapters on pan-genomics, genome annotation, and seed technologies featured in Springer and other academic publications. Her voice resonated in classrooms and conferences alike—she presented her research at seven+ national and international symposia, passionately advocating the integration of molecular genetics with field- level solutions. In April 2024, her accomplishments were recognized with the Young Scientist Award by Agri Meet Foundation and CCSHAU, Haryana, at the International Conference on Advances in Agriculture and Sustainable Development.

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A Living Legacy: Pusa Aswini (Pusa chickpea 4037)

In a historic tribute, on April 14, 2025, the Government of India notified a novel chickpea variety named "Pusa Aswini", developed by the ICAR-IARI Chickpea Team, in her memory. This variety is a game-changer—high-yielding (36.46 q/ha), high protein (24.8%), resistant to multiple diseases, suitable for mechanical harvesting, and is recommended for cultivation in the North-Western Plains Zone of India. This remarkable gesture immortalizes her contributions, making her name eternal in Indian agriculture.

A Life Cut Short, A Light That Shines On

Tragically, during a journey to Raipur from their native, Dr. Aswini and her father lost their lives in a devastating flood on 1st September, 2024, cutting short a life brimming with promise and purpose. Her untimely demise sent shockwaves across the scientific and farming communities. Her work exemplifies how precision breeding, guided by molecular insights, can help overcome the pressing challenges of yield, stress tolerance, and sustainability in Indian agriculture.

Yet, her work, spirit, and vision live on—in every genotype she developed, every gene she mapped, every farmer she served, and every student she inspired. Dr. Nunavath Aswini will forever be remembered as the Glittering Golden Girl of Indian Agriculture—a symbol of what passion, intellect, and perseverance can achieve. Her journey from a tribal village to the pinnacle of Indian agricultural science proves that no dream is too distant, and no legacy too short to inspire generations.

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Progress and Applications of E-Nose and E-Tongue in Horticultural and Food Industries

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Abstract

E-sensing technologies are current trends in developing digitalized horticulture, food, and other industrial sectors. Mimic human olfaction and taste perception artificial sensing systems connected through sensory arrays and sophisticated data processing techniques, further performing pattern recognition algorithms to provide output. Technologies such as electronic nose (E-nose), electronic tongue (E-tongue), and electronic ear (E-ear) are providing top-tier solutions against various pre-harvest and postharvest horticultural management and food control. These recent technologies are rapid, non-destructive, and offer good quality control, detection of adulteration, flavour profiling, etc. Furthermore, it helps in overcoming limitations of traditional sensory evaluation, minimising human error, and chemical analysis methods. Additionally, enhance food authentication, safety monitoring, and product standardization. Integration of technologies with machine learning improves classification accuracy, making them for manufacturers, regulatory agencies, and researchers in ensuring food integrity and consumer trust.

Key words: E-sensing, minimising human error, artificial sensing, product standardization

Introduction

Digitalised technologies such as electronic noses and electronic tongues play important roles in ensuring the quality and safety of horticultural food produce and processed products through detection and monitoring. Lu et al. (2022) quoted applications ranges from food production includes quality control, shelf life monitoring; supervision includes safety detection, adulteration and authenticity; and daily life includes freshness assessment and recognition. These mimic models have ability to assess aroma and taste is basic in food quality evaluation, product authentication, and consumer preference analysis. Over all advantageous including reliable, objective solutions reduce human error, and chemical analysis methods, still approaches that are often subjective, time consuming, require extensive training and sensor issues.

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E nose is designed to mimic the human olfactory system by detecting and analysing volatile organic compounds emitted. E-nose is mainly used in areas such as food, bioprocess control, medical diagnosis and environmental monitoring. By using an array of various chemical sensors (optical, thermal, electrochemical and gravimetric sensors) and pattern recognition algorithms, system can classify and differentiate between products based on their unique odour profiles. E-nose used as an analytical tool in food industries including food authentication, freshness assessment, and adulteration detection, making it a valuable tool in industries such as dairy, tea, coffee, wine, and meat processing. This technique is an effective alternative to sensory methods, chromatographic, and spectrometric methods. Cost effective and can perform real time analysis.

Similarly, the E-tongue mimics human taste perception through electrochemical sensor arrays (potentiometric, voltametric) that analyze taste components such as sweetness, bitterness, acidity, saltiness, and umami. After sensor analysis, electronic interface device generates output, converts it to digital signal. By generating digital taste fingerprints, E-tongue technology enables rapid and precise quality control in various liquid food products, including juices, honey, edible oils, and dairy products. Also, e-tongue have ability to detect various organic and inorganic compounds. It predicts the chemical composition and flavour. It was used in determination of the origin and quality of raw and finished products. It helps in assessment of tea and coffee, taste profile of wine and other beverages.

E sensing technologies are comprehensive, non-destructive, and automated approach to food analysis, reducing the reliance on human sensory evaluation, improves efficiency and consistency, and provide real-time analysis. Limitations such as sensitivity, selectivity, and cross-sensitivity, leading to inaccuracies in complex sample analysis. Mahanti et al., (2024) stated that environmental factors, sensor drift, and aging require frequent calibration, while limited dynamic ranges hinder trace detection. Some challenges including external conditions like temperature, humidity, and background odors affect precision, and high costs for maintenance and calibration. Overall future focus on these areas are to improve their reliability and expand their applications in food safety and quality control.

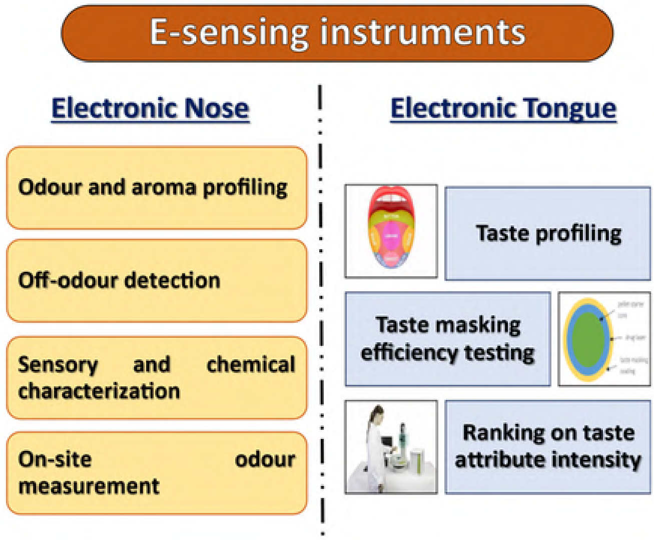

Fig. 1. Roles of E-Sensing instruments in Horti-Food Industries

History: Timeline of E-Nose and E-Tongue Development

Beginning in the 1960s with foundational reaserch on artificial olfaction, followed by theoretical studies on sensor-based volatile compound detection (1970s). Metal oxide semiconductor (MOS) sensors used in 1980s. By the 1990s, the term "electronic nose" gained recognition, with MOS and conducting polymer sensors enabling food quality applications, while the first electronic tongue was introduced in 1994 for taste analysis. In 20th centuries, significant advancements in sensor materials and data processing, improving E-nose and E-tongue performance, including the miniaturization of E-nose devices using MEMS technology are emerged. Also, widespread of applications areas such as e-nose (environmental monitoring and medical diagnostics) and e-tongue (pharmaceutical and water quality analysis) (Fig. 3 E-nose and Fig. 4 E-tongue).

Electronic Nose - Principle and Functionality

An electronic nose (E-nose) is a sensor-based system designed to mimic the human olfactory system. It plays a crucial role in assessing food quality and detecting hazardous gases in the environment. Industries such as food and beverage, perfumery,

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cosmetics, and chemicals traditionally rely on human sensory panels for odor evaluation. However, while the human nose can reportedly detect over one trillion scents through approximately 400 scent receptors, individual perception biases and an inability to reliably detect toxic gases limit its effectiveness.

E-nose systems utilize sensor arrays that generate unique response patterns (fingerprints) when exposed to volatile compounds. These responses are analyzed using pattern recognition algorithms, including Artificial Neural Networks (ANN), to simulate human olfactory processes such as sensing, interpreting, and differentiating odors. When volatile molecules interact with sensor materials, changes in electrical properties—such as conductivity—are detected and analyzed to classify and discriminate odors. Compared to traditional analytical methods like Gas Chromatography–Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC), E-noses provide a cost-effective and time-efficient approach for odor detection and classification. They offer consistent, reproducible measurements.

Electronic Tongue :Principle & Functionality

An electronic tongue (E-tongue) complements the E-nose by mimicking human taste perception, which plays a critical role in food and beverage quality evaluation. E-tongues provide rapid, objective, and cost-effective taste assessments. The human taste system identifies five basic tastes—sweetness, sourness, bitterness, saltiness, and umami—essential for evaluating food palatability. Traditionally, sensory panels assess these attributes, but the process is time-consuming, expensive, and subject to variability due to differences in individual perception.

E-tongues employ arrays of chemical sensors, including electrochemical sensors, biosensors, and optical mass sensors, to detect taste compounds in food samples. These sensors generate specific response patterns that are processed using pattern recognition algorithms. The system configuration varies depending on the type of sensors and data processing strategies used, enhancing versatility in taste analysis.

Different Types of Sensors Used in E-Nose and E-Tongue:

Electronic nose (E-nose) and electronic tongue (E-tongue) technologies rely on various sensors to detect and analyze volatile compounds and taste molecules. These sensors play a crucial role in food authentication, quality control, and safety monitoring (Mahanti et al., 2024).

Electrochemical Sensors

1. Metal Oxide Semiconductor (MOS) Sensors – Detect gases by measuring conductivity changes in metal oxides like tin dioxide. Sensitive to VOCs but affected by humidity and temperature.
2. Polymer Sensors exhibit alterations in their electrical along with optical properties during gas exposure. This sensing technology comes at an affordable price however its performance declines because of drift issues as well as interference factors.
3. The electric potential which forms when sensors track ion interactions serves as their detection method. Highly sensitive but require careful calibration.
4. Amperometric Sensors – Detect analytes via electrochemical reactions. Effective for the device responds to liquids although its performance depends on both pH conditions and temperature variations.

Piezoelectric Sensors

1. Quartz Crystal Microbalance (QCM) Sensors – Detect mass changes by measuring shifts in resonance frequency. Highly sensitive but need frequent calibration.
2. Surface Acoustic Wave (SAW) Sensors – Monitor changes in acoustic wave propagation upon gas interaction. Enable real-time detection but are sensitive to environmental factors.

Optical Sensors – This type of sensors are sensitive to changes in light properties such as fluorescence or absorbance when in contact with the target molecules. Result in fast analysis with no detriment to the evidence but requires initial calibration. While Biosensors include the biological parts as enzymes/antibodies for sensing the particular species

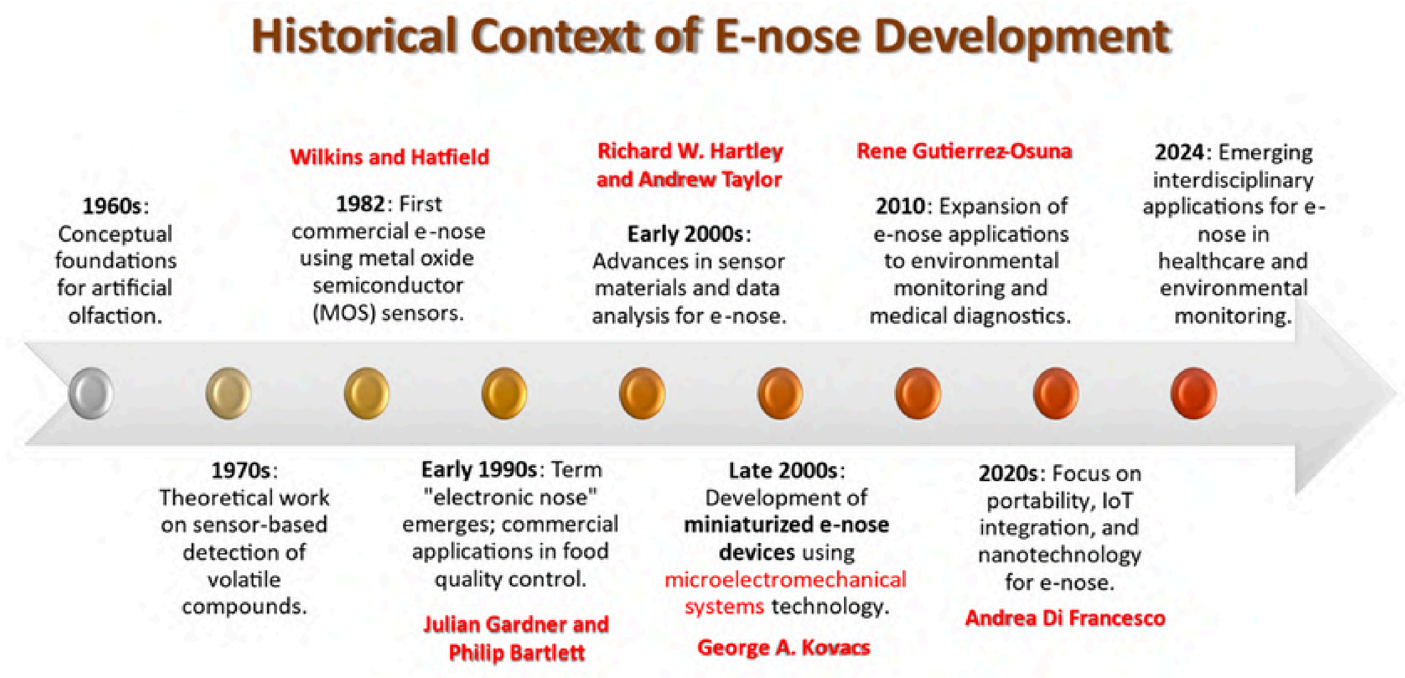

Fig. 2. Historical advancements in E-nose technology

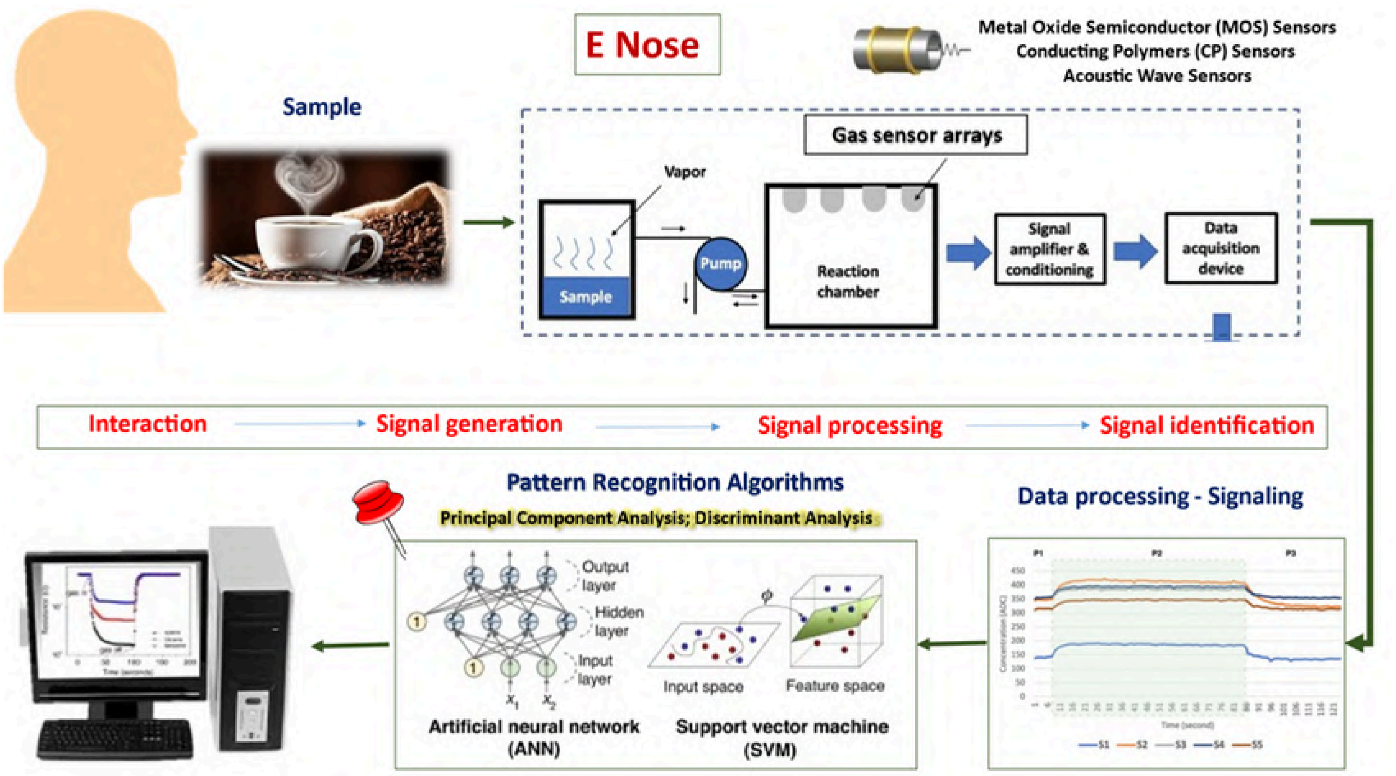

Fig . 3. Functional mechanism of the E-nose

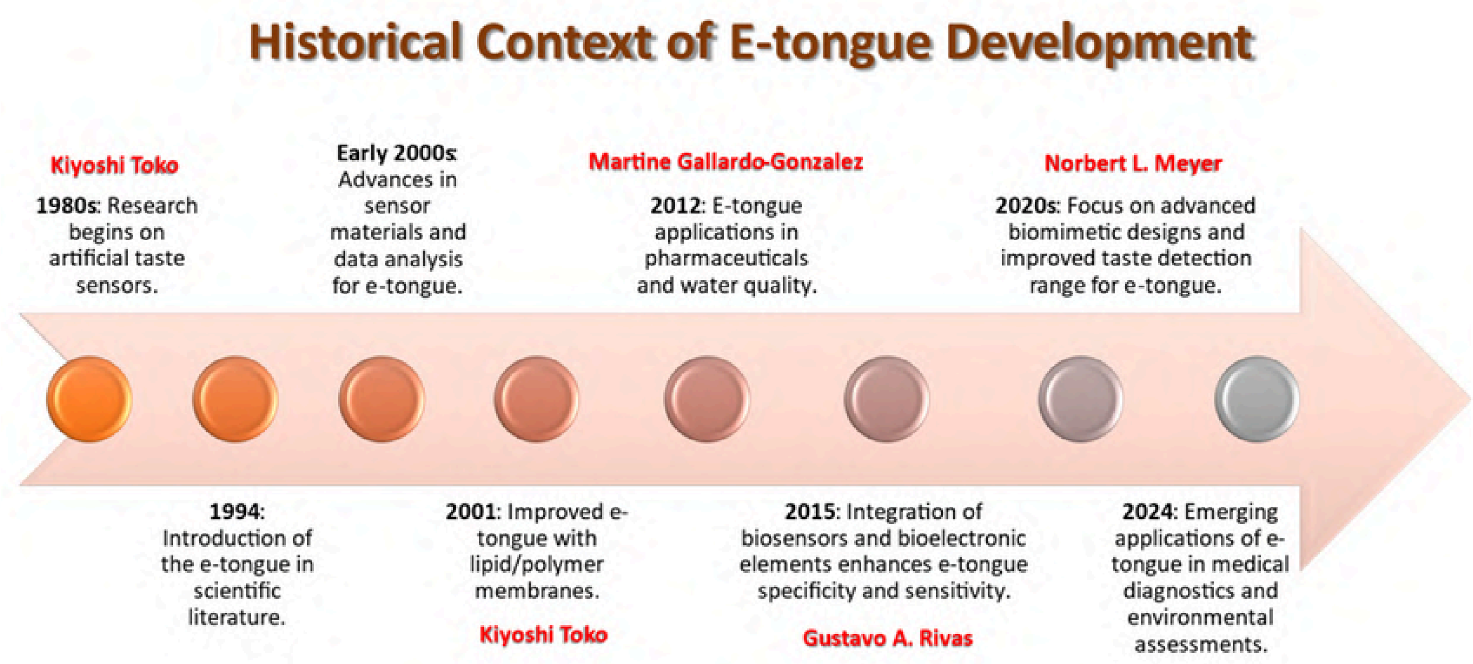

Fig. 4. Historical advancements in E-tongue technology

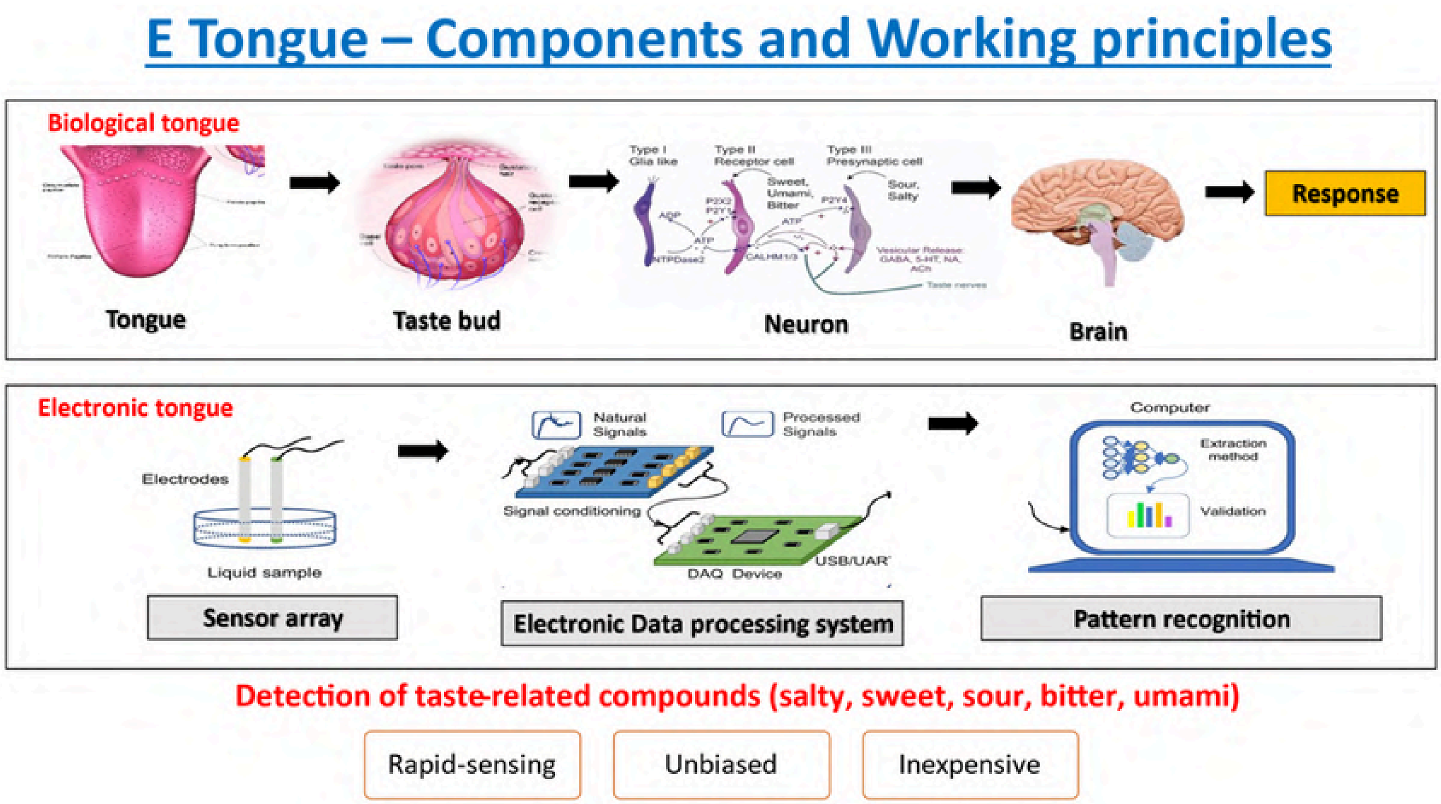

Fig. 5. Functional mechanism of the E-tongue

of interest. They are usually highly selective and sensitive; however, their accuracy depends on specific conditions of the environment.

Application of E-Nose and E-Tongue in Horti-Food Processing

The electronic noise (E-nose) together with the electronic tongue (E-tongue) represents emerging artificial sensor technology that transformed quality control and food evaluation processes in industry. New artificial sensing technologies from the recent generation achieved revolutionary results in food quality control, quality assessment safety, and product development in the food industry. Using the E-tongue to detect these devices examine contaminants while verifying taste quality and determining shelf duration and authenticating ingredients. Its identification work in detecting adulteration combined with food flavor analysis and additive perception plays a major role taste are immense. The E-nose, on the other hand, serves applications like quality control, this instrumentation enables testing of product flavors as well as measurements of storage stability through the evaluation of product maturity levels and ripeness states. The devices determine the ripeness condition of fruits and vegetables through their maturity assessment. It does especially well with monitoring food processing such as cocoa bean fermentation and coffee. The E-nose system performs effectively at both meat freshness and spoilage detection and in the processes of bean roasting. Together, these the combination of these technologies enables the generation of important data regarding food composition features along with sensory attributes. The combination of sensors enables better food quality safeguards as well as safer food products that fulfill consumer requirements. Recent advances in the recent advances in this field can be found in the following table:

(Table .1) Recent advances of E-Nose and E-Tongue in Horti-Food Processing.

Technology	Application	Findings	Reference
E-Nose	Apple ripeness classification	Achieved100% accuracy in ripening stage classification of 'Golden Delicious' apples based on VOC emissions using machine learning.	Trebar et al., (2024)
E-Nose	Mango quality assessment	An ensemble-learning model combined image processing and sensor data, achieving high accuracy in mango sorting.	Nguyen et al., (2024)
E-Nose	Fungal contamination in fruits	Identified fungal infections in peaches and apples with over 97% accuracy.	Martínez et al., (2025)
E-Nose	Tomato disease detection	Used metal-oxide sensors to detect early-stage anthracnose fruit rot (Colletotrichum coccodes) before visible symptoms appeared.	Khlaif et al., (2024)
E-Nose	Food authentication	Reviewed portable sensors like NIR, E-nose, and nanozyme-based sensors for food authenticity in supply chains.	He et al., (2024)
E-Nose	Wine quality control	Identified origin, fermentation process, and defects when combined with E-Tongue.	Zheng et al., (2025)
E-Nose	Floral scent classification	Classified ten cut lily varieties based on VOC emissions with 91.5% PCA variance explained.	Zhou et al., (2025)

E-Nose	Postharvest floral scent monitoring	Differentiated postharvest scent changes in cut Lilium and various Iris species.	Sun et al., (2023); Cai et al., (2024)
E-Nose	Chilli adulteration	Identified adulterants in chili powder using the Histogram of Oriented Gradients algorithm.	Peng et al., (2024)
E-Nose	Environmental VOC monitoring	Applied in air quality assessment but faces challenges in sensitivity at low concentrations.	Li et al., (2024)
E-Tongue	Taste profile	Evaluated the impact of fixation temperature on the taste profile of Longjing tea by analyzing bitterness, astringency, and chemical composition changes.	Shan et al., (2023)
E-Tongue	Coffee beans	Analyzed the impact of roasting conditions on physicochemical, taste, volatile, and odor-active compound profiles of Coffea arabica L. (cv. Yellow Bourbon).	Hong et al., (2024)
E-Tongue	Coconut water classification	Microfluidic impedimetric E-tongue distinguished fresh and industrialized coconut water samples with >90% accuracy using PCA and PLSR.	da Silva et al., (2024)
E-Tongue	Capsaicin detection	ZnO/ITO-based electrochemical E-tongue exhibited high sensitivity and stability for detecting capsaicin.	Ahmed et al., (2024)
E-Tongue	Rice quality analysis	Integrated E-tongue, NIR grain testing, and machine vision to automate amylose content and rice genotype classification.	Fayaz et al., (2024)
E-Tongue	Coffee adulteration detection (coffee shell & stick)	Successfully identified adulterants and quantified impurity levels in roasted coffee after pattern recognition analysis.	de Morais, Rodrigues, Souto, & Lemos et al., (2019)
E-Tongue	Roasted coffee adulteration detection	PLS-DA analysis achieved 100% accuracy in identifying doped samples and 96% for undoped samples.	Rodrigues, Fragoso, & Lemos et al., (2021)

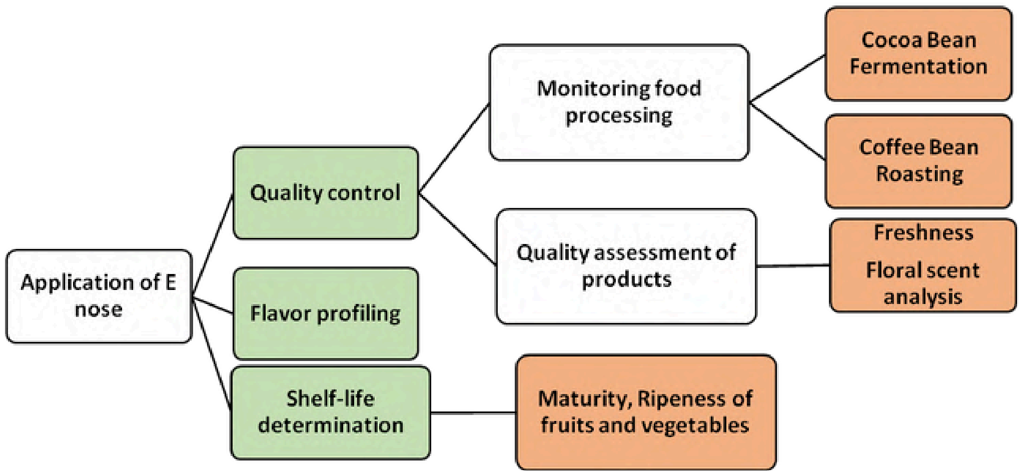

Fig. 6. Glimpses of Application of E-nose in Horti-food Industries

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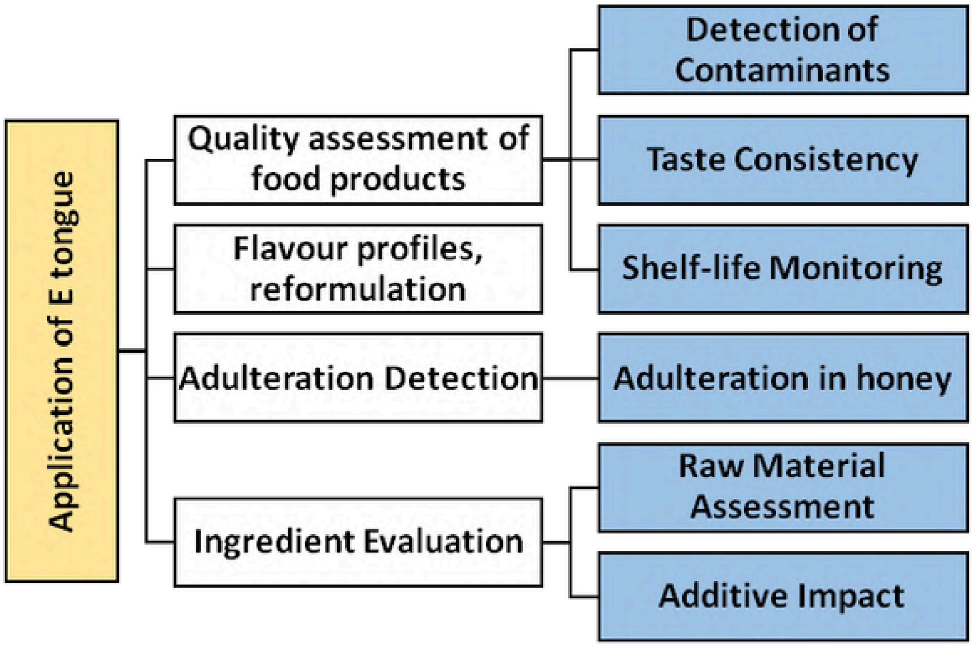

Fig. 7. Glimpses of Application of E-tongue in Horti-food Industries

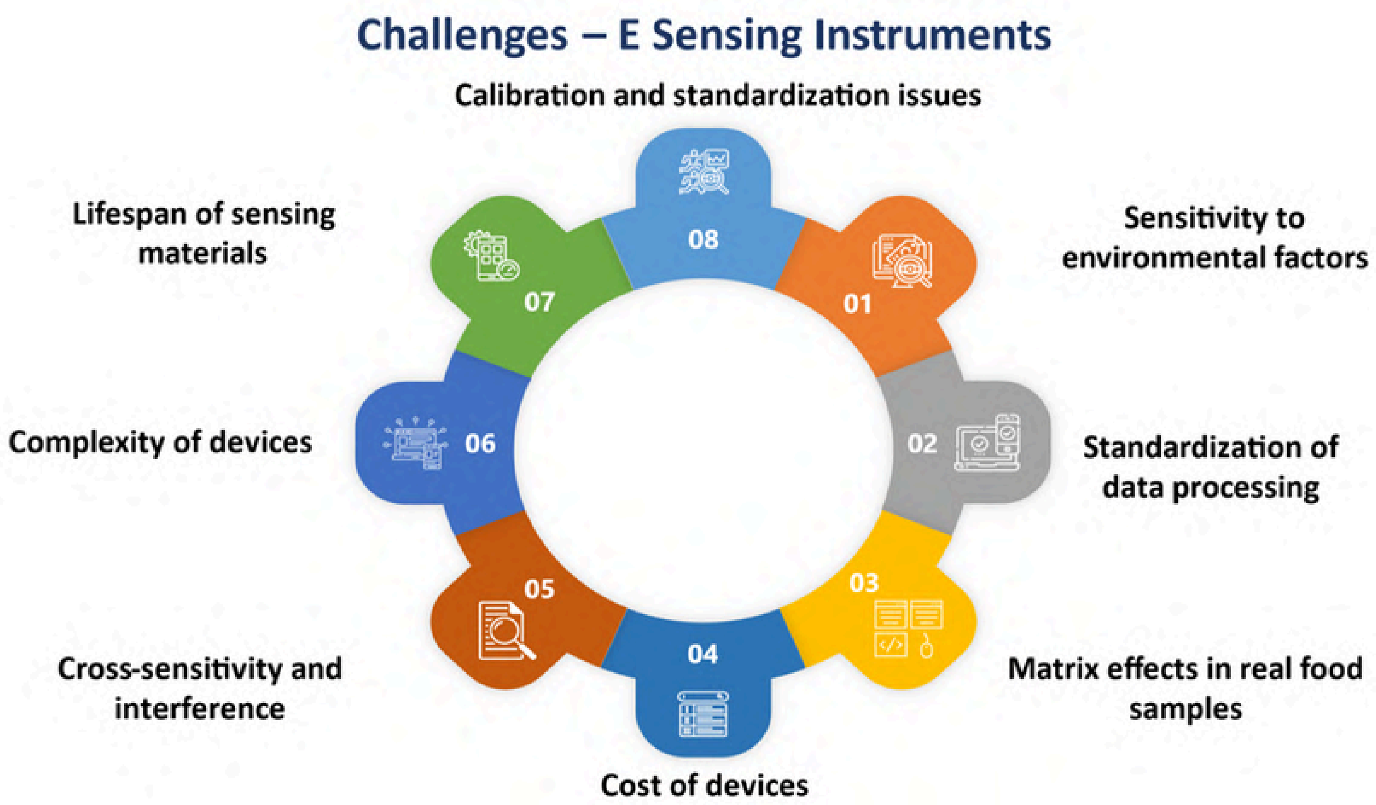

Fig. 8. Challenges of E-Sensing Instruments

Conclusion

Through E-nose and E-tongue technologies the industry has revolutionized food authentication and quality assessment and safety evaluation by performing quick reliable assessments. The latter implies in the use of machine learning that makes the work accurate and helps in achieving better production and less cost especially in terms of manpower though resultant quality is very constant. Such systems link capability of computing with intelligence factor and the ability to use the feeling of touch to create a comprehensive food inspecting technique. It is, however, important to note that while there is room for advancing on the aspects of sensor technology and data processing to tackle non-algorithm adaptability and misidentification that ranges from 4 to 20%, there are the benefits of these systems. Technological development in the future aims to minimize equipment size as well as integrate systems smoothly to enhance accessibility and operational efficiency of these systems. The evolution of E-nose and E-tongue systems presents a vital opportunity for food safety realization and industrial standardization and advancement throughout the food sector.

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Exploring genetic resistance for Blackleg disease in *Brassica napus*

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Abstract

Brassica napus is widely cultivated for its oil and seed meal. Its narrow genetic base and wide cultivation has made the crop prone to various biotic and abiotic stresses. Blackleg disease, caused by pathogen *Leptosphaeria maculans*, causes devastating losses in yield and oil quality. Integrated disease management practices although crucial, are not a sole strategy to control the devastating blackleg disease. The virulent strains of *L. maculans* continuously evolve and pose constant threat to the stability of the resistant B. napus. Resistance genes and loci in the genome are known to facilitate breeding durable resistance cultivars. Qualitative (R gene) and quantitative trait loci (QTL) in the germplasm can mediate resistance at different stages of the plant growth. In this communication, we will discuss the complex life cycle of the deadly pathogen and understand the genetic interactions between the host crop and the pathogen. Further, we will explore the genetic basis of resistance facilitated by the R genes, and QTLs against blackleg disease. In addition, we will dwell into the different resistance genes identified and emphasize their combined use in crop breeding through gene pyramiding for durability of the developed resistant cultivars.

Key words: *Brassica napus*, Blackleg disease, Genetic resistance, RMR gene, QTL, Gene pyramiding

Introduction

Brassica napus is an important oilseed crop worldwide with a global production of over 85,000 million metric tons (USDA-FAS 2025). As cultivated varieties of B. napus were bred focusing on agronomic traits they became genetically uniform; thus, resulting in their increased susceptibility to diseases, pests, and environmental stresses. In particular, blackleg fungal disease became a prominent, causing an annual yield loss of 10-15% on average and has a potential to cause up to a 90% yield

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loss during epidemics (Fitt et al., 2006a; Wang et al., 2020, 2023).The prominent symptom of this disease is stem canker, which affects the vascular system that facilitates water and nutrient transport.The first blackleg disease epidemic was recorded in total collapsed fields of oilseed rape in western Australia during the 1970s (Sivasithamparam et al., 2005). Subsequently, further losses were observed in early 2000s in other regions of Australia, with complete breakdown of single dominant gene-based resistance from *B. rapa supb.sylvestris*. Many other significant losses were reported from the UK, Canada, and mainland Europe in the following years (Neik et al., 2017). In addition to *L. maculans*, which mainly causes blackleg, a closely related but lesser-known species, Leptospheria biglobosa, is also often associated with this disease (Cai et al., 2014). *L. biglobosa* causes less severe symptoms, specifically on the upper stem; however, it is often out-competed by *L. maculans* when present together (Fitt et al., 2006b). In this communication, we will be discussing the disease pertaining to the main pathogen species, *L. maculans*.

Recognizing the importance of blackleg disease, scientists have explored the *Brassica* genetic base for resistance. However, eventually the research converged in one direction: mining for single major genes (qualitative resistance) from *B. rapa* due to its ease of use in breeding. Unfortunately, because of changing environments and evolving new pathotypes, this qualitative resistance rapidly breaks down. In response to this challenge, scientists have recently shifted their focus to finding novel stable resistance from other sources, specifically from *B. oleracea*. Therefore, it is crucial to delineate the underlying genetic and molecular mechanism of blackleg resistance (BR) for breeding resistant *B. napus* cultivars.

Blackleg disease pathogen, *Leptosphaeria maculans*

Leptosphaeria maculans belongs to Ascomycetes family of Fungi kingdom, which follows a hemi-biotrophic mode of nutrition, capable of infecting all stages of the crop growth. Its life cycle consists of both sexual (ascospore) and asexual (pycnidiospores) spores, facilitating high evolutionary potential and adaptivity to harsh environments. The crop debris from the previous crop cycle acts as a congenial environment for the resting spores, acting as a primary source of inoculum (Hall et al., 1992). Upon the spore germination, it first enters through the leaf stomata or wounds and causes necrotic lesions (Rouxel et al., 2003). Further, the blackleg pathogen enters and grows through the petiole to establish in the stem. However, during this initial infection phase, no significant symptoms are visible. As the plant grows and matures, pathogens turn to a necrotrophic mode of nutrition and colonize the stem crown region which restricts the flow of nutrition, weakens the plants, and reduces yield. In severe cases, infection leads to stem canker leading to plant death (Hammond et al., 1985). Primary infection during the early stages is initiated through ascospores, and subsequently, the pycnidiospores inflicts multiple cycles of infection throughout the growing season (West et al., 2001). Ascospores rapidly multiply and have the ability to travel via wind, facilitating infection in subsequent crops and the spread of the disease to distant regions (Rouxel and Balesdent et al., 2005).

L. maculans has evolved unique strategies to overcome the resistance incorporated into canola. One of its most dangerous features is its ability to build a large population, attributed to its ability to reproduce through both sexual and asexual modes. This facilitates pathogens to undergo rapid evolution and overcome single gene resistance. In addition to these biological features, the main character that determines its efficiency is its compartmentalized genome that facilitates rapid diversification and quick adaptation to new host resistance (Rouxel et al., 2011).

The variation in the avirulence (Avr) gene profile of the pathotypes is likely a result of the pressure exerted by race-specific resistance of the qualitative genes present in resistant cultivars. Consequently, emergence of new pathotype isolates carrying novel Avr genes is the result of pathogen's evolutionary dynamics (Van de Wouw et al., 2024). Therefore, updating and standardizing differential sets will be essential for effectively defining evolving pathotypes/races in the future. To mitigate this disease, several cultural, chemical and mechanical management practices are followed (West et al., 2001). However, these efforts have been quite futile for complete control. Developing canola cultivars carrying genetic resistance against the blackleg pathogen is the most environment friendly and economical approach.

Sources of genetic resistance against blackleg disease

B. napus (AABB) and its diploid progenitors, *B. rapa* (AA) and *B. oleracea* (CC), are the primary source of genetic resistance against blackleg. Winter – type *B. napus* is genetically more diverse with broad range of resistance genes in comparison to spring- type *B. napus* varieties that majorly relies on few genes e.g., Rlm1, Rlm3, Rlm4 genes for resistance (Rouxel et al., 2003; Light et al., 2011; Larkan et al., 2016). However, as a consequence of its highly inbred nature,resistance in *B. napus* is scarce. The A genome has been a major source of BR carrying several resistance genes—such as Rlm1, Rlm2, Rlm7, LepR1-4, and Rlm11—mapped on *B. rapa* genome. In contrast, resistance genes have been less frequently identified in *B. oleracea*, among the few known genes, Rlm13 and Rlm14 have been characterized in detail (Ferdous et al., 2020, Raman et al., 2021; Degrave et al., 2021). Additionally, some level of resistance is reported in *B. oleracea* var. *capitata* (Korean germplasm) and in the C genome of the allotetraploid species *B. carinata* (Robin et al., 2017; Ferdous et al., 2020).

The approach to broaden the genetic diversity in resistance to combat the blackleg disease is the most sustainable approach (Rouxel et al., 2024). Breeding effort are being carried out to identifying newer resistance species from the wide gene pool of Brassicacea family. Attempts in crossing these wild resistance species and progenitor species with cultivated *B. napus* are being carried out to introduce the resistance into the commercial lines. For instance, wild *brassica* species, *Sinapis arvensis*, is reported to demonstrate strong resistance against multiple aggressive strains of *L. maculans* (Winter et al., 2003; Snowdon et al., 2007). Further, *B. napus* has been hybridized with its related allopolyploid species such as *B. juncea* (AABB) and *B. carinata* (BBCC), which are known to carry novel genetic resistance against the disease (Katche et al., 2019; Quezada-Martinez et al., 2021, Wu et al., 2024). In the following sections, we will discuss in detail the two major categories of BR; qualitative resistance, which is mediated by major R genes and quantitative resistance which is brought about by multiple minor-effect loci.

Understanding qualitative resistance for Blackleg disease

Single gene resistance (R) that produces robust and rapid gene response is termed as qualitative resistance. These qualitative genes mediate resistance independently or in coordination with environmental factors at different stages of the plant development. Interaction between *B. napus* and *L. maculans* follows gene for gene interaction, where a response is triggered as a reaction to the pathogen, which carries corresponding Avr gene (Bent and Mackey et al., 2007). Hence the R-mediated resistance (RMR) is usually considered to be race- specific. RMR is linked with cell death and hypersensitive response (HR) reaction and can be easily accessed through cotyledon assay (Table 1.). RMR genes are mostly found to be highly heritable and hence, are tested at the cotyledon stage efficiently. The presence and absence of the Avr genes, forms the basis for the pathogen race classification.Many of the RMR genes identified do not have a published genomic location and are recognized by their characterized Avr (Rlm5, Rlm6, Rlm10, Rlm14) despite being introgressed into *B. napus* and thus are assumed to segregate as single gene (Borhan et al., 2022). In addition, LepR series of qualitative genes on the A genome of *B. rapa* ssp. *sylvestris* have been introgressed successfully into B. napus (Yu et al., 2013). Genes especially LepR1 and LepR2, play a crucial role in resistance at both cotyledonary and adult plant stages (Yu et al., 2005). LepR1 offers complete resistance at all stages of plant growth and LepR2 confers partial resistance at cotyledonary stage only (Yu et al., 2005). However, as the plant grows, it faces several diverse pathotypes, as a consequence, cultivar resistance is not retained consistently till crop reaches adult stage.

The huge phenotypic effect of the R gene in a cultivar, imparts strong selection pressure which forces the pathogen to evolve higher virulence and new pathotypes. Consequently, resulting in complete breakdown of resistance within a few years of the resistant cultivar/variety release. Hence, the constant race between the host and pathogen, characterized as the boom-and-bust cycle needs to be strongly considered while breeding for resistance. The genetic basis of BR is very complex, loci of RMR genes that facilitate the resistance at cotyledonary stage are known to overlap with quantitative trait loci (QTL), which mediate resistance at adult plant stage.

Understanding quantitative resistance for Blackleg disease

Quantitative Resistance (QR) provides partial, race non-specific resistance against a broad range of pathogenic isolates imparting low selection pressure on the pathogen (Table 2.). Therefore, despite being highly influenced by environmental factors, it is very durable in comparison to RMR (Brun et al., 2010). Phenotype evaluation found that QR reduces only disease symptoms and doesn't completely eliminate the disease (Amas et al., 2021). There is a huge effect of genotype × environment interaction on the QR identified in a mapping population and hence, their effect is significantly lower than the RMR.The major reasons behind the ambiguity and ignorance towards their use in breeding resistance varieties is due to: (i) complex genetics of QR, where several QTLs control resistance at various levels during different stages of plant growth. (ii) Influence of varying environmental factors on disease progression and (iii) lack of precision in phenotyping of minor resistance showcased by the minor effect of QR genes.

Identifying characteristic quantitative gene resistance (QR) by genome-wide markers

gene The goal of QTL mapping is to sort continuous (QR), non-Mendelian variation into discrete groups of Mendelian factors (R sets) (Paterson et al., 1988). Researchers developed mapping populations including Double haploid populations from Major × stellar and resistant lines, Caiman, Canberra, ^{AV}Sapphire and Rainbow, which were then used to identify and map several QTLs (Ferreira et al., 1995, Kaur et al., 2009). Exploration of Australian *B. napus* cultivars AG-Castle and AG-Sapphiare was found to be immensely vital in identifying four prominent QTLs with constant heritability on previously identified blackleg QTLs on chromosomes A01, A09, A08 and C06 (Larkan et al., 2016).

Darmor has been the primary source for evaluating blackleg QR in canola (Pilet et al., 1998, Pilet et al., 2001, Jestin et al., 2012, 2015). DH lines from Darmor-bzh/Yudal (DYDH) population in Australian field conditions were used to identify 27 significant QTLs across 12 chromosomes explain 2.14% - 10.13% of the genotypic variance. Among these, seven QTLs on chromosomes A02, A07, A09, A10, C01 and C09 were found consistently across different experiments in multiple environments (Raman et al., 20r18). The consistent identification of QTLs on Darmor and its parent Jef Neuf reiterate their significance as vital germplasms for BR. However, identifying exact location of the QTLs in canola has been challenging due to non-uniform evaluation of different genetic mapping populations from diverse backgrounds (e.g., spring, semi-winter, or winter). With the recent publication of *B. napus* cv. Darmor-bzh sequence and knowledge on physical positions of 425 R genes (Alamery et al., 2019), it is now possible to compare different QTLs and RMR genes identified across various studies and locations

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(Table 1.) RMR genes identified in the Genus *Brassica*.

RMR gene (location)	Mapping population/ Genotype	References
Rlm1 on chr. A7	B. napus (DH "Maxol", and "Columbus", Cultivar "Westar," "Quinta," and "Glacier,")	Raman et al., (2012a), Ansan-Melayah et al., (1995), (1998)
Rlm2 and LepR3 (Allelic version of the same gene) on Chr. A10	B. napus (Cultivar "Westar," "Quinta," and "Glacier,") and B. rapa (cultivar "Surpass 400")	Ansan-Melayah et al., (1998), Li and Cowling (2003); Yu et al., (2008); Larkan et al.,(2015)
Rlm3 on Chr. A7	B. napus (Cultivar "Glacier, Maxol")	Li and Cowling et al., (2003); Delourme et al., (2004); Yu et al., (2008)
Rlm4, Rlm7 and Rlm9 (Allelic version of the same gene) mapped on chr. A7	B.napus (Cultivar "Jet Neuf, Caiman, Darmor- bzh")	Balesdent et al., (2001), (2002); Delourme et al., (2004); Raman et al., (2012b) Larkan et al., (2020); Haddadi et al., (2022)
Rlm5 and Rlm6 (have epistatic interaction)	B. juncea(Cultivar "Aurea" and "Picra")	Balesdent et al., (2002)
Rlm8	B. rapa (Line "156-2-1")	Balesdent et al., (2002)
Rlm 10 on Chr. B4	B. juncea (Cultivar "Junius")	Chevre et al., (1997)
Rlm11on Chr. A7	B. rapa(Accession "02-159-4-1" (R)* × DH "Z1" (S)*, and with "Darmor" and "Eurol")	Balesdent et al., (2013)
Rlm12 on chr. A1	B. napus (GWAS panel of 179 accessions from DH population SAgS)	Raman H. et al., (2016)
Rlm 13 on C03	*B. napus* (Cultivar "ATR-Cobbler")	Raman et al., (2021)

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Rlm14	*B. oleracea* (Cultivar "Monaco")	Degrave et al., (2021)
BLMR1 and BLMR2, single major gene on chr. N10	*B. napus* (Mapping populations of cultivar "Surpass 400" (R) ×"Westar" (S))	Long et al., (2011)
ClmR1(same genetic interval as LmR1) chr. A7	*B. napus* (Two different mapping populations, "DH12075" from cultivar "Cresor" (R) × re-synthesized line "PSA12" (S) and "Shiralee" (R) ×"PSA12" (S))	Mayerhofer et al., (2005)
LepR1(dominant nuclear allele) on chr.A2	*B. napus* (DH population, "DHP95" and"DHP96" with resistance introgressed from *B. rapa* subsp. *Sylvestris*)	Yu et al., (2005)
LepR2 (incomplete,reduces growth) onA10	*B. rapa* (Cultivar "Surpass 400")	Van De Wouw et al., (2009); Neik et al., (2022)
LepR3 on A10	*B. rapa* (Cultivar "Surpass 400")	Li and Cowling et al., (2003); Yu et al., (2008); Larkan et al., (2013); Larkan et al., (2014); Larkan and Bohran et al., (2015)
LepR4 recessive on A genome, N6 linkage group of B. napus	*B. napus* ("DH12075" derived from cultivar"Cresor" that has R gene LmR1 × Westar (S))	Yu et al., (2013)
RlmSTEE98 on A9	*B. napus* (Cultivar "Yudal")	Jiquel et al., (2021)
LmR1 onLinkage group 6	*B. napus* (DH population from cultivar "Shiralee" and "Maluka" (R)× advanced breeding lines (S))	Mayerhofer et al., (1997), Long et al., (2011)

LEM1Linkage group 6	*B. napus* (DH population from cultivar "Major" (R) × "Stellar" (S))	Ferreira et al., (1995)
LmFr1 on A7	*B. napus* (DH from cultivar "Cresor" (R) × "Westar" (S))	Dion et al., (1995), Kaur et al., (2009)
Two independent genes,onedominant (LMJR1 on J13 and one recessive (LMJR2 on J 18)	*B. juncea* (F2 population from F1progeny of Cultivar "AC Vulcan" × Inbred line "UM3132")	Christianson et al., (2006)

(R)- Resistant, (S)- Susceptible

(Table 2.) List of other QR genes identified in B. napus

QR gene (location)	Mapping population/crosses	References
aRLMc and aRLMrb (Adult stage) linked to cRLMm & cRLMrb (cotyledon stage)	*B. napus* (DH population developed from cultivar "Maluka,""Cresor," and "RB87-62" × "Westar" (S))	Rimmer et al., (1999)
Three QTL (Adult plant resistance) on chr. A1, A8, A9, and C6	*B. napus* (DH populations developed from cultivar "AG-Castle" and "AV-Sapphire"(R) × "Topas" (S))	Larkan et al., (2016)
17 QTL for adult plant resistance across 13 linkage groups	*B. napus* (DH lines from BnaDYDH mapping population, initially derived from "Darmor-bzh"(R) × "Yudal" (S))	Huang et al., (2016)
One major QTL on chr. A1	*B. napus*(Worldwide accession from Germplasm Resource Information Network)	Rahman et al., (2016)

Discussion

A constant threat is posed by evolving pathotypes of *L. maculans*, making it essential to develop resistant lines by employing race-specific genes in rotation with stable quantitative genes. Major challenge in identifying QTL for BR is its sensitivity to environmental variation which necessitates evaluating the lines under uniform disease conditions. Next-generation sequencing is a useful tool to associate phenotypic observations with putative molecular mechanisms and capture the large genetic variability (Starosta et al., 2024). Today, genome sequences of all *Brassica* diploids and amphidiploids species, including *B. napus* are available for study and application (Chalhoub et al., 2014; Bayer et al., 2017). Further, utilizing advance genotyping tools like 60K *Brassica* Infinium SNP array and genotyping-by-sequencing (GBS) has swiftly accelerated identification of genes/ QTLs for BR (Rahman et al., 2016).

Earlier, to avoid the pathogen population buildup and RMR gene breakdown, rotation of resistant gene sources every year was recommended. However, as qualitative resistance started staggering, researchers have diverted their attention to the prospects of utilizing QR alongside RMR. While it's undeniable that quantitative resistance (QR) is controlled by multiple genes, exerts low pressure on pathogen evolution and reduces the risk of resistance breakdown, it's also necessary to consider that QR doesn't completely prevent allele diversification, and eventually losses occur over time. Nevertheless, QR plays a significant role in extending durability of R-genes and preventing sudden blackleg epidemics. A Five-year research study by Brun et al., (2010) evaluated Darmor MX introgression line carrying both major gene (Rlm6) and Darmor QR genes and found prolonged resistance in comparison to lines with only RMR genes. Additionally, this strategic use of both RMR and QR genes maintained the avirulence/ virulence alleles of the pathogen resulting in stable resistance (Delourme et al., 2014; Huang et al., 2018). Hence, it can be concluded that during the initial stage of plant growth, RMR restricts the pathogen's colonization and as the plant grows, QR further restricts the spread of blackleg to the petiole main crown region, thereby exhibiting effective resistance.

Conclusion and Future perspectives

Blackleg disease remains a persistent challenge in *B. napus* (canola) cultivation, significantly impacting crop yields and economic sustainability. Integrating genetic resistance with sustainable cultural management practices is vital for a comprehensive disease management strategy. The continuous evolution of *L. maculans* poses a formidable barrier to breeding durable, resistant canola cultivars. To combat this pathogen, plants employ two primary resistance mechanisms: qualitative (major gene) resistance and quantitative resistance (QR). It is mandatory to pyramid both qualitative and quantitative genes for developing stable *B. napus*. Where major gene resistance provides strong but often short-lived protection, quantitative resistance—due to its polygenic nature—offers more durable and sustainable defense.

Given the dynamic nature of the pathogen, the demand for novel resistance genes will remain ongoing. A collaborative effort targeting in compositing a universally accessible database encompassing resistant germplasm is essential. Further, advancements in genome sequencing,multi-omics and gene technologies need to be employed for identifying novel resistant genes and understanding the complex genetic and molecular basis of resistance. Rapid expansion in use of computational biology, machine learning, data mining, and artificial intelligence and high-throughput phenotyping, has revolutionized resistance breeding by facilitating the development of prediction models for precise selection in breeding programs. Therefore, integrated approach combining modern molecular tools with agronomic practices will enhance the durability of resistance, ensuring stable *B. napus* yields.

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Seed Biopriming: A sustainable approach for stress tolerance and enhancement of seed quality

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Abstract

Priming is a pre-sowing technique used to improve seed vigour in terms of germination potential and various biotic as well as abiotic stress resistance. Different priming treatments can be used depending on the plant species, seed form and physiology, all of which facilitate the seed germination and so-called as "pre- germinative metabolism". Various priming methods such as hydropriming, osmo priming, chemo priming, nutri priming, hormo priming and biopriming can be used to enhance seed or plant performance. Of all the methods, biopriming is a realistic technique to improve seed performance in a variety of ways, such as, the increasing germination rates, improving plant growth, disease resistance, yield and eliminating seed as well as soilbornephytopathogens. Bio-priming is an adaptive agricultural method that is critical for food, nutritional and health security. This will assist us in ending poverty, ending hunger, improving health and well-being and so on. Current research work on biopriming continues to explore the potential of these Techniques in addressing agricultural challenges and Improving plant productivity.

Keywords: Biopriming, Biotic and abiotic resistance and Biocontrol agents

Introduction

In an agricultural world, scientists, researchers and farmers are constantly seeking innovative ways to boost agriculture production and productivity. Recently, most of the farming community has moved towards theorganic and sustainable agriculture, creating a need for an efficientbiological management of diseases as an alternative to existing chemicalfungicides. Biological seed treatments with suitable bioinoculants may provide an ecofriendly substitute to chemicalcontrol (Reddy et al., 2013). One such technique that has gained significant importance recently is seed bio-priming. Bio-priming is a technique of seed treatment that integrates biological (inoculation of seed with beneficial organism) and physiological activation (seed hydration) of disease control (Fig. 1.).

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This technique is recently used as an alternative method for controlling many seed- and soil-borne pathogen. (Reddy et al., 2013). Biopriming, an advanced seed enhancement technique, involves immersing seeds in a microbial suspension for a specified period to enable microbial absorption (Callan et al., 1990). Like other priming methods, biopriming enhances germination rate, improves uniformity of germination, and increases seed vigour while also protecting seeds against soil and seed-borne pathogens.This pre-sowing treatment has gained significant attention, offering a wide range of benefits that can lead to improved seed yields and overall plant health. The attractiveness of seed bio-priming lies in its ability to activate the seed's 'pre-germinative metabolism' without allowing the emergence of the radicle, by penetrating the seed coat. One of the most promising techniques involve soaking seeds in a solution containing carefully selected beneficial microorganisms, such as bacterial or fungi biocontrol agents, that can penetrate the seed coat, colonize the seed surface and finally establish in the plant's root system. These biocontrol agents, which include plant growth-promoting rhizobacteria (PGPR), work in synchronization with the plant to enhance its seedling growth and protect it from various biotic as well as abiotic stresses. The mode of action of these biocontrol agents includes mycoparasitism, competition for space and nutrients, production of antibiotics and secondary metabolites, and induction of defense responses, including systemic resistance responses in the plant. In addition, they enhance plant growth and increase crop yields (Harman et al., 2004). Bioinoculants suppress diseasesthrough mechanisms such as siderophore production, secretion of antimicrobial secondarymetabolite and lytic enzymes (Keswani et al., 2014). Currently, biological control is gaining larger attention due to its low-cost and its ecofriendly application. The use of biocontrol agents presents a promising alternative for improving seed quality, enhancing plant growth, and minimizing disease incidence.

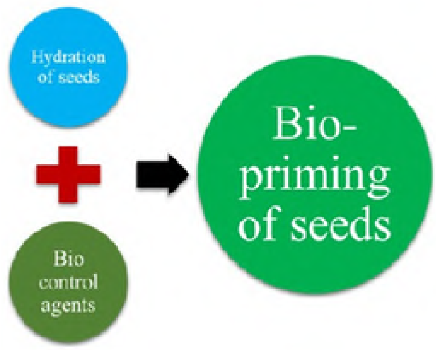

Fig. 1. Biopriming of seeds

Procedures involved in seed biopriming

Ø Selection of an appropriate Bio-inoculants - Beneficial microorganisms (bio-inoculants) are selected and cultured on suitable growth media

Ø Preparation of Suspension of Bio-Inoculants - The cultured bio-inoculants are transferred to a liquid medium to prepare a microbial suspension.

Ø Uniform Mixing of Bio-Inoculants The microbial suspension of bio-inoculants mixed uniformly to ensure even distribution of bio-inoculants

Ø Preparation of microbial Suspension with Different Concentrations - Seeds are soaked in microbial suspensions at different concentrations to determine the optimal treatment.

Ø Drying of Seeds to bring back original moisture content - After soaking, soaked solutions were drained out and the seeds are dried back to their original moisture content under controlled conditions.

Ø Kept for Germination or sowing and evaluation- The bioprimed seeds are placed in petri dishes or germination paper for germination tests to evaluate the effects of biopriming on seed quality and seedling growth.

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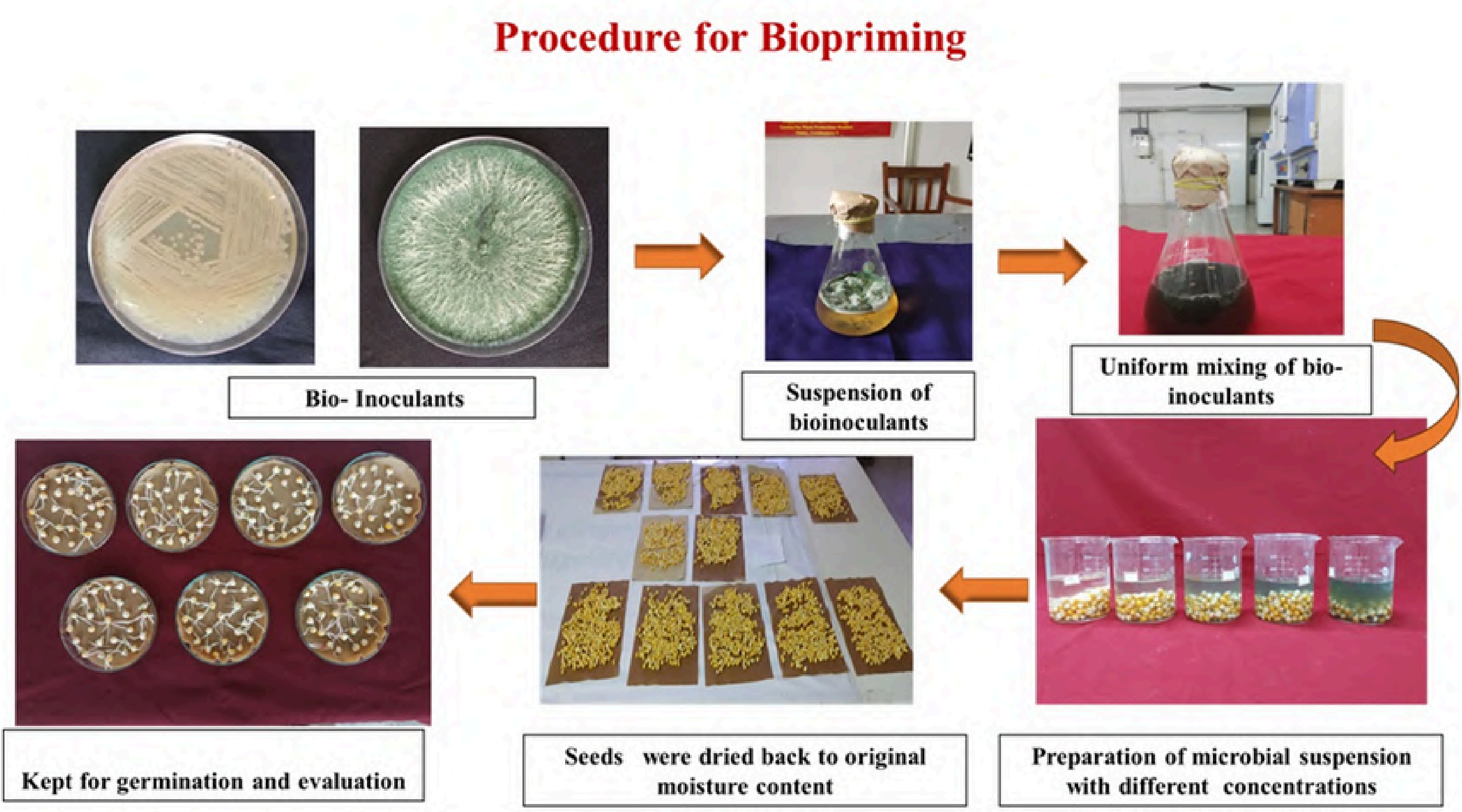

Fig. 2. Procedures involved in seed biopriming

Advantages of Bio-priming Over Other Techniques for Seed Priming

Bio-priming, like other priming techniques, increases the rate and uniformity of seed germination while simultaneously protecting seedlings from seed and soil-borne diseases. Hydration of pathogen-infected seeds during priming can accelerate pathogen growth, potentially reducing germination and seedling vigor. Nonetheless, incorporating biocontrol agents during priming offers a sustainable approach to managing seed-borne diseases (Reddy et al., 2013). Furthermore, certain bacteria that are employed as biocontrol agents can colonize the rhizosphere, promoting plant health both directly and indirectly beyond the germination stage (Callan et al., 1997). Compared to other methods like pelleting and film coating, seed biopriming has proven to be highly effective disease management strategy (Muller and Berg et al., 2008). While hydro priming, osmo-priming, hormo-priming, solid matrix priming, chemo-priming, and nutri-priming primarily targets abiotic stress, biopriming is effective in managing both biotic and abiotic stress. In the early stages of germination, bio-primed seeds outperform non-primed seeds due to their enhanced carbohydrate reserves, which support seedling survival under low oxygen stress in waterlogged conditions (Ella et al., 2011). Additionally, seed biopriming provides an environmentally beneficial alternative to chemical fungicides. As a result, biopriming is currently recognized as a highly effective biological strategy for sustainable agriculture.

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(Table .1) Bio-priming agents for enhancing biotic and abiotic stress tolerance in various crops

Sl.No	Crop	Bio-priming agents	Tolerance against	Reference
1	Rice	Bacillus amyloliquefaciens and Serratia marcescens	Magnaporthe oryzae	Amruta et al., (2019)
2	Soybean	Pseudomonas aeruginosa	Colletotrichum truncatum	Begum et al., (2010)
3	Garden pea	Bacillus velezensis, B. subtilis, B. mojavensis, B. amyloliquefaciens and B. halotolerans	Fusarium proliferatum and F. equiseti	Miljakovic et al., (2024)
4	Pearl millet	Pseudomonas fluorescens	Sclerospora graminicola	Raj et al., (2007)
5	Chilli	Trichoderma asperellum	Fusarium solani and Pythium ultimum	Chin et al., (2022)
6	Maize	Pseudomonas aeruginosa	Rhizoctonia solani	Singh et al., (2020)
7	Oil seed rape	Serratia plymuthica and Pseudomonas chlororaphis	Leptosphaeria maculans	Abuamsha et al., (2011)
8	French bean	Beauveria bassiana and Metarhizium anisopliae	Leaf miner insects	Akello et al., (2017)

Sl.No	Crop	Bio-priming agents	Tolerance against	Reference
9	Mungbean	Pseudomonas fluorescens and Trichoderma viride	Whitefly and Aphid	Dhar et al., (2020)
10	Mungbean	Mixture strains of Pseudomonas fluorescens + Rhizobium phaseoli	Drought stress	Nawaz et al., (2021)
11	Squash	Trichoderma harzianum and Bacillus subtilis	Salt stress	Tarchoun et al., (2024)
12	Cumin	Pseudomonas fluorescence	Drought stress	Piri et al., (2019)
13	Maize	Trichoderma harzianum	Cold stress	Afrouz et al., (2023)
14	Wheat	Trichoderma harzianum	Drought stress	Shukla et al., (2014)
15	Wheat and mungbean	Trichoderma hamatum and Paecilomyces lilacinus	Salt stress	Irshad et al., (2023)

Conclusion

Seed bio-priming is highly innovative technique that not only improves seed germination and seedling vigour but also helps plants overcome both biotic and abiotic stresses.A variety of bacterial or fungal bioagents, such as biopesticides or biofertilizers, may be effective as biopriming agents. Seed bio-priming offers benefits across agricultural, horticultural, and forestry crops. As a sustainable practice, it plays a vital role in boosting crop yields, minimize dependency on chemical inputs, and enhance food security. With the growing challenges of climate change and the increasing global population, continued research and development of seed bio-priming techniques will be essential for ensuring resilient and sustainable agricultural systems.

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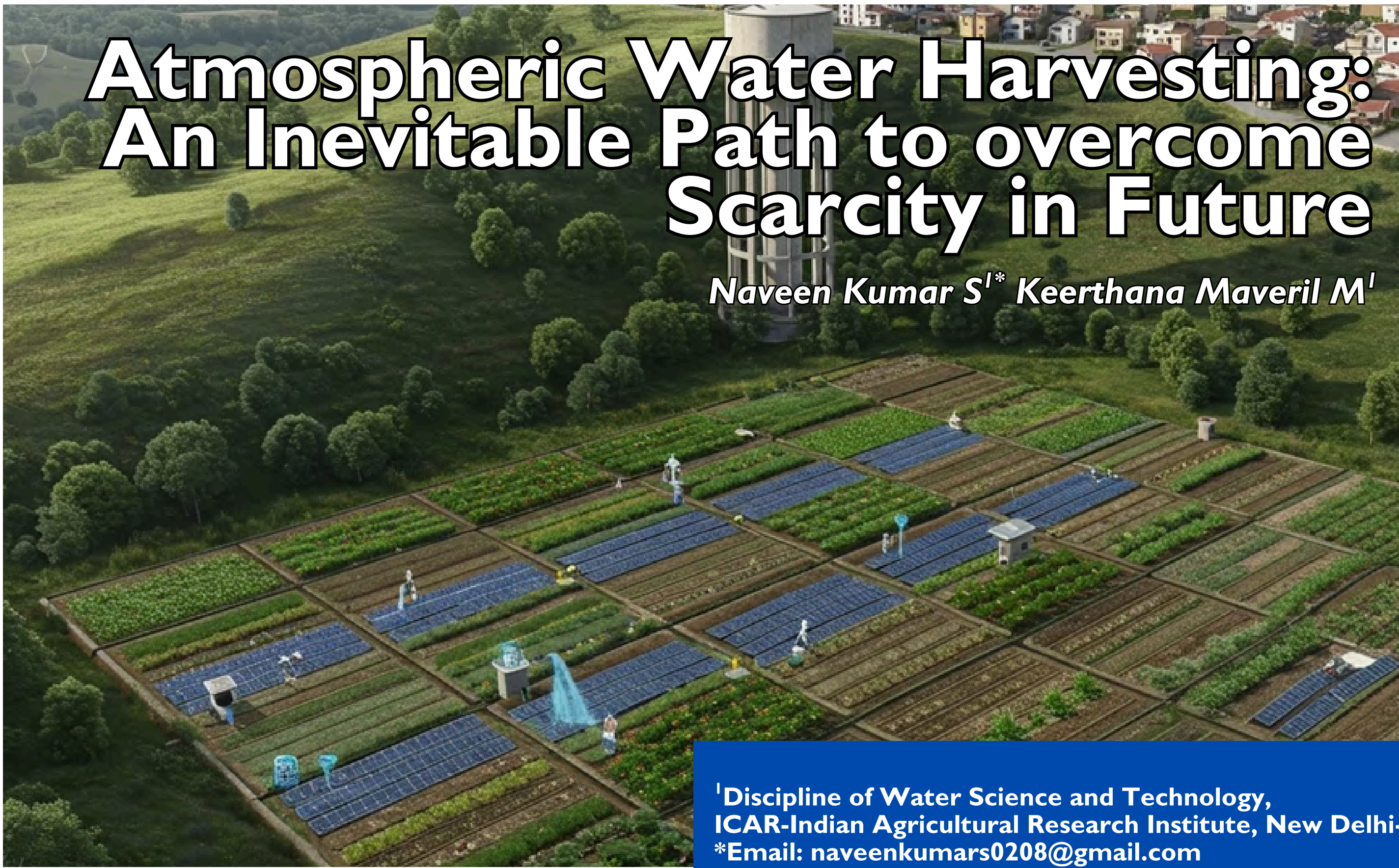

Atmospheric Water Harvesting: An Inevitable Path to overcome Scarcity in Future

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Abstract

Water scarcity is one of the inevitable global challenges recognized by the United Nations, and the level of water stress is anticipated to intensify. Atmospheric water harvesting is extracting water from the atmosphere, typically from humidity in the air, to provide a sustainable source of fresh water. The three main techniques are active cooling, passive cooling and desiccation technology. These technologies offer permissible solutions to the lack of drinking water in water scarcity areas. This article briefly overviews the evolution, principles, types and problems of atmospheric water harvesting.

Keywords: Water, technologies, atmosphere, harvesting.

Keywords: Kalpavriksha, nematodes, quarantine, management

Introduction

water stress is anticipated to increase in the upcoming years (Du Plessis et al., 2019). Both developed and developing countries are facing the challenge of freshwater shortages. Approximately 2.2 billion people lack access to water, while 4.2 billion do not have clean water sources or adequate sanitation facilities (Shingne et al., 2022). According to the United States Bureau of Reclamation, only about 3% of Earth's water is freshwater. Of this, 2.5% is inaccessible, trapped in glaciers, ice caps, the atmosphere, soil, or deep underground. The remaining 0.5% is the accessible freshwater available (Kunde et al., 2021). Approximately 13,000 km³ of freshwater is found in the atmosphere, with 98% in vapour and 2% in the condensed phase. This amount is nearly equivalent to all the freshwater available on the Earth's surface or underground, excluding glaciers and ice caps (Gido et al., 2016). It offers safe drinking water at a small community level without harming the environment (Wahlgren et al., 2001).

Need for atmospheric water harvesting

Atmospheric water harvesting systems are a cost-effective, energy-efficient method for water collection compared to traditional water supply infrastructures. It is safer, chemically stable and environmentally

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friendly than other water sources. It can give life support for people to tolerate water scarcity in dry and polluted areas (Wang et al., 2018).

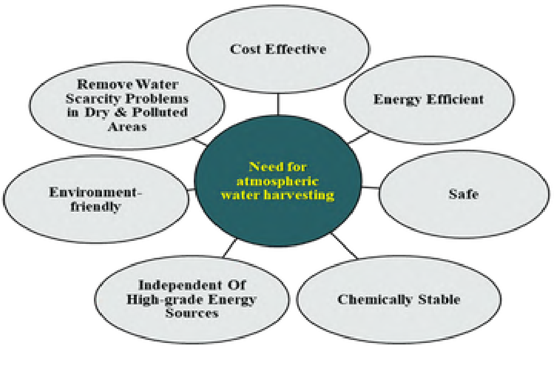

Fig. 1. Need for atmospheric water harvesting

Progress of major developments in fog water collection technology

In 1900, scientists at the University of California, Berkeley, conducted a study to measure fog water in Table Mountain. It leads to the foundation for developing a new fog water collection system type. Then, after 1969, the initial fog collection system was established in South Africa, using fog plastic screens. After the next two decades, research and experimentation continued and finally in 1987, 100 large Raschelmesh type fog collectors were installed to supply water in Germany. By 1995, many countries adopted this technology after successfully installing fog collectors in Chile. The timeline concludes in 2018 with the development of various designs of fog collectors, including 3D plastic mesh net structures

Principles of atmospheric water harvesting

The basic principle of atmospheric water harvesting was Condensation. The Namib Desert beetle has a unique surface texture with alternating hydrophobic (water-repellent) and hydrophilic (water-attracting) regions. Water droplets condensed on the hydrophilic sections and then moved down the waxy, hydrophobic grooves to the beetle mouth parts for drinking. This confusion has now been resolved, and researchers use this naturally found principle to develop fog collection techniques. Condensation is when a gas (usually water vapour) changes into a liquid. This occurs when the water vapour is cooled to its dew point, at which the air becomes saturated and cannot hold all of the water vapour as a gas. As a result, the excess vapour turns into liquid droplets. The process behind condensation involves the reduction in temperature, change of gaseous phase to liquid phase and latent heat of condensation.

Suitable weather conditions for Atmospheric Water Harvesting

Relative humidity: High relative humidity enhances the density of water droplets in fog.

Wind speed: Optimal wind speeds ranging from 2 to 5 m/s are required for effective fog collection, which can balance the sufficient airflow to transport water droplets to collection surfaces while avoiding excessive turbulence that disrupt the process.

Temperature: Temperature below 10℃ enhances condensation on collection surfaces, thereby

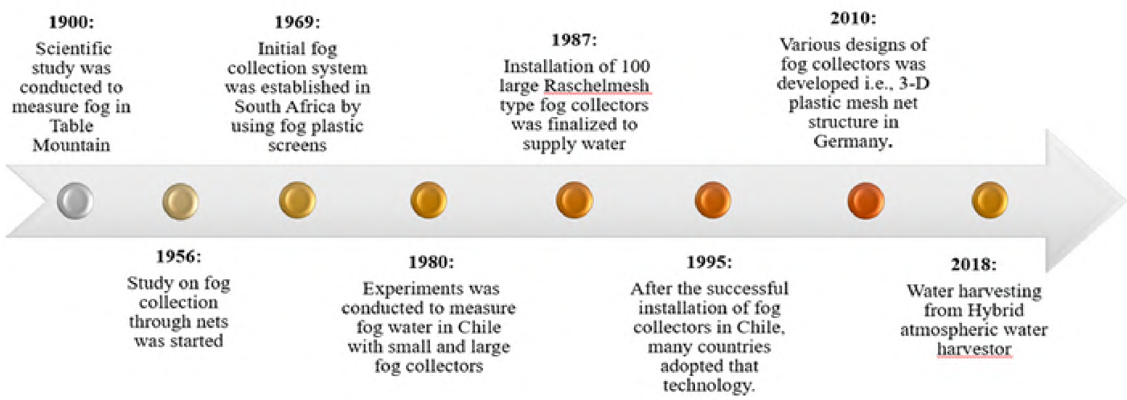

Fig. 2. Progress of major developments in water collection technology (Qadir et al., 2021)

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improving water collection efficiency because lower temperatures increase the condensation rate on mesh surfaces used for atmospheric water collection.

Fog density Denser fog, influenced by factors like humidity and temperature, contains more water droplets, thus allowing for greater water collection

Atmospheric Water Harvesting Technologies

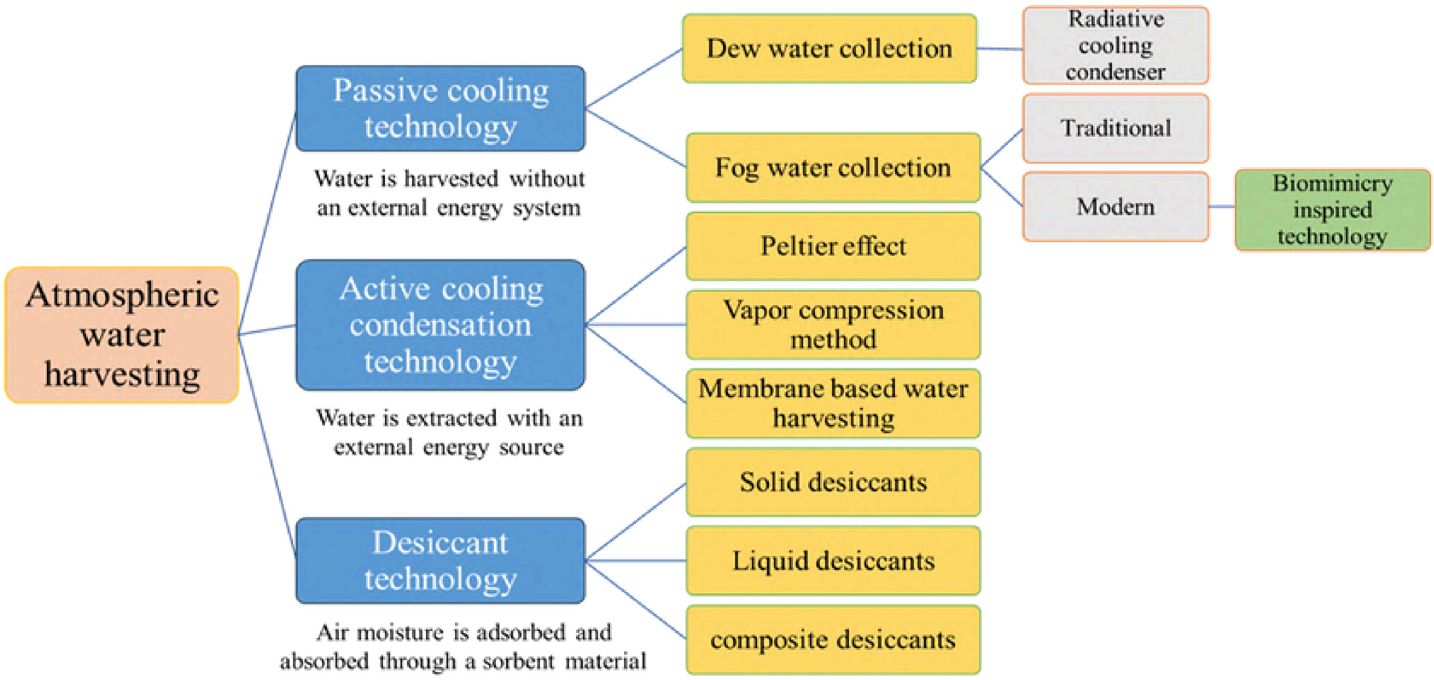

Fig. 3. Different technologies of atmospheric water harvesting (Bilal et al., 2022)

improving water collection efficiency because lower temperatures increase the condensation rate on mesh surfaces used for atmospheric water collection.

Passive cooling technology

Passive cooling technology collects atmospheric water without the use of external energy. It includes techniques like dew collection, i.e., radiative cooling condenser and fog water harvesting using traditional and modern methods inspired by biomimicry technology. Some of this technology includes Stimulus-trigger water collecting technology, which is bio-inspired by desert beetles, dip-coating strategy by spiders, etc.

Active cooling technology

It uses external energy sources to extract water from the atmosphere. In this technology, vapour compression, Peltier cooling, and membrane-assisted techniques are the modern methods that use active cooling technology to collect water from the atmosphere.

Desiccant technology

The sorbent materials can absorb moisture from the air, which can be collected by heating the absorbent to evaporate that water The water can then be placed in an enclosed chamber like glassware.

Problems behind atmospheric water harvesting

∅ Efficiency depends on humidity and temperature, reducing effectiveness in low humidity or cooler regions.

∅ Installation costs for advanced systems can be prohibitive.

∅ Regular maintenance is needed, increasing operational costs.

∅ Scaling up to meet large-scale demands remains challenging.

∅ Potential ecological disruptions need careful management.

∅ Ensuring potable water requires effective filtration and purification.

∅ Ongoing challenges include optimizing materials and enhancing collection efficiency.

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Conclusion

Atmospheric water harvesting is a promising and reliable source of life-saving potable water in arid regions and other water-scarce areas. It is also a supplementary resource for consumers and industries with limited water sources. It does not completely solve the world's water scarcity problems, but it can give a life path for thirsty people suffering from severe water scarcity. By improving this technology in the future, we will provide a new path and source of water for future generations.

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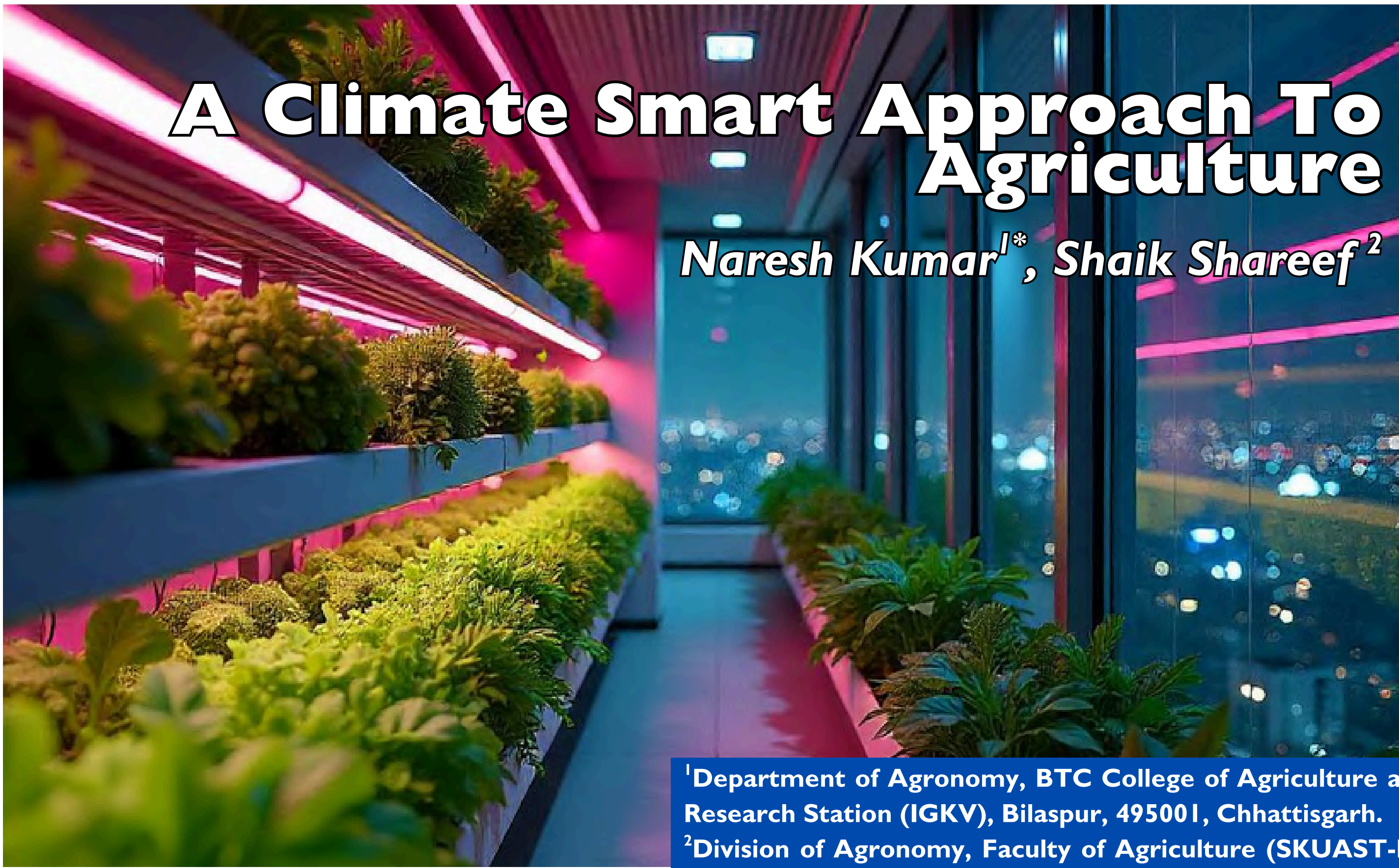

A Climate Smart Approach To Agriculture

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Abstract

As we experienced in our daily life that human population are increasing enormously while our resources for livelihood are limited like land, fresh water. Accordingly, we have to think wisely for our future generations also. CSA is a holistic approach that integrates sustainability, resilience and productivity to address the challenges of food security and climate change. Its main aim to transforming the agricultural systems to be more productive, resilient and sustainable in the face of climate change e.g., use of drought resilient varieties, conservation agriculture, crop diversification, soil conservation techniques, use of drones and sensors for precision farming, carbon sequestration and reduce pollution by minimising the use of fertilizers and pesticides.

Key words: Climate-smart agriculture, sustainability, climate resilience, adaptation strategies, digital agriculture.

Introduction

Agriculture stands at the intersection of two of the most serious global challenges of the future generations ensuring their sustainable growth in food security for a growing population and minimise the harmful impacts of climate change. As the global population is projected to reach nearly 10 billion by 2050, the demand for food is expected to increase significantly. As emphasized by FAO (2021), climate-smart agriculture constitutes innovations which are aligned with three purposes: (a) Increase in sustainable productivity of crops; (b) enhance the resilience of crops against mighty change of climate and (c) minimise the greenhouse gas emissions. However, climate change give a significant threat to agricultural productivity, as increasing temperatures cause a remarkable decline in wheat production worldwide due to rise of temperature in early February coincide with flowering. Recent studies carried out in India highlights the possible loss of 4-5 million t/ha in wheat production with every 1°C increase in temperature (Aggarwal et al., 2008), unpredictable precipitation patterns and a higher occurrence of intense disastrous weather events interfere with global food systems.

Need of CSA Adoption

The importance of adopting CSA practices is underlined by the divergent impact of climate change on vulnerable communities, particularly small land holder farmers in the developing countries. These farmers, who contribute significantly to global food production, often lack the resources and technologies needed to cope with climate-related risks. CSA provides a framework to empower these communities through research and development, innovative implementation of the paramount practices such as conservation agriculture, natural farming, agroforestry, precision farming, and improved package of practices all of which enhance productivity while minimising environmental footprints.

Challenges

Global warming is the steady rise in the surface average earth's temperature which significantly increase the levels of greenhouse gases in the atmosphere. These gases are mainly CH_4, CO_2, N_2O and O_3.

According to the IPCC (2007), these GHG emissions could rise by 25 – 90% by 2030 relative to 2000 and the earth could warm by 3 °C at the end of this century.

The Intergovernmental Panel on Climate Change (IPCC) forecasts that even a temperature increase of 1-2.5°C will lead to severe adverse effects, including the decline in crop yields in tropical and subtropical regions, increase the risk of food shortages, proliferation of climate-sensitive diseases like malaria, and an elevated threat of extinction for 20–30% of Earth's biodiversity.

Since the pre-industrial era, human-induced emissions have significantly elevated atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The harmful and detrimental impact of climate change on global crop production has been extensively documented. (e.g., Challinor et al., 2014; Kuwayama et al., 2019; Lachaud et al., 2021; Miller et al. 2021; Schmitt et al., 2022).

For example, the Latin America and the Caribbean study by Lachaud et al., (2021) showed that climate change reduces farm productivity by 9.03–12.7% in 2015–2050. Analyzing a half-decade panel dataset, Amale et al., (2022) demonstrated that delayed monsoon onset harms crop production in India. The adverse impacts of global climate change, coupled with the imperative to enhance agricultural productivity, necessitate the adoption of Climate-Smart Agriculture (CSA) practices to alleviate climate-induced challenges. However, the widespread implementation of CSA is impeded by several factors, including substantial initial investment requirements, limited access to technological innovations, and insufficient policy support. Additionally, the success of CSA initiatives often depends on the integration of local knowledge, stakeholder collaboration, and supportive institutional frameworks.This review paper aims to explore the principles, practices, and policies underpinning climate-smart agriculture, critically analyse its benefits and limitations, and highlight opportunities for scaling up its implementation.

Resolution of challenges

By integrating the traditional knowledge of research which are usually based on natural practices and existing along with the role of emerging technology i.e., artificial intelligence for providing better and sustainable future for the farming communities, so that farmers get maximum benefits while utilizing optimum resources. It also aims to identify gaps in current knowledge and propose directions for future research, with the ultimate goal of informing policymakers, researchers, and practitioners in their efforts to build climate-resilient food systems.

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In a world grappling with the dual crises of climate change and food insecurity, climate-smart agriculture offers a beacon of hope, bridging the divide between environmental sustainability and agricultural productivity.

Overview of Climate-Smart Agriculture (CSA)

Climate smart agriculture is a holistic approach that integrates various components and make a way for the sustainable food security, climate resilient varieties, adaptation towards drought and stress. It is generally based on three important points.

1. Increasing Agricultural Productivity and Incomes: CSA aims to sustainable increment in crop yields to fed the growing demand for food while improving farmers' livelihoods status. It is clear, if the farmer of a country are satisfied with the government decisions and they earned surplus production then the country revenue enhanced by manifolds especially in developing countries like India. So we have to assure our farmers by giving them maximum benefits such as by implementing various government schemes and MSP for their products.

2. Adaptation and Resilience: CSA focuses on building the capacity of agricultural systems to resist climate-related shocks, such as stress, droughts, floods, and extreme weather conditions.

3. Reduce the emissions of the Greenhouse Gases: There are several factors which significantly contributes towards GHGs emissions such as emission of CH_4 from the paddy field, N_2O emits from fertilizers industry and cattle livestock, O_3 emission pose serious health impacts on living beings.

Management

- Reduce dependency on synthetic nitrogen fertilizers like urea, the highest contributor of GHG emission due to its widespread uses.
- To effectively manage N_2O emissions from livestock, major focus on improving the nitrogen use efficiency and reduce nitrogen input.
- To manage CH_4 emission from paddy field, adopt Alternate wetting and drying method which saves water also.

The idea of Climate-Smart Agriculture (CSA) arose from the understanding that conventional farming methods are inadequate to tackle the problems posed by climate change. By incorporating climate-related factors into agricultural planning and practices, CSA offers a comprehensive approach to achieve the goal of especially Zero hunger SDG 2 and Climate Action SDG 13.

Key Practices and Technologies in CSA

I. Sustainable Farming Practices

II. Better practices of land and water management

III. Technological Innovations

I. Sustainable Farming Practices

a.) Conservation Agriculture: Conservation agriculture involves minimal soil disturbance, use of zero tillage, soil cover with green manure or crop residue (mulching), and crop rotation to improve soil structure, porosity, and organic matter accumulation while saving fuel, time, and labour. Conservation tillage improves soil fertility, water, and crop productivity, while no-tillage provides better soil protection than conventional tillage, which leaves only 1-5% of the soil surface covered with crop residues

b.) Agroforestry: Integrating trees into farming systems increases biodiversity, sequestration of carbon, and provides additional income sources for farmers such as timber, fuel, food, fodder, medicines etc.

c.) Integrated Pest Management (IPM): Reducing reliance on chemical pesticides by using biological controls like neem oil for altering the behaviour of insects and crop diversification minimizes environmental impacts.

d.) Crop diversification and crop intensification: Crop diversification is to alternatively sow different crops in a sequence in the same piece of land in the same year to next year. And crop intensification is that instead of doing one crop, grow two crops and instead of two crops grow three crops in a sequence in same year.

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II. Better practices of land and water management

Improving land and water management is important for sustainable agriculture, eco-friendly environment and tackle the threats of soil degradation, climate change and water scarcity. The following practices are as:

Land management

1. Crop rotation: It is the rotation of different crops on the same piece of land generally cereals are followed by legumes and tap root system crop by shallow rooted crop.

It plays an important role in climate smart agriculture as it maintains the soil fertility, soil structure, increased water holding capacity of soil and soil organic matter content.

2. Zero tillage: In which the primary tillage is completely avoided and secondary tillage is restricted to row zone only. It's a key component of CSA helps by reducing the emissions of GHGs as lower fossil fuel use, enhancing the carbon sequestration in soil and maintains the microbial population of the soil.

3. Agroforestry: It supports CSA by enhancing the overall agricultural productivity and diversification, enhance the carbon sequestration, increase resilience to climate change.

4. Zero budget natural farming: Focus on locally available inputs where one enterprise becomes the output of other enterprise. It maintains the soil fertility by restricting the use of synthetic fertilizers, minimise vulnerability to climate change impacts, also reduce environmental pollution.

5. Cover cropping: such as cowpea has a large canopy protects the soil from erosion, fixes atmospheric nitrogen in the root nodules, enhance nutrient availability to the succeeding crops.

Water management

1. Drip irrigation: Drip irrigation can be defined as the process of slow application of water in the form of discrete, continuous drop, tiny streams or miniature sprays through mechanical devices called emitters. Modern drip technology was invented by Simcha Blass in Israel. It is also known as trickle system. Drip system has the greatest potential where water is scarce or expensive.

Advantages of Drip irrigation

- 40-70% saving of water
- 25-100% increase in yield
- 50% saving in energy by reducing pumping hours and friction losses.
- Drip is better for saline soils not for saline water.

2. Sprinkler irrigation: Sprinkler irrigation is a method of applying water to crops mimicking natural rainfall. It is suited to topographic or hilly areas. It is evolved in 1946. Also known as overhead irrigation.

It is not used if the wind speed is greater than 15Km/hr. It is not ideal for crops, sensitive to fungal disease.

Advantages:

- It saves 25-50% water
- It increases irrigable area 1.5-2 times to that of surface irrigation at the same amount of water.
- Water use efficiency can be increased 3-4 times with sprinkler over irrigating sandy soil with flooding

3. Mulching: It has been referred to the gardener's straw and leaves used as soil cover (Jacks et al,1955). Mulching is the technique of covering the soil surface around the plants with an organic or synthetic material to create congenial conditions for the growth and development of plant and efficient production. (Bakshi et al. 2015).

Advantages of Mulching:

- It maintains the soil temperature.
- It controls the evaporation loss.
- It suppresses the weed growth.
- Increase the infiltration of water.
- Improves microbial activity.
- It controls salinity development.

4. Rainwater harvesting: It is the process of collecting, storing and utilizing rainwater for various purposes such as irrigation, domestic use or groundwater recharge. This sustainable technique helps to conserving water and reduce the impact such as soil erosion especially where erratic rainfall occurs.

III. Technological Innovations

- Precision Agriculture: Using GPS, remote sensing, and data analytics to optimize input use (e.g., fertilizers, water) increases efficiency and reduces

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environmental impacts.

- Renewable Energy: Solar-powered irrigation pumps and biogas systems reduce reliance on fossil fuels and lower greenhouse gas emissions.
- Digital Tools: Mobile apps and online platforms provide farmers with real-time weather forecasts, market prices, and advisory services.

Policy and Institutional Frameworks

- **Global Initiatives:** FAO's CSA Framework: The Food and Agriculture Organization (FAO) has been a key advocate for CSA, providing guidelines and technical support to countries.
- **Paris Agreement:** Under the United Nations Framework Convention on Climate Change (UNFCCC), many countries have included CSA in their Nationally Determined Contributions (NDCs) to reduce emissions and enhance resilience.
- **National Policies :** At the global level, the United Nations Framework Convention on Climate Change (UNFCCC) addresses issues related to CSA through a number of frameworks such as REDD+(Reducing Emissions from Deforestation and Forest Degradation, conservation and sustainable management of forests, and enhancement of forest carbon stocks) as well as the Ad-Hoc Durban Platform, National Adaptation Plans, and technology transfer (Campbell et al., 2014).
- **Subsidies and Incentives:** Governments can promote CSA by providing financial incentives for adopting sustainable practices and technologies.
- **Capacity Building:** Training programs and extension services help farmers understand and implement CSA practices.
- **Research and Development:** Investing in agricultural research fosters innovation and the development of climate-resilient technologies.
- **Challenges in Policy Implementation Lack of Funding:** Limited financial resources hinder the scaling up of CSA initiatives.
- **Coordination Issues:**Fragmented efforts among stakeholders (e.g., governments, NGOs, private sector) can reduce the effectiveness of to CSA programs.
- **Policy Gaps:** Inconsistent or inadequate policies may fail to address the specific needs of vulnerable communities.

Benefits and Impacts of CSA

a.) Environmental Benefits

- **Carbon Sequestration:** Practices like agroforestry and conservation agriculture capture and store carbon in soils and vegetation.
- Carbon sequestration potential of agroforestry in India. The CO_2 reduction in atmosphere can only be achieved by shifting from lower biomass land uses (e.g., grasslands, crop fallows etc.) to treebased systems such as agroforestry, forests, and plantation forests (Roshetko et al., 2007). There are ample evidences to show that the overall (biomass) productivity, soil fertility improvement, soil conservation, nutrient cycling, microclimate moderation, and carbon sequestration potential of an agroforestry system is generally greater than that of an annual system (Dhyani et al., 2009). According to Pandey et al., (2002) carbon sequestration in Indian agroforests varies from 19.56 Mg C/ha/yr in north Indian state of Uttar Pradesh to a carbon pool of 23.46–47.36 Mg C/ha/yr in tree-bearing arid agro-ecosystems of Rajasthan.
- Carbon sequestration in terrestrial pools include the above ground plant biomass, such as timber, fuelwood and belowground biomass such as roots, soil microorganisms, and all the forms of organic and inorganic C in soils including deep root zone. In agroforestry systems, two major components i.e., trees and crops are mainly responsible for CO_2 sequestration. The total amount sequestered in each component differs greatly and is dependent largely on a number of factors that includes the type of system (and the nature of components and age of plant), site quality, and previous land-use (Albrecht and Kandji et al., 2003, Newaj and Dhyani et al., 2008).
- **Biodiversity Conservation:** Diverse cropping systems and integrated farming approaches enhance ecosystem resilience.
- **Soil Health:** Improved soil management practices increase organic matter and reduce degradation.

b.) Economic Benefits

- **Increased Yields:** CSA practices often lead to higher productivity, improving farmers' incomes. In agroforestry, nowadays it has a great potential to reduce the impact of climate change alongside increase the income of the farmers

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- **Cost Savings:** Efficient use of inputs (e.g., water, fertilizers) reduces production costs. For example, if we intercrop a pulse crop like cowpea in between eucalyptus trees, both have different root depth and growth habit. Cowpea has a shallow root system while eucalyptus has a deep tap root system.
- **Market Access:** Certification schemes for sustainable products can open new markets for farmers. Although International market like Europe and North America get their eco-friendly and sustainable product from India such as jute textiles, renewable energy sources and growing capabilities in biodegradable packaging.

c.) Social Benefits

- **Food Security:** By enhancing resilience and productivity, CSA contributes to stable food supplies. In agroforestry system, we got many products as timber, fuel, food, fodder etc.
- **Gender Empowerment:** Green jobs and the promotion of a green economy are crucial to achieve economic and social development in an environmentally sustainable manner. When aligned with decent work principles, particularly gender equality, they lay a strong foundation for a well-balanced approach to sustainable agriculture and rural development. Sustainable agriculture has the potential to be a net creator of jobs that provide higher returns to labour inputs than conventional agriculture. Rural women are significantly involved in crucial green economy sectors such as agriculture and energy, and clearly they can potentially benefit by turning their reliance on natural resources into opportunities for green and decent jobs. For instance, rural women can participate in a wide array of newly emerging employment opportunities, from running small, resource-based businesses and the environmental maintenance of nurseries and forests to engaging in water and land management, rural ecotour ism, or bio-fuel production based on small-scale, low-in put agriculture.CSA initiatives involve women farmers can improve gender equality and livelihoods.

Community Resilience: Strengthened local capacities enable communities to better cope with climate shocks.

Challenges and Obstacles to CSA Adoption

- **Financial limitations:**High upfront costs for technologies and infrastructure (e.g., irrigation systems, renewable energy) can be prohibitive for smallholder farmers.
- **Knowledge and Awareness Gaps:** Limited understanding of CSA practices and their benefits hinders adoption.Inadequate extension services and training programs exacerbate this issue.
- **Socio-Cultural Factors:** Traditional farming practices and resistance to change can slow the uptake of CSA. Gender disparities may limit women's access to resources and decision-making.
- **Institutional and Policy Barriers:** Weak governance, lack of coordination, and insufficient policy support can impede CSA implementation.

Case Studies and Success Stories

a.) Sub-Saharan Africa

I.In Kenya, the adoption of drought-tolerant maize varieties has increased yields and improved food security for smallholder farmers.

The Drought Tolerant Maize for Africa project aims to mitigate drought and other constraints to maize production in sub-Saharan Africa, increasing maize yields by at least one ton per hectare under moderate drought and with a 20 to 30 percent increase over farmers' current yields, benefiting up to 40 million people in 13 African countries. The project brings together farmers, research institutions, extension specialists, seed producers, farmer community organizations and non-governmental organizations. It is jointly implemented by CIMMYT and the International Institute for Tropical Agriculture, in close collaboration with national agricultural research systems in participating nations. Millions of farmers in the region are already benefiting from the outputs of this partnership, which includes support and training for African seed producers and promoting vibrant, competitive seed markets.

II. In Niger, farmer-managed natural regeneration (FMNR) has restored degraded lands and enhanced resilience to climate change.

b.) South Asia

I) In India, the System of Rice Intensification (SRI) has reduced water use and increased rice yields. Field experiments conducted in many parts of India have shown the significant effect of SRI on root growth, tillering, yield, grain qualities, nutrient uptake and microbial dynamics.

Economics and the adoption pattern by farmers have also been studied. Higher grain yield and straw yield coupled with lowered cultivation costs, leave farmers with higher net income (Stoop et al., 2002; Uphoff et al., 2002; Thiyagarajan et al., 2005; Rajendran et al., 2005).

II. In Bangladesh, floating gardens have enabled farmers to grow crops in flood-prone areas.

c.) Latin America

I. In Brazil, integrated crop-livestock-forestry systems have improved productivity while reducing deforestation and emissions.

Future Directions and Opportunities

a.) Emerging Trends

I. Digital Agriculture: Advances in artificial intelligence, blockchain, and IoT offer new opportunities for precision farming and supply chain transparency.

II. Circular Economy: Integrating waste recycling and resource efficiency into agricultural systems can enhance sustainability.

b.) Research Priorities

The actual aim of farmers and government institutions behind agroforestry was improving rural livelihood and meeting various needs, viz. food, fuel, timber, fodder of the farmers. But in recent era of climate change, agroforestry became economically and ecologically very attractive tool for mitigating harmful effect of GHGs. Since, the Kyoto Protocol allowed industrialized countries with a GHG reduction commitment so as to invest in mitigation projects in the developing and least developed countries under the Clean Development Mechanism (CDM) and there is an attractive opportunity for major practitioners of agroforestry, especially the resource poor farmers (Nair et al., 2009).

I. Interdisciplinary Approaches: Combining agronomy, ecology, economics, and social sciences can provide holistic solutions. Crop productivity is apparently influenced by genetic potential, cultivation practices and climatic factors; of which genetic potential is very important with respect to crop and varietal adaptability under specific conditions. Arid region demands crops and varieties having high tolerance to moisture stress and high temperature stress under limited nutrient availability for climate resilience. The inherent potential of pearl millet, moong bean, moth bean and cluster bean to survive under hot arid conditions made them the principal crops of the region occupying maximum acreage. Earliness in crop varieties is an important trait to add climate resilience in arid environment.

II. Long-Term Studies: More research is needed to assess the long-term impacts of CSA practices on productivity, resilience, and emissions.

c.) Policy Recommendations

- Scaling Up CSA: Governments and international organizations should prioritize funding and capacity-building for CSA.
- Inclusive Policies: Policies should address the needs of marginalized groups, including women, youth, and smallholder farmers.
- Global Collaboration: Strengthening international cooperation can facilitate knowledge sharing and technology transfer.

Conclusion

The study's results offer valuable insights into the impact of CSA adoption. Regarding the first CSA goal to sustainably increase agricultural productivity and incomes, our analysis reveals that CSA adoption enhances farm productivity and incomes through increased crop yields and productivity, income, and technical and resource use efficiency. Addressing the second CSA goal of fostering resilience in people and agrifood systems against climate change, our findings demonstrate that CSA adoption bolsters individuals' resilience by boosting food consumption, dietary diversity, and food security. Moreover, at the system level, CSA adoption enhances agrifood system resilience by mitigating production risks and decreasing vulnerability. Concerning the third CSA goal of lowering GHG emissions, our review establishes that CSA adoption contributes to reducing emissions, including CO_2, N_2O, and CH_4. In addition, CSA adoption promotes carbon sequestration in soils and biomass, thereby improving soil quality.

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Natural Farming: A Sustainable Agricultural Approach

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Abstract

Natural Farming (NF) is an ecological and sustainable agricultural approach that eliminates synthetic agrochemicals and emphasizes the enhancement of soil microbiota through organic inputs. This method integrates principles of agroecology, permaculture, and regenerative agriculture to optimize nutrient cycling and soil health. NF promotes minimal soil disturbance through no-till or shallow-till practices, year-round crop cover, and biodiversity through polycropping systems with at least eight crop varieties annually. It relies on biostimulants such as Beejamrit (seed inoculant) and Jeevamrit (microbial consortium) to augment rhizosphere microbial activity, thereby enhancing both soil fertility and organic matter accumulation. A critical sub-component of NF is Zero Budget Natural Farming (ZBNF), pioneered by Subhash Palekar, which advocates for resource-efficient, climate-resilient agricultural practices. ZBNF minimizes external inputs through in situ nutrient recycling via cow dung-based biofertilizers, mulching, and Whapasa (optimal soil moisture management). It significantly reduces production costs by eliminating synthetic fertilizers and pesticides while maintaining competitive yield levels. Government initiatives, such as Bharatiya Prakritik Krishi Paddhati (BPKP) and National Mission on Natural Farming (NMNF) aim to scale NF adoption across India, enhancing agronomic sustainability, environmental resilience, and economic viability for smallholder farmers.

Keywords: Soil Health, Agroecology, Regenerative Agriculture Natural Farming

Introduction

Natural farming, also known as "do-nothing farming," represents a sustainable cultivation method rooted in ecological principles. It encompasses various approaches, including organic farming, agroecology, and permaculture. Although not entirely effortless, natural farming prioritizes avoiding manufactured inputs and relying on natural processes. Natural farming operates in conjunction with local ecosystems, leveraging plant-animal relationships and adapting to

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climate conditions. Its goal is to produce food and medicinal products that possess aesthetic and spiritual qualities, contributing to human flourishing. The underlying philosophy focuses on maximizing nutrient quality and minimizing the reliance on chemical interventions. In addition to providing healthy, sufficient amounts of food or nutraceuticals, it is a reliable strategy to stop soil erosion, environmental loss, and water contamination (Anderson et al., 2005).

Principles of Natural Farming

A healthy and productive soil microbiome is the cornerstone of optimal soil health, profoundly impacting the well-being of plants, animals, and humans alike. To promote optimal health, soils should ideally be covered with crops throughout the majority of the year. Crop diversification is also key, with farms encouraged to cultivate at least eight different crop varieties annually across their fields. Minimizing soil disturbance is paramount; therefore, no-till or shallow tillage practices are highly recommended. The integration of livestock into farming systems further contributes to improved soil health. These integrated approaches are crucial for promoting natural farming practices. A flourishing soil microbiome is essential for retaining and building soil organic matter, which is fundamental for sustainable agriculture. To stimulate microbial activity, biostimulants are vital, and in India, these are often produced through the fermentation of animal dung, urine, and healthy soil. Equally important is increasing both the volume and variety of organic residues returned to the soil, including crop residues, cow dung, compost, and other organic materials. For pest management, prioritizing robust agronomic practices, as outlined in Integrated Pest Management (IPM), is essential. Botanical pesticides should only be considered as a last resort. The use of synthetic fertilizers, chemical pesticides hinders natural soil regeneration and is strongly discouraged. (Singh et al., 2022).

Farmers who consistently practice natural farming consider the following components as essential (Palekar et al., 2016):

1.Beejamrit – A seed treatment to protect seeds from pests and diseases.

- **Ingredients:** 5 kg cow dung, 5 liters cow urine, 50 g lime, 1 liter cow milk, 20 liters water, and a handful of soil (preferably from under a banyan tree).
- **Process:** Soak cow dung in water for 12 hours, squeeze it out, and mix the extract with cow urine, lime water, and milk. Stir well and use within 24 hours to treat seeds

2. Jeevamrit – A microbial culture that enhances soil fertility and microbial diversity.

- **Ingredients:** 10 kg cow dung, 10 liters cow urine, 2 kg jaggery, 2 kg pulse flour, 200 liters water, and a handful of soil.
- **Process:** Mix all ingredients in water and ferment for 5-7 days, stirring twice daily. Apply to soil or crops every fortnight.

3. Mulching – Covering the soil with organic materials to minimize moisture loss and suppress weeds.

- **Materials:** Organic (straw, leaves, compost) or inorganic (plastic sheets).
- **Process:** Spread mulch evenly over the soil surface to conserve moisture, regulate temperature, and suppress weeds

4. Whapasa – Managing soil moisture efficiently to reduce water stress and enhance plant growth.

- **Principle:** Maintain soil moisture at an optimal level by minimizing irrigation frequency and ensuring soil aeration. This minimizes water stress and promotes microbial activity

Characteristic features of Natural Farming

Natural farming has characteristic features like;

- Natural Farming is environment friendly
- It respects the life and opposes human exploitation
- Natural Farming products have good quality, yield and taste
- Natural Farming does not use pesticide
- Natural Farming does not use herbicide

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- Natural Farming uses the native weeds rather than killing them
- Natural Farming doesn't use chemical fertilizers
- Natural Farming minimizes waste water emissions
- Natural Farming cares nutritive cycle theory
- Natural farming maintains the growth of native soil microorganisms

Components of Natural Farming: Natural Farming primarily relies on these key elements

1) Organic pest and weed management
2) Organic compost and leaf-applied nutrients
3) Biological methods for pest control.

Zero Budget Natural Farming (ZBNF)

Zero Budget Natural Farming (ZBNF) is a sustainable and climate-resilient agricultural practice that enables farmers to grow crops using entirely natural inputs, eliminating the reliance on expensive and harmful chemical fertilizers and pesticides. Developed by Subhash Palekar, often referred to as "Krishi ka Rishi," ZBNF addresses critical challenges such as rising labour costs, environmental degradation, erratic monsoons, and food security. Its success lies in its eco-friendly methods, low input costs, and reduced usage of water and electricity. Additionally, it promotes the production of high-quality, healthy food, minimizes the need for external labour, and incorporates multi-cropping techniques to enhance income under bio-entrepreneurship. To minimize reliance on external labour, bio-entrepreneurship can utilize multi-cultivation techniques to enhance net income. Zero Budget Natural Farming (ZBNF) presents a valuable opportunity for bio-entrepreneurship, particularly given that 70% of agricultural land is dryland farmed by resource-limited farmers. With a relatively low national average pesticide usage of 0.6 kg/ha compared to China (13 kg/ha) and Korea (16.56 kg/ha), ZBNF is readily implementable. It can achieve 80% of conventional yields while also allowing farmers to command premium prices, ranging from 22-35% higher than conventional produce. Furthermore, diversified cropping within ZBNF ensures year-round income and provides a buffer against crop failure. The resulting farm income is high due to low input costs.

ZBNF is based on four pillars (Fig 1): Beejamrita (seed treatment), Jeevamrit (soil inoculant), Mulching, and Waaphasa (soil aeration) (Thakur et al., 2020 and Sharma et al., 2023).

Fig. 1. Components of ZBNF (Source: MoA & FW, GoI. 2024)

Current Scenario of Natural Farming in India

Sustainable agricultural practices such as Zero Budget Natural Farming (ZBNF) are gaining traction in India as a cost-effective alternative that reduces dependency on chemical inputs while promoting sustainable practices (Palekar et al., 2016). India is a playing significant role in promoting natural farming by integrating local ecological principles and indigenous knowledge

Government Support

In 2020-21, the Central Government introduced the Bharatiya Prakritik Krishi Paddhati (BPKP) scheme under the Paramparagat Krishi Vikas Yojana (PKVY). By 2023, this initiative had expanded to encompass 6.1 lakh hectares with an allocated budget of Rs 49.8 crore. Currently, natural farming practices are implemented across more than one million hectares in India, with Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Kerala, Odisha, Himachal Pradesh, Jharkhand, and Tamil Nadu at the forefront of this agricultural shift. One of the significant economic advantages of natural farming is the substantial reduction in cultivation costs, ranging from 60-70%, achieved by eliminating the need for costly chemical fertilizers and pesticides. This approach also prioritizes sustainability by maximizing the efficient use of resources like soil, labour, and equipment, which in turn boosts crop productivity. Natural farming promotes the rapid growth of soil microbiota and enhances soil aeration through the application of natural inputs. Globally, increasing awareness of environmental issues and health concerns has led to a surge in demand for sustainable and organic agricultural products. To support this trend, the government has been actively promoting organic farming through schemes such as the Paramparagat Krishi Vikas Yojana (PKVY). Specific initiatives include the establishment of a five-kilometers natural farming corridor along the Ganges River, targeting 960,000 hectares. Furthermore, the National Mission on Natural Farming has set ambitious goals, aiming to create 15,000 clusters in Gram Panchayats, involve 1 crore farmers, and bring 750,000 hectares under natural farming practices (MoA & FW, GoI, 2023).

Conclusion

Climate and environment is changing at an alarming rate due to anthropogenic activities. Within a few years we will be on the edge of extinction if we will not go back to the nature. The degradation of natural resources will continue if sustainable practices are not adopted. To reduce the negative impacts and to improve the health of human beings, Natural farming is essential in modern ways. The techniques discussed in the present paper could also provide ample opportunity in livelihood sectors under bio-entrepreneurship. Hence, the sustainability of the environment, ecology and human activities, the global implementation of Natural farming is essential.

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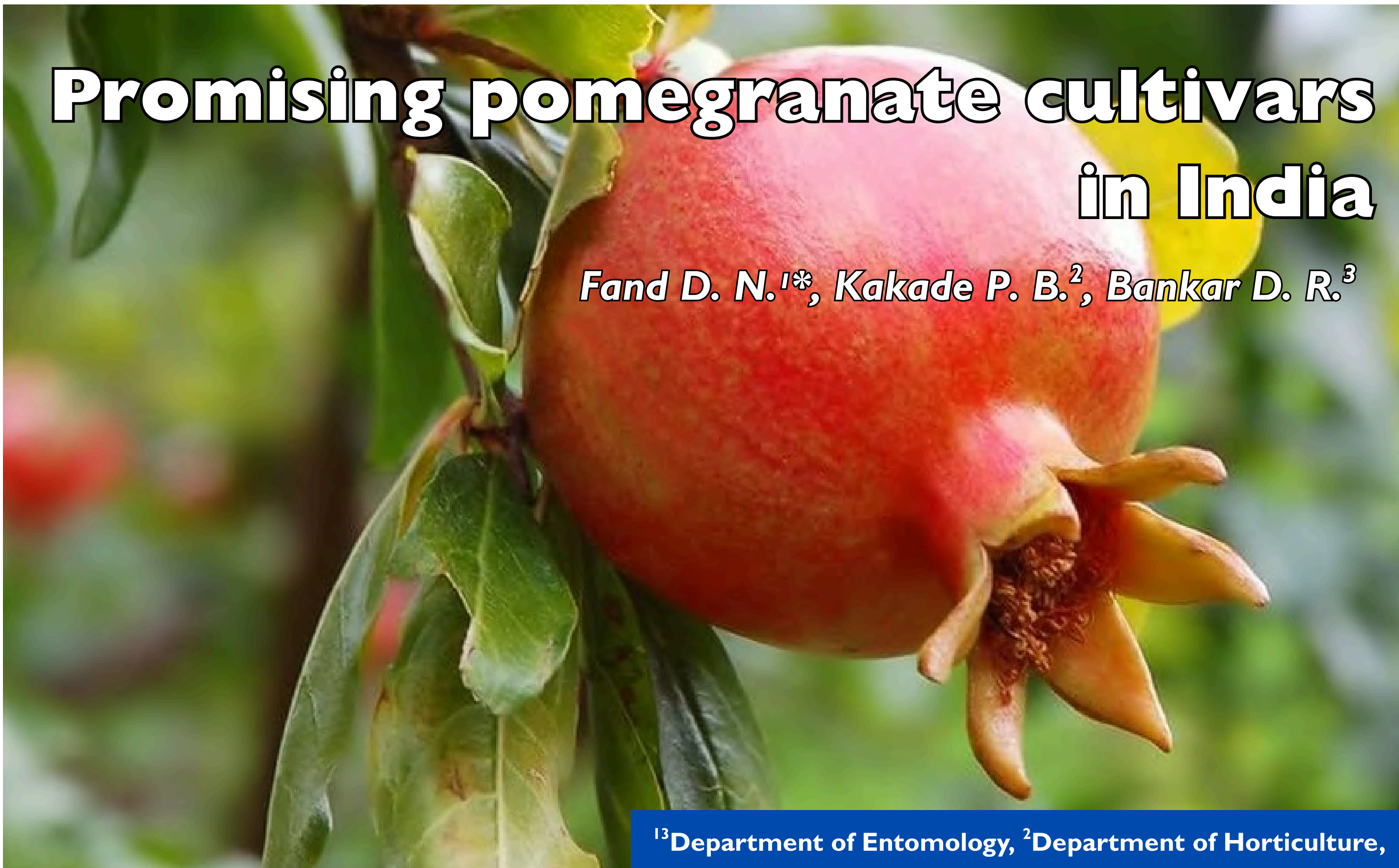

Promising pomegranate cultivars in India

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Abstract

In pomegranate cultivation Maharashtra is the leading state (*Punica granatum*) in India, with the variety 'Bhagwa' revolutionizing production and exports since 2003. Various improved cultivars have been developed to enhance yield, quality and marketability. This study compiles information on commercially important pomegranate cultivars, emphasizing their morphological, physico-chemical and agronomic characteristics. 'Sharad King' exhibits large fruit size, thick rind and high export potential, while 'Solapur Lal,' a biofortified variety, matures earlier than 'Bhagwa' and has higher nutrient content. 'Ganesh,' released in 1970, remains popular for its soft-seeded fruits, whereas 'G-137' and 'Mridula' are selections with improved juice yield and aril colour. 'Phule Arakta,' 'Phule Bhagwa Super' and 'Phule Anardana' are high yielding varieties suited for both fresh and processed markets. Other cultivars like 'Dholka,' 'Ruby,' 'IIHR Selection,' 'Jyoti' and 'Gul-E-Shah' exhibit unique traits such as high juice recovery, distinct aril colour and adaptation to specific climatic conditions. The identification and characterization of these cultivars provide insights into their suitability for domestic and export markets, processing industries and breeding programs. This compilation will aid farmers, researchers and policymakers in selecting appropriate varieties to improve productivity and market competitiveness in pomegranate cultivation.

Keywords: pomegranate, productivity ,high yield ,climate conditions

Introduction

Pomegranate (*Punica granatum* L.) in India grown on area of 2,57,900 hectares producing 30,97,700 tons with an average yield of 12 tons per hectare. Maharashtra led all Indian states with 1,37,850 hectares under cultivation, producing 15,54,350 ton at an average productivity of 11.28 tons per hectare (Anonymous, 2024). Pomegranate is evergreen bush with spiny branches. The leaves are opposite, ovate and lanceolate. Flowers borne singly or in cluster on terminally or auxiliary position. Flowers having three s

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ex forms viz., male, female and intermediate or hermaphrodite and three flowering season/bahar (Ambe or Ambia, Mrig and Hastha). In 2003 Bhagwa Pomegranate variety revolutionized the pomegranate cultivation in India by opening the new horizons in the international market. National Research Center on Pomegranate in 2017 released biofortified pomegranate variety "Solapur Lal.

1. Bhagwa

This variety holds popularity and having the largest area under it even after 22 years. Bhagwa variety having different local names such as Shendri or Sinduri, Asthagandh, Kesar, Jai Maharashtra, Red Diana and Mastani. This variety released by Mahatma Phule Krishi Vidyapeeth, Rahuri for cultivation in 2004, developed from F2 population of the cross Ganesh x Gul-E-Shah Red by selection.

The flowers are dark saffron colour. Fruits are attractive smooth glossy red thick rind whereas arils are blood red in colour, soft seeds hence fruits develop very high demand both in domestic and export market. At ambient conditions keeping quality of fruits is 15-20 days. fruits mature within 180-190 days with 30-35 kg fruit/tree. Average weight of fruit is 405.97 g. with having 15.38 per cent T.S.S. and 0.37 per cent acidity.

There is a high demand for this variety for export markets particularly in United Kingdom, Holland, other European and Gulf countries etc. (Saroj and Sharma, 2017).

2. Sharad King

In 2009, in an orchard of 'Bhagawa' progressive farmer Mr. Vitthal Pundlikarao Bhosale from Jalgaon taluk, Chhatrapati Sambhajinagar, Maharashtra noticed mother plant of 'Sharad King' with bigger size of fruit and thicker rind. ICAR-NRC on Pomegranate, Solapur has evaluated the newly identified pomegranate variety 'Sharad King' at Tupewadi, Chhatrapati Sambhajinagar, Maharashtra, India. This variety is now popular in Maharashtra and as per the demand from farmers for planting material for cultivation soon it will take place of Bhagawa. Till 2023-24, 125 pomegranate growers cultivated this variety with one lakh planting material but the recent data on cultivated area is not available.

This variety found promising for both table and processing purposes with large fruit size, attractive red colour thick rind, more number of arils per fruit, sweet red arils, soft seeds, better shelf life. 'Sharad King' matures in about 160-170 days.

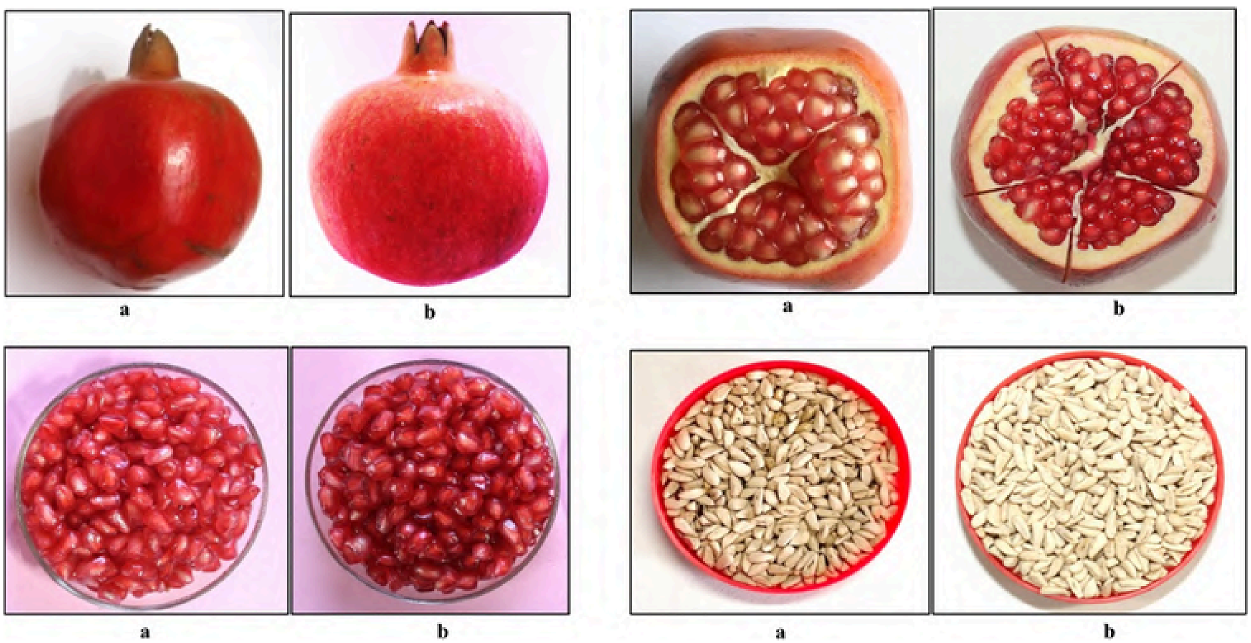

Fig. 1. Morphological features of variety Bhagwa (a) and Sharad King (b)

3. Solapur Lal

First biofortified pomegranate variety developed by ICAR-NRC on Pomegranate, Solapur from Bhagwa × [(Ganesh × Nana) × Daru].

This variety mature 15-20 days earlier than Bhagwa. Average yield of 35-39 kg/tree with 130-140 no. of fruits/tree. Fruit size slightly lesser than Bhagwa while TSS 17.5-17.7° Brix which is more than Bhagwa. Vitamin-C, anthocyanins, iron and zinc significantly higher than Bhagwa. However, seed are harder than Bhagwa and it is released for Processing (Juice, value addition) and table purpose (ICAR-NRCP, 2024).

This variety helps farmer to grow pomegranate where problem in defoliation before taking bahar.

Fig. 2. Solapur Lal

4 . Ganesh

This variety also known as GBG-1 and selected by Dr. Cheema in 1936. This variety is a soft seeded selection from seedlings of hard seeded Alandi. While, in 1970, it was renamed as 'Ganesh'. In Maharashtra Ganesh variety mature within 145-155 days. Fruit is round, smooth, rind colour pinkish yellow to reddish yellow. Arils are sweet in taste with pink colour in winter months while whitish in warmer months. Fruits weighing between 225 to 250 gm, with 16° Brix T.S.S. having acidity of 0.3 per cent.

5.G-137

It was released in the year 1989 by Mahatma Phule Krishi Vidyapeeth Rahuri. This variety is a clonal selection from variety Ganesh. Fruit is reddish yellow colour, round and smooth, weighing 232-270 g, light pink colour arils with sweet in taste. TSS observed to be 16.20°-17.4° Brix, acidity 0.42-0.49 per cent.

6 .Mridula

It was released in the year 1994 by Mahatma Phule Krishi Vidyapeeth, Rahuri. This variety having medium size fruits (300-350 g) with reddish brown skin colour. This variety has all the characters of the Ganesh variety except the arils are dark red in colour 15.6° Brix TSS. Variety is suitable for long distant market. The arils colour in 'Ambe' bahar and 'Mrig' bahar is dark red in colour whereas pink during the 'Hasta' bahar.

7 .Phule Arakta

It was released in the year 2003 by Mahatma Phule Krishi Vidyapeeth, Rahuri. It is selection from F-2 progeny of Ganesh × Gul-e-Shah Red. This variety is heavy yielder with maturity within 130-140 days. Fruit is round, smooth and glossy, dark brick red in colour, arils are sweet in taste with dark red in colour. Medium size fruits (182.70 g) with rind thickness 0.24 cm. Fruits are juicier (63.71 %) with TSS 15.89° Brix and 0.45 per cent acidity. Fruit yield 29.83 kg/tree, with 78-90 number of fruits per tree.

8 .Phule Bhagwa Super

It was released in the year 2013 by Mahatma Phule Krishi Vidyapeeth, Rahuri. Fruits are medium in size (271- 299 g). Fruit surface is glossy, having attractive dark saffron rind colour, rind thickness is 0.35 cm and seeds are soft. This variety mature in 176.60 days. Fruit yield 30.6 kg/tree.

9. Phule Anardana

It was released in the year 2015 by Mahatma Phule Krishi Vidyapeeth, Rahuri. Medium sized fruits with attractive red surface, more acidic, arils are bold and blood red in colour, highly suited for preparation of anardana. Anardana recovery is 13.95 per cent and yield is about 1.58 kg/plant anardana.

10 .Dholka

It is a popular variety of Gujarat. Fruits large, rind yellowish red with pinkish white aril. TSS 15.41° Brix. Mature within 165 to 175 days.

11 .Ruby

This variety is developed by IIHR, Bangalore. The mature fruits resemble variety Ganesh with respect to shape and size. However, the rind of this variety is reddish brown with green streaks containing red bold

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arils. The fruit weighs 270 g.

12. IIHR selection

It is a selection from the open pollinated seedlings. Mean fruit weight is 255 g with soft seeds.

13. Jyoti

This variety developed by UAS Bengaluru a selection from Bassein Seedless and Dholka. Trees are dwarf, fruits remain small in size. Average fruit weight is 200 g. Fruits having red colour rind with pinkish-reddish coloured arils. The juice has TSS 15° Brix with very low acidity.

14. Amlidana

This variety was developed in 1999 by IIHR, Bengaluru from Ganesh x Nana. Plants are dwarf. Medium size fruits, highly acidic arils (4.8 %). Suitable for Anardana.

15.Nana

A dwarf variety of pomegranate good for bonsai and ornamental.

Fig. 3. Nana

16. Gul-E-Shah

Fruits are round, smooth and pink in colour with reddish tinge. Arils are pink with acidic in taste. Fruit weighing from 175-182 g. TSS of the juice observed to be 13.2-14.0° Brix.

Conclusion

Pomegranate cultivation in India has seen significant advancements with the development of various high yielding and commercially viable varieties. Among them, Sharad King is a promising new variety with superior fruit quality and better shelf life. Bhagwa remains the most widely cultivated variety, favoured for both domestic and export markets due to its attractive fruit characteristics. Biofortified varieties like Solapur Lal offer nutritional advantages and early maturity, benefiting farmers facing defoliation issues. Traditional varieties such as Ganesh and its selections like G-137 and Mridula continue to be popular for their sweetness and adaptability. Additionally, specialized varieties like Phule Anardana and Amlidana cater to processing industries, particularly for anardana production. Dwarf varieties such as Nana and Jyoti provide options for ornamental and small scale cultivation.

The continuous research and development of new pomegranate varieties by institutions like ICAR-NRCP, Solapur and Mahatma Phule Krishi Vidyapeeth, Rahuri, have significantly contributed to improving yield, quality and market potential. With increasing global demand, these varieties offer farmers diverse options suited for fresh consumption, processing and export, ensuring sustained growth in the pomegranate industry.

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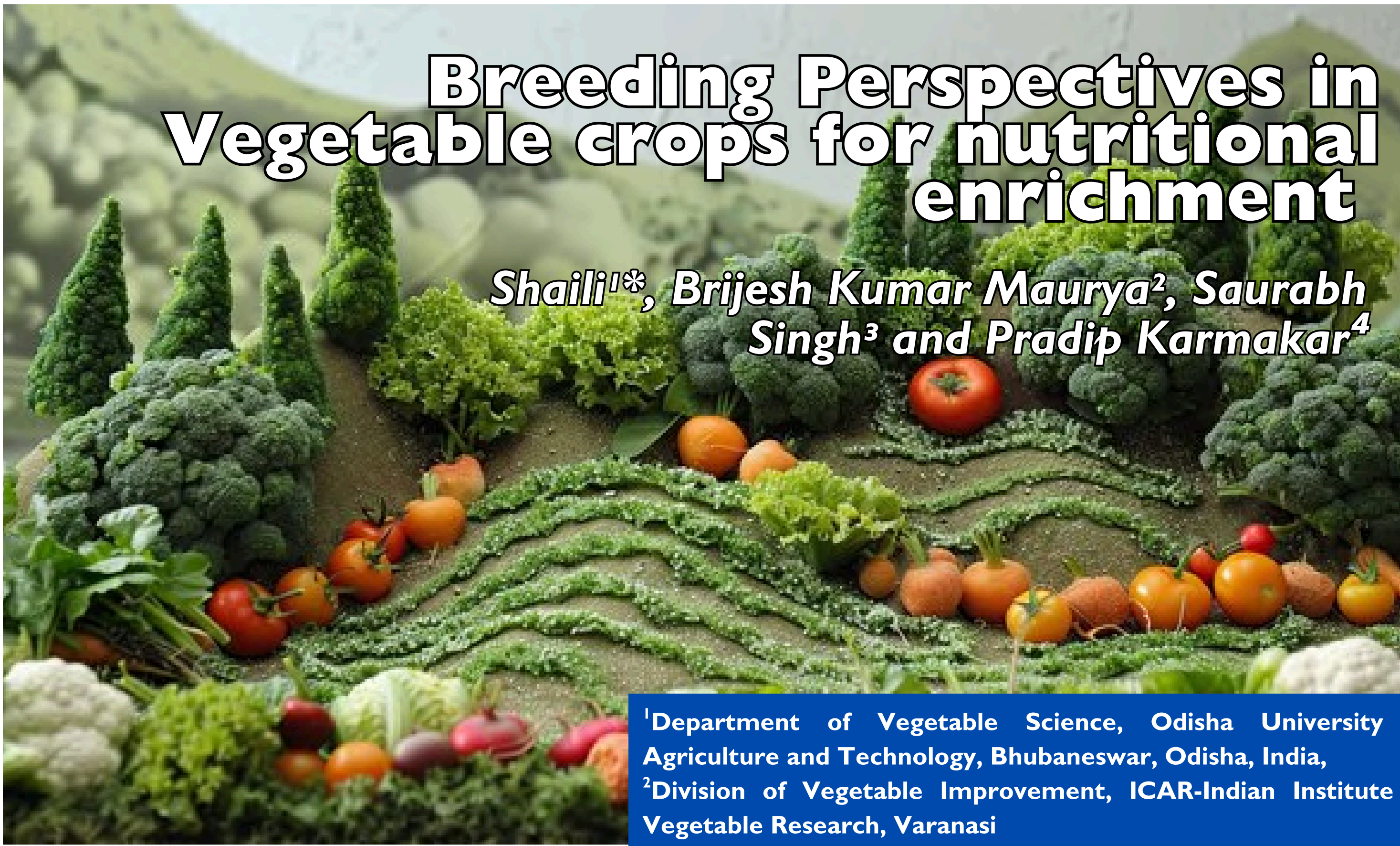

Breeding Perspectives in Vegetable crops for nutritional enrichment

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Abstract

Knowledge regarding health benefits of vegetable is not new. From the time immemorial several vegetables have been used to recover or reduce many physiological malfunctions. Breeding vegetables for enhanced nutritive qualities is an emerging focus in modern agriculture to address global health and food security challenges. Vegetables are richest and cheapest sources of essential vitamins, minerals, antioxidants, and bioactive compounds that promote health and prevent chronic diseases. However, significant variability in nutrient content among vegetable varieties provides opportunities for targeted breeding initiatives. This article explores conventional and advanced strategies for developing nutrient-rich vegetable cultivars, emphasizing the integration of conventional breeding, genetic engineering, and molecular marker-assisted selection. Conventional breeding methods, such as selection and hybridization, have been pivotal in enhancing phytonutrient content, with notable successes in tomatoes, cabbage, and ridge gourd etc. Advanced techniques, including mutation breeding and polyploidy, have yielded nutrient-dense and stress-resilient varieties, while transgenic approaches and molecular breeding have enabled precise improvements in traits like vitamin accumulation and mineral bioavailability. The article also highlights the potential of biofortification as a sustainable solution for improving dietary nutrients in vegetables through genetic and agronomic methods.

Key words: breeding, hybridization ,stress-resilient ,biofortification, sustainable solution

Introduction

The concept of vegetables being beneficial for health is an age-old knowledge. Since the time immemorial, several vegetables have been used to aid in recovery or alleviate many physiological malfunctions. In recent decades, intensive search is underway to find natural sources of bioactive nutritional compounds, including fruits, vegetables, pulse, cereals, and fish. Among these, vegetables are vital due to their rich composition of bioactive compound like vitamins, trace elements, antioxidants,

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dietary fibers, polyunsaturated fatty acid (PUFA). These nutrients not only improve the state of health and wellbeing but also reduce risk of various degenerative disease such as cancer, cardiovascular disease, macular degeneration and ageing.

Vegetables are integral part of a balanced diet and are consumed in various forms fresh, cooked, dried, juice and processed. They are relatively affordable and widely available throughout the year. Thus, vegetables play a major role in ensuring nutritional security and alleviation of nutrition related diseases.

Breeding of vegetables for nutritive qualities is an essential aspect of modern agriculture, aiming to improve their nutritional value and to address global health and food security challenges. The natural variation in nutrient content among vegetable varieties present an opportunity for targeted breeding efforts to maximize their nutritive potential. With the growing emphasis on nutrition-sensitive agriculture, breeders are increasingly focusing on improving traits such as higher levels of vitamins (e.g., Vitamin A, C, and E), minerals (e.g., iron, zinc, and calcium), and secondary metabolites like carotenoids, polyphenols, and flavonoids. Additionally, these efforts also aim to reduce anti-nutritional factors such as oxalates and phytates,which can hinder nutrient bioavailability.

Gene Resource Utilization

Several studies have shown that nutritional contents of vegetables can be improved by fertilizer application and developing novel varieties with enhanced levels of nutrients, beneficial photo chemicals and reduced anti-nutrients. Extensive screening for genetic variation in nutrient content is a prerequisite for improving nutrient qualities. Several germplasm accessions rich in TSS (Total Soluble Solids), ascorbic acid and citric acid in tomato, protein in pea, vitamin-C, protein and dry matter in potato, carotene in capsicum, vitamins-A and carotene in carrot have been identified. Wild relatives of several vegetables are also rich in nutritional contents. These are *S. pimpinellifolium, S. cheesmanii,* and *S. peruvianum* in tomato (Willits et al., 2005), *Solanum khasianum* and *S. aviculare* in brinjal (Lyngdoh et al., 2025), *Capsicum annum* var. *aviculare* in *capsicum* (González et al., 2015), *Cucumis sativus* var. *xishuangbannanesis* in cucumber (Qi et al., 2022), *Solanum microdontum*, *S. vernei* and *S. phureja* in potato (Camire et al., 2009).

Studies have also been conducted on inheritance of nutritional traits. For example:protein content in vegetable soybean is controlled by a dominant gene (Diers et al., 2023), whereas polygenes regulate protein content in broad beans (Dahiya et al., 1977). Vitamins A content in tomato and chilly is determined by additive gene (Stommel et al., 1993), in carrot by complementary genes (Oliveira et al., 2020) and in cucurbits by polygenes. Similarly additive and dominant gene in *Cucumis melo* (Kaur et al., 2022). and chilli, additive gene in tomato (Martin et al., 1986) and polygenes in pea (Pallanca & Smirnoff et al., 2000) control vitamins C content. Carotenoid content in carrot has a complex inheritance. All this information has been effectively used by breeders to develop nutritionally superior varieties using traditional breeding interspecific hybridization and efficient selection procedures

Several nutritionally rich vegetable varieties have been developed through breeding programs to enhance the content of vitamins, minerals, antioxidants, and other beneficial compounds. For instance, 'Double Rich' tomato is specifically bred for its high lycopene and vitamin C content, while 'Pusa Red Plum' and 'Pusa Ruby' are known for their deep red color and elevated antioxidant levels. In peas, varieties like 'GC195' and 'Kinnauri' offer improved protein content and cold tolerance, catering to high-altitude regions.

Efforts have also been made in leafy vegetables—for example, 'Arka Anupama' spinach contains higher levels of iron and folate, while 'Arka Arunima' amaranth is recognized for its enhanced beta-carotene content. In cucurbits, 'Durgapur Madhu' muskmelon and 'Mateera AHW19' watermelon stand out for their superior sweetness and carotenoid profiles. Similarly, root crops like 'Surkh Chanteny' carrot are targeted for high provitamin A carotenoids.

Parallel to improving nutritional traits, significant work is underway to reduce anti-nutritional factors and toxic compounds in vegetables. For example, breeding efforts aim to lower carotatoxin levels in carrots, nitrates and alkaloids in lettuce, and glucosinolates and cholinesterase inhibitors in cruciferous vegetables like cabbage and cauliflower. In spinach and beetroot, attempts are being made to reduce oxalates, phytates, and saponins, which can interfere with mineral absorption. Sweet potatoes are being screened for lower levels of ipomeamarone, a toxic compound, and watermelons for reduced serotonin content, which can affect gastrointestinal health.

Strategies and Approaches in Breeding of vegetables for Nutritive Quality

Advancements in conventional breeding techniques, coupled with biotechnological tools such as marker-assisted selection (MAS), genetic engineering, and genome editing, have significantly accelerated the development of nutrient-rich vegetable varieties.

Conventional Breeding Methods

Conventional breeding methods, primarily based on selection and hybridization, either independently or in combination, have proven to be powerful tools for improving the nutritional quality of various crop plants (Balyan et al., 2013; Farneti et al., 2015). Enhancing nutritional quality can be achieved through mass selection or single plant selection targeting specific traits, or through intraspecific or interspecific hybridization to develop new genotypes with improved nutritional attributes. Traditional breeding and conventional selection methods are particularly effective in increasing phytonutrient content in vegetables, especially for traits with a quantitative genetic basis.

Significant research efforts have been directed towards diversifying and enhancing phytonutrients such as carotenoids and flavonoids in tomatoes. These initiatives utilize single-point mutations or quantitative trait loci (QTL) that influence phytonutrient levels. A notable example is the use of high pigment (hp) mutants in tomatoes, which have been incorporated into key genetic resources to boost lycopene content (Levin et al., 2006). Advanced breeding techniques, such as double hybridization, three-way crossing, and population improvement methods like synthetic and composite breeding, have shown potential for enhancing mineral concentration in cabbage heads.

In ridge gourd, Karmakar et al., (2013) evaluated combining ability for antioxidant properties using hermaphrodite inbred lines, while Hedau et al., (2002) reported heterosis for calcium and phosphorus content, with ranges of 0.54% to 21.30% and 3.29% to 22.74%, respectively. Geleta and Labuschagne et al., (2006) utilized hybrid breeding to enhance vitamin C content in chili. Introgressing chromosome segments from the wild relative Brassica villosa successfully increased glucosinolate levels in broccoli (Juge et al., 2007). Interspecific hybridization has also been employed to improve protein content in cowpea (Hazra et al., 2006). Additionally, Rosati et al., (2000) identified the β- mutant in tomato, which exhibited increased LYCB activity compared to normal fruits.

Advanced Breeding Techniques

Mutation Breeding

In addition to traditional breeding methods, techniques such as mutagenesis and somaclonal variation have been widely employed to isolate nutritionally rich genotypes in various vegetable crops. For instance, (γ-rays, spontaneous mutations and somaclonal variation have been used in tomato (γ-rays and Ethyl-methane-sulphonate (EMS) in capsicum), (spontaneous mutations incauliflower) and (somaclonal variation in sweet potato). Mutation breeding has shown significant potential for genetic improvement in vegetable soybean, with mutants exhibiting high protein and low fiber content identified for further evaluation (Kavithamani et al., 2010). Globally, out of 3000 mutant varieties developed, 776 have been induced specifically for improved nutritional quality (Jain and Suprasanna et al., 2007). Minor genomic modifications, such as point mutations or single-gene insertions, frequently observed through metabolomic analysis, can lead to substantial changes in biochemical composition and antioxidant levels (e.g., anthocyanin, lycopene) as demonstrated in the tomato cultivar

(Table 1.) Crop wild relatives/landraces/accessions rich in quality traits useful for breeding

Crops	Wild Relatives/Accessions/Landraces	Nutrients	References
Tomato	S. pimpinellifolium, Caro Red (Rugers × S. hirsutum)	Vitamin A	Smith, & Lee,(2015).
	S. pennellii IL6-2, IL7-2	Phenolics	Bovy et al., 2007.
	S. pennellii IL12-4	Ascorbic Acid	Rousseaux et al., 2005.
	S. chilense and S. atroviolacium from S. cheesmani	Anthocyanin	Mes et al., 2008.
Chilli	C. annum var. IC: 119262 (CA2)	Ascorbic Acid	Owk and Sape, 2009
Cucumber	Xishuangbanana gourd (C. sativus var. xishuangbananensis)	Beta-carotene	Renner, 2017
Spine Gourd	Momordica dioca	Protein	Sood and Sharma, 2012
Sweet Gourd	M. cochinchinensis	Lycopene	Ishida et al., 2004
Bitter Gourd	DRAR-1, DVBTH-5	Beta-carotene	Yadav et al.,2010.
	DRAR-1, DVBTG-5	Ascorbic Acid	Yadav et al.,2010.
Broccoli	Brassica villosa	Glucosinolates	Raimondo et al., 2023
Cassava	UMUCASS 44, 45 & 46	Vitamin A	Yusuf, 2014

Moneymaker (Giliberto et al., 2005). Sapir et al., (2008) highlighted that the high pigment-1 (hp-1) mutation in tomato is associated with increased flavonoid content in fruits. Spontaneous mutations have also played key role in improving nutritional quality; for example, The orange'cauliflower mutation (Li et al., 2001) and orange-fleshed sweet potato mutants contain significantly higher β-carotene levels (30-100 ppm) compared to white-fleshed varieties (2 ppm). Notable orange-fleshed mutant varieties include Nancy Gold and Murff Bush Porto Rico (La Bonte and Don et al., 2012).

Polyploidy Breeding

This technique has emerged as an effective startegy in vegetable crop impropment, particularly for enhancing nutraceutical quality and aesthetic traits such as color. Tetraploid varieties of radish, pumpkin, muskmelon, and watermelon exhibit higher productivity and improved quality. For instance, Zhang et al., (2010) developed a tetraploid muskmelon with significantly higher levels of soluble solids, soluble sugars, and vitamin C relative to diploid fruits. Similarly, Liu et al., (2010) reported that lycopene content in diploid watermelon fruits ranged from 33.2 to 54.8 mg/kg, while triploids ranged from 41.2 to 61.8 mg/kg, and tetraploids ranged from 38.1 to 59.8 mg/kg. Their findings indicate that triploid and tetraploid watermelons generally contain more lycopene than diploids, although ploidy level did not influence lycopene content in the variety 'Fan Zu No.2'.

In a separate study, Marzougui et al., (2009) successfully induced polyploidy in *Trigonella foenum-graecum* L. using a 0.5% colchicine solution. The resulting autotetraploid cultivar exhibited larger leaf area and greater productivity in terms of seed number, pod number, and branch number compared to diploids. Additionally, its leaves were found to be rich in essential minerals such as potassium, sodium, calcium, and phosphorus.

Molecular Breeding

Molecular markers are powerful tools for improving nutritional traits in vegetable crops through marker-assisted selection (MAS). (QTLs) associated with bulb pungency and Sulphur assimilation have been identified in onion, enabling more efficient selection during breeding programs. In cauliflower, mutants at the Or locus—characterized by elevated β-carotene levels in the curd—have been instrumental in identifying ten amplified fragment length polymorphism (AFLP) markers closely linked to the locus, facilitating positional cloning. In broad been, a sequence characterized amplified repeat (SCAR) marker linked to the zt-2 gene which is associated with increased protein levels and reduced fiber holds potential for developing tannin-free varieties. Similarly, QTLs linked to elevate β-carotene levels have been identified and successfully introgressed into commercial cucumber varieties through MAS.

Transgenic Approach

Genetic engineering is another attractive tool for rapid and directed improvement of vegetables. Potato tubers naturally low in essential amino acids like lysine, tyrosine, methionine and cysteine have been improved by expressing. *Amaranthus* seed albumin gene AmAn1, resulting in elevated levels of total protein and essential amino acids. Three genes from *Erwinia*—phytoene synthase (CrtB), phytoene desaturase (CrtI), and lycopene beta-cyclase (CrtY) —have been introduced into potatoes to enable β-carotene production. Lu et al. (2006) demonstrated that transgenic cauliflower with Or gene integration induced a cellular process that promotes the differentiation of proplastids or other non-colored plastids into chromoplasts for carotenoid accumulation. They suggested that the Or gene could serve as a key genetic element for biofortification in other crops.

Carotenoids, which serve as antioxidants and vitamins-A precursors,. are synthesized via the isoprenoid biosynthetic pathway. Genetic manipulation of this pathway can improve both organoleptic (taste/smell and appearance) and nutritional qualities. In tomato, transgenic lines expressing the bacterial crtl gene (phytoene desaturase) exhibited elevated carotenoid levels. Likewise, transgenic potato plants with antisense or co-suppression of the zeaxanthin epoxidase gene showed a six-fold increase in carotenoids and 2–3 fold higher α-tocopherol (vitaminE) content.

Biofortification: A Sustainable Solution

Biofortification refers to the enhancement of health-promoting dietary nutrients in crops through conventional breeding, molecular techniques, genetic engineering, and agronomic practices. It offers a sustainable, cost-effective strategy to combat micronutrient deficiencies particularly in regions with

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limited access to diverse diets and fortified foods. One of the key advantages of biofortification is its potential to enable on-site production of nutrient-rich vegetables, especially those that are perishable, thereby directly serving the nutritional needs of local populations. Moreover, surplus produce from biofortified crops can be directed to pharmaceutical and cosmeceutical industries for the extraction of valuable bioactive compounds, adding further economic value.

Significant progress has been made in biofortification, with successes in increasing vitamin A content in vegetables like sweet potato, cassava, sweet corn, tomato, and cauliflower. Additionally, iron biofortification has enabled millions of people particularly in developing countries to grow and consume crops with improved nutritional profiles (Bouis and Saltzman et al., 2017).

(Table 2.) List of some biofortified vegetable varieties developed by agri-research institute of India

Crops	Biofortified Varieties	Special Characters
Cauliflower	Pusa Beta Kesari 1	Provitamin A (8.0-10.0 ppm)
Potato	Kufri Manik	Anthocyanin (0.68 ppm)
	Kufri Neelkanth	Anthocyanin (1.0 ppm)
Sweet Potato	Bhu Sona	Provitamin-A 14.0 mg/100g
	Bhu Krishna	Anthocyanin 90.0 mg/100g
Greater Yam	Sree Neelima	Anthocyanin 50 mg/100g Protein 15.4 % Zinc 49.8 ppm
	Da 340	Anthocyanin 141.4 mg/100g iron 136.2 ppm Calcium 1890 ppm
Carrot	Kashi Arun	Lycopene 7.5 mg/100g
	Kashi Krishna	Anthocyanin 275-300 mg/100g
Radish	Kashi Lohit	Anthocyanin 39.9 µg/100g
Okra	Kashi Lalima	Anthocyanin 3 mg/100g
Bitter Gourd	Pusa Hybrid 4	Iron 18.28 mg/100g

(Source: https://icar.gov.in/biofortified-varieties-sustainable-way-alleviate-malnutrition-third-edition)

Conclusion

Consuming vegetables sufficiently protects the human body against various chronic degenerative diseases, as they are universal sources of phytonutrients. Modern consumers are increasingly health-conscious and well-informed about the nutritional value of vegetables. Offering vegetables at affordable prices can encourage their inclusion in daily diets, providing motivation for vegetable breeders to develop genotypes with enhanced nutritional qualities. Vegetable breeders have a unique opportunity to address human nutritional needs by creating nutrient- and nutraceutical-rich cultivars. Augmentation and evaluation of genetic resources coupled with traditional and modern vegetable improvement tools are likely to result in development of more nutritious vegetables.

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The Green Symphony: Exploring the Evolution, Significance, and Benefits of Interior Landscaping

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Abstract

The Interior landscaping involves adding plants and other natural elements indoors to enhance architectural spaces. It promotes physical and mental wellness by increasing air quality and lowering stress. From this article we explore the history, essential component, advantages and disadvantage of the interior scaping. Interior landscaping has evolved significantly since the beginning of human civilization, with the usage of technologies like as hydroponics, aquaponics, and aeroponics becoming increasingly popular. Plants of various varieties, such as bushy, climber, bulb, succulent, and cactus, are utilized to generate aesthetic appeal and increase value, as well as to offer productive interior spaces. Furthermore, not only does it give improved air quality, cognitive function, and stress reduction, but it also contributes to a better harmony with environment, which is beneficial to human mental wellbeing. Limiting airborne pollutants, such as volatile organic compounds, can prevent sick building syndrome (SBS). However, proper maintenance and consideration of dust formation on plant health should be considered. Finally, it is the easiest way to make the interiors more aesthetic and environmentally responsible at a very little cost in the interior space, which has both psychological and environmental advantages as urban living becomes more popular.

Keywords : Interiorscaping, air quality , aesthetic , indoor scaping

Introduction

Indoor landscaping or interiorscaping, is a form of indoor gardening that creates a naturalistic environment within indoor spaces. Nowadays, various type of gardens are popular among citizens. Mediation gardens promote relaxation and tranquility, while rooftop and kitchen gardens (Potager) provide fresh produce for home purpose. In addition to that, Interiorscaping is an emerging and rapidly growing sector in floricultural industry. Although it has many benefits, its beneficial effects on humankind's physical and mental health are by far its greatest.

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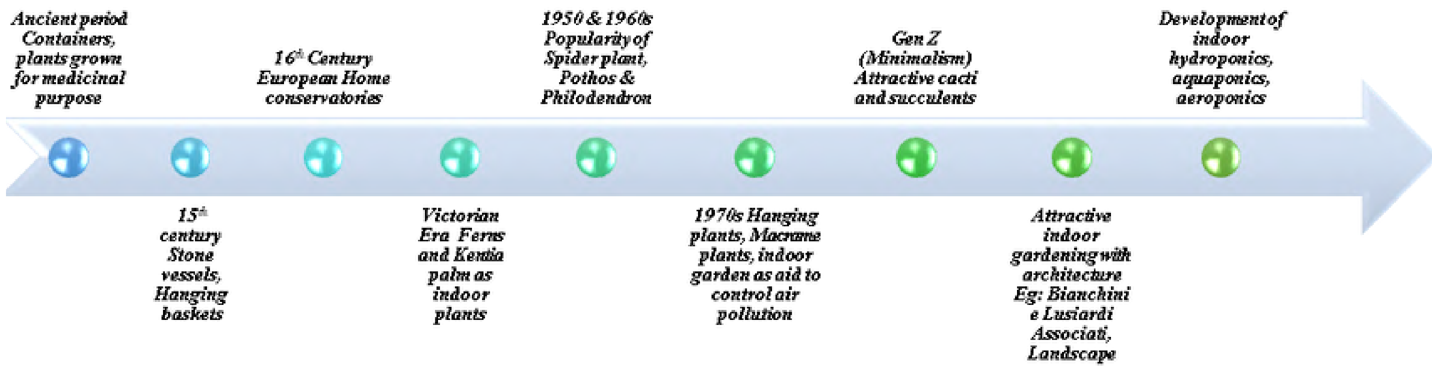
Indoor gardening improves people's quality of life and strengthens the bond between people and plants. Academics and horticulturists will be especially interested in this expanding area of the floriculture industry. Using hanging pots and containers, ancient civilizations engaged in indoor horticulture before progressively developing more complex interior design methods. Indoor hydroponics, aquaponics, and aeroponics are examples of recent advancements in this discipline that have increased the potential for indoor plant cultivation. Because it improves occupants' well-being by affecting their mood and productivity, themed internal landscaping is becoming more and more popular in workplaces. By integrating color psychology with strategic plant placement, interiorscaping created more engaging and comfortable environment. Some of the examples includes blues indicates calmness and trustworthy, yellow indicates spirits level up. Overall, Interiorscaping provides potential benefits such as enhances the beauty and aesthetic appearance into workplaces, home and other indoor environments.

Historical Development of Interior Landscaping

People have been growing plants in containers since ancient times; some of these species were cultivated for their therapeutic and medicinal qualities. Stone jars were discovered to be utilized as containers in Italian peristyle gardens, while in the fifteenth century, bamboo and orchids were utilized in Chinese gardens. Europeans started keeping conservatories at home around the 16th century, and this practice persisted into the 17th century when Joseph Banks enlarged Kew Gardens and brought in new plant species. Since the 1830s Victorian era, the ferns and kentia plant have had popularity, particularly in the Wardian case, which has helped protect plants during transport. From 1970, environmental issues have concerned us, leading to advancement in indoor gardening.Nowadays, interior landscaping is mostly practiced for its aesthetic appeal, to foster connection with nature, and to improve the indoor air quality



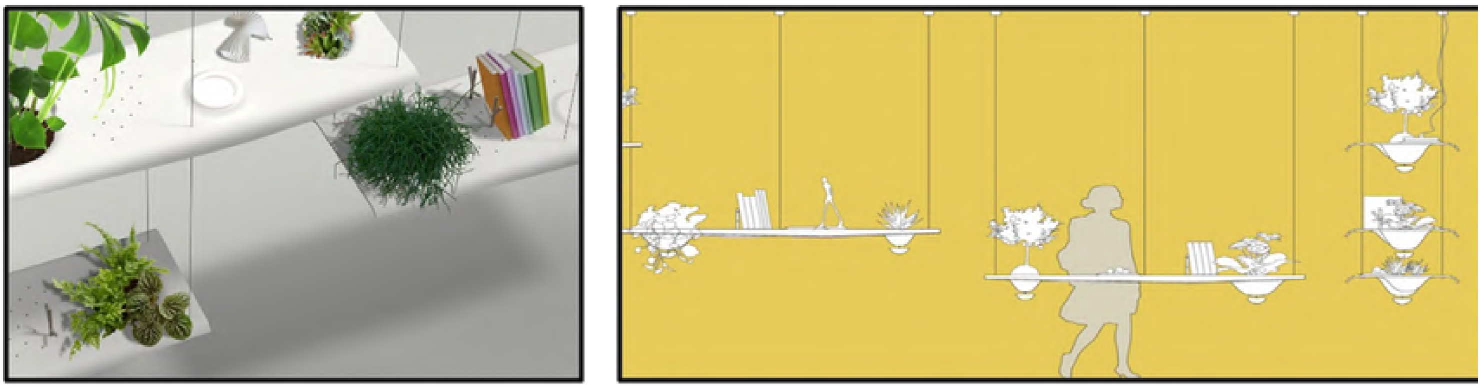


Fig. 1. Bianchinie Lusiardi Associati, Landscape

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Element of Interior Landscaping

- **Proportion:** Choose plants that complement the room's scale to maintain balance and harmony.
- **Form:** Consider the three-dimensional shape of plants to enhance spatial aesthetics.
- **Texture:** Mix different foliage textures to create contrast and visual interest.
- **Color:** Use bold or complementary plant colors to unify or accentuate a space.
- **Repetition:** Repeat plant forms or patterns for a cohesive and structured design.
- **Focal Point:** Highlight a striking plant to draw attention to a specific area.
- **Balance:** Distribute plant mass evenly for symmetry or an intentional asymmetrical look.

(Table .1) Plants suitable for Interior Landscaping

Types of plants	Examples	Features	Required enivironment / practices
Bonsai	*Ficus spp.* and *Juniperus spp.* are commonly used	aesthetic and architectural beauty, perfect for tabletop display.	bright light, consistent watering, and periodic pruning
Cacti and Succulents:	*Aporocactus flagelliformis* and *Aloe variegata*	add texture and unique shapes to indoor environments and also Low-maintenance, drought-tolerant plants.	bright light and minimal watering
Palms and Cycads:	*Areca lutescens* and *Cycas revoluta*	tropical feel indoors and are suitable for spacious areas due to their upright growth and also Air-purifying	low humidity and adapt well to indoor conditions
Flowering Pot Plants:	*Pelargonium* and *Chrysanthemum*	Suitable for temporary indoor displays (colourful flowers) due to the season life cycle of the plants	partial shade and consistent care.

Types of plants	Examples	Features	Required enivironment / practices
Climbers	*Asparagus spp* and *Ficus repens*	grow vertically or trail downwards, ideal for small spaces	Require vertical support (moss sticks, bamboo), moderate light and humidity
Trailing	*Chlorophytum comosum* and *Tradescantia spp*	hanging baskets, or decorative frames indoors	shelves, hanging pots, and require bright, indirect light
Flowering House Plants	*Anthurium* spp, *Begonia spp*, and *Heliconia spp*	offer seasonal blooms and also adds color and vibrancy to interiors.	moderate humidity (50%-60%) and indirect sunlight
Bulbous Plants	*Gloriosa superba* and *Hippeastrum spp*	Provide seasonal blooms and easy to grow indoors	Requires Good drainage and bright indoor areas and less frequency of watering
Bushy and Upright Foliage Plants	*Aglaonema spp, Dracaena spp*, and *Ficus elastica*	provide a bold, structured appearance, enhancing room décor and suited for floor pots or tabletop displays	minimal maintenance and suits in low-light conditions
Ferns and *Selaginella*	*Nephrolepis exaltata* and *Selaginella spp.*	Moisture-loving plants that adds a soft, lush texture to interiors.	low to moderate light and high humidity

Important considerations of Interiorscaping

The choice of indoor plants includes the selection of species that can tolerate varied indoor conditions, like excessive heat, cold, or dryness. Evergreen plants with showy foliage are usually chosen for indoor purposes. The soil used should have high water-holding capacity while also providing adequate drainage, with 5-10% non-capillary pore space for adequate aeration. A well-textured soil like loam or sandy loam is preferably used, with a pH ranging from 5.5 to 6.5, except for orchids and ferns, which thrive in a more acidic soil with a pH of around 4.For plants to grow as best they can inside, the ideal temperature range is between 21 and 32 °C in the atmosphere, while the ideal soil temperature is between 18 and 21 °C.Regarding relative humidity, it needs 50–60%, although very few plants (like orchids) need higher humidity, like 80–90%. The plant needs extra care to maintain light intensity, such as a 5000–10,000-foot candle of light according to the season. In order to maintain the intended size and shape of the indoor plants, pruning is required on a regular basis in the cultural practice. Fertigation and slow-release fertilizers helped to guarantee that the plants were receiving the right amount of nutrients. To lower the chance of fungal infection and root rot, we should be careful not to overwater the plant. The majority of indoor plants are kept in either plastic pots because they can retain water better and are more suited for cactus and succulents, or earthen pots because they

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allow for air circulation. Pots mostly contain one drainage hole at the bottom and are kept on saucers or platters to hold excess water. Self-watering pots are also gaining popularity because of their convenience. Pots come in different shapes based on customer preference, such as round, oval, hexagonal, or pentagonal shapes to beautify.

Advantages of Interior Landscaping

Interior Landscaping brings immense pleasure and excitement while adding charms to the architectural beauty of buildings. Unlike traditional gardening, it does not require a fertile land. It is highly efficient in removing air pollution and is also cost -efficient and year-round solution . Interiorscaping gives access to the fresh herbs and better condition for the environment to protect the plants. It also enhances the air quality, improves the cognitive function, helps in focus, and reduces stress. It's easily accessible for the individual with disabilities, allowing them to enjoy it and also maintaining green scenery without the need for direct outdoor space. It also provides and promotes mood enhancement and relaxation; ultimately, these help in health by providing therapeutic value. Furthermore, in addition to its health benefits, it helps improve the visual appeal of interior spaces by making them more pleasant and enhancing the atmosphere. Overall, improving the indoor environment provides environmental sustainability.

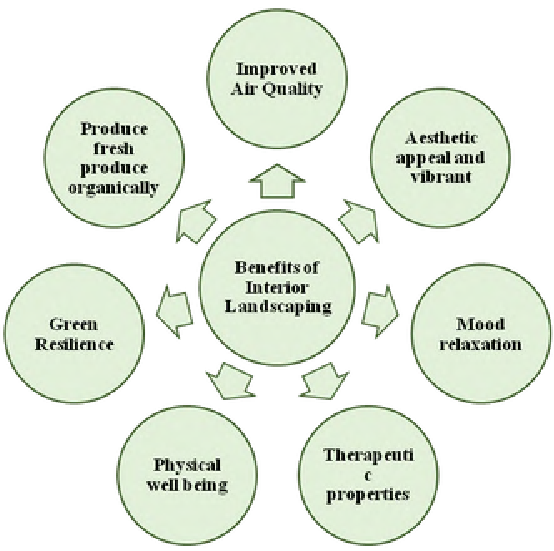

Fig. 2. Benefits of Interior Landscaping

Some potential disadvantges of Interior Landscaping,

- Mostly the shade- and semi-shade-loving plants are suitable for the indoor areas.
- Regular monitoring is required because the leaf stomata clog by the dust accumulation.
- In poor indoor conditions, the plant growth can be retarded; it leads to reduced root growth and less greenery.
- Excessive fertilizer can affect the plant health by the soluble salt accumulation.
- ndoor temperature, air conditioning, and cleaning chemicals can cause plant damage.
- Furthermore, the combination in the pot or container utilized determines the health of the plant.

Impact of Interior Landscaping on Sick building syndrome

Sick building syndrome refers to a condition where workers who experience acute health problems linked to their workplace i.e., building without a specific illness or cause whereas Building-Related Illness (BRI) refers to cases where diagnosable illnesses are caused by airborne building contaminants (USEPA, 1991). SBS Symptoms include headaches, irritation (eyes, nose, throat), dry cough, dizziness, nausea, skin issues, difficulty concentrating, and fatigue. BRI symptoms are clearly identifiable cause, include cough, chest tightness, fever, chills, and muscle aches. Cause of SBS may including inadequate ventilation such as insufficient space per occupant, Poor indoor air quality IAQ, defective HVAC (heating, ventilation, and air conditioning) system.

Indoor plants, such as Peacelily, Dracaena, Pothos, have potential to remove Volatile organic compounds (VOCs) like Benzene, Xylene, Formaldehyde etc. They contribute to improve air quality, provide peaceful environment that enhances employee morale and productive. Additionally, indoor gardening can help combat Sick Building Syndrome (SBS) and Building-Related Illness (BRI). Their overall positive impacts on human psychology significantly benefits both physical and mental wellbeing.

Fig. 3. Kempegowda International Airport

Fig. 4. Jewel Changi Airport, Singapore

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Conclusion

The environment has a major impact on people's physical and emotional health, but even a minor indoor plant change can have a favourable effect. By incorporating living plants into the area, interior landscaping contributes significantly to urban eco culture, which raises the value of interior design. By bringing a sense of nature, it can improve the fast-paced lifestyle of today and create a better attitude. An excellent example of the new trend in urban interior landscaping is the incorporation of green spaces, which enhances the atmosphere, promotes relaxation, and creates a stunning scene. Jewel Changi Airport and Kempegowda International Airport are notable examples.

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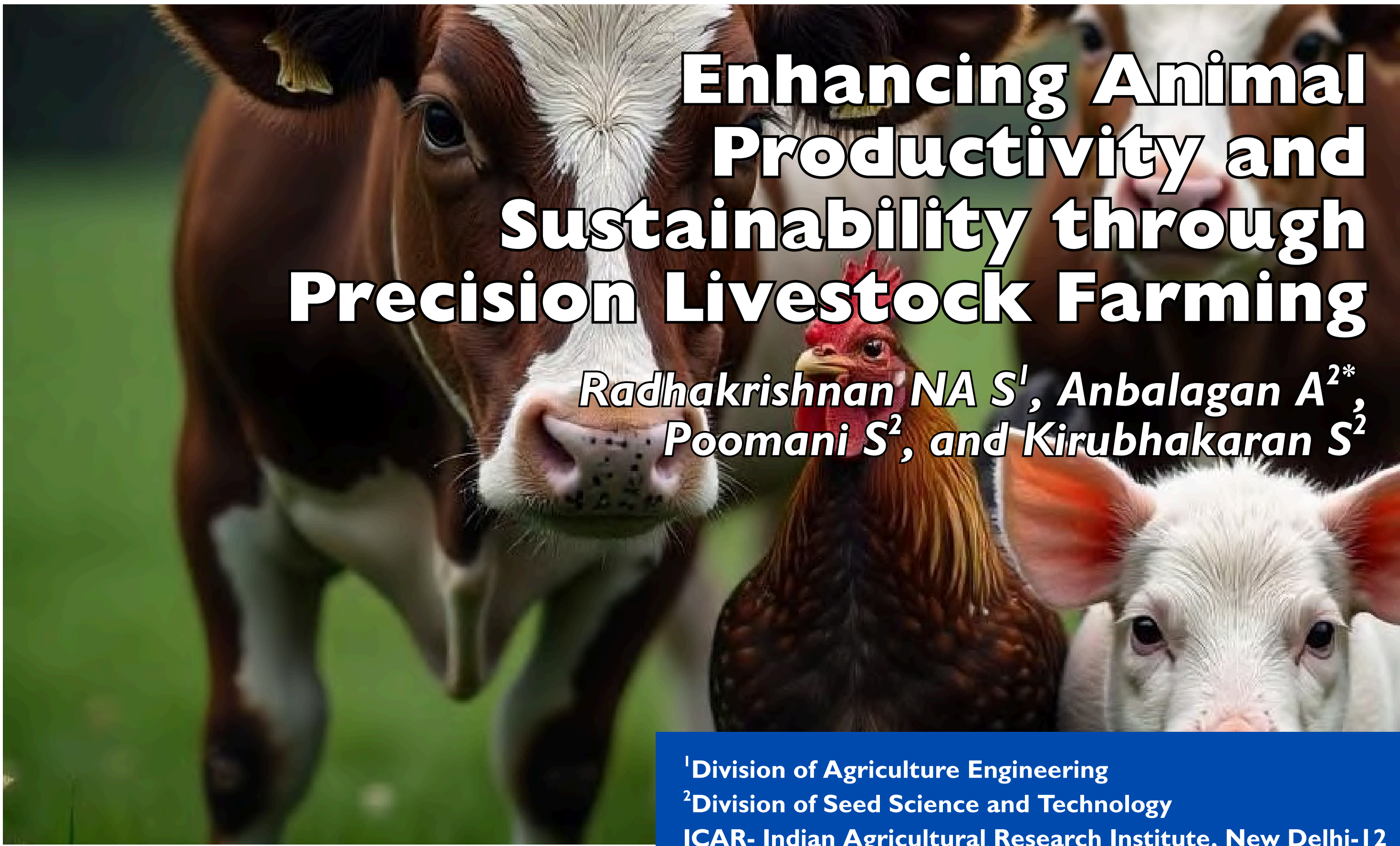

Enhancing Animal Productivity and Sustainability through Precision Livestock Farming

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Abstract

The major constraint in livestock farming is the continuous monitoring of animals for better production. Poor environmental conditions, inadequate nutrient supplements, and improper disease management may lead to major losses. Precision livestock farming integrates continuous monitoring of animals and their behavioral changes to environmental conditions and their productivity through the use of instruments, sensors, data analytics, machine vision, and so on. Livestock farming requires monitoring and management in all aspects of the identification of individual cattle, their physiological movements, disease prediction, feed intake, and environmental conditions. Identification techniques such as RFID tagging, biometric identification, and GPS has enabling accurate management and tracking of animals. Precision feeding improves livestock health through proper nutrient intake and reducing feed waste. Environmental monitoring systems regulate the favorable climate conditions whereas physiological data collection using wearable sensors and advanced techniques aids in better health assessment and early detection of diseases. Precision livestock farming can maximize the farmers' profit and improve overall productivity by reducing the costs of production as well as environmental impacts.

Key words: Precision Livestock Farming, Sensors, Environment, Animal Husbandry

Introduction

Livestock is an important source of income, particularly for small and landless farmers. Across the world, around 1.3 billion people are involved in livestock farming. In India, a livestock census is taken every five years. According to the 20th census, the total livestock population is 535.78 million (Government of India, 2019), being first in milk production with 239.30 million tonnes in the year 2023-2024 (Department of Animal Husbandry and Dairying, 2024).However, the major constraints in livestock farming are related to the inability to continuously monitor and notice animals resulting in inadequate distribution of feed and nutrient supplements, lack of disease control and eradication, and improper environmental maintenance ultimately resulting in increased cost of production or decrease in the yield. Hence continuous monitoring is required. Traditional livestock farming the decision making is based on the experience. Precision livestock farming (PLF) utilize advanced technologies to continuously monitor and manage livestock in real-time. (Berckmans et al., 2014) This can improve individual animal health, welfare, productivity and the environmental impact of animal husbandry, contributing to the economic, social and environmental sustainability of livestock farming (FAO, 2021). Our Indian Government has also taken several initiatives like National Digital Livestock Mission for creating a digital ecosystem using artificial intelligence (Department of Animal Husbandry and Dairying, 2022), Internet of things and data analytics, Rastria Gokul Mission (RGM) promotes the digital use of Pashu Aadhar and automated milking systems (Department of Animal Husbandry and Dairying, 2023), e- Gopala App by National Animal Disease Control Programme (NACDP) provides information at farm level based on data-driven decisions (National Dairy Development Board, 2020). Research institutions such as National Dairy Research Institute (NDRI) and Indian Veterinary Research Institute (IVRI) are also focusing on PLF technologies. These initiatives highlight the government's efforts towards the livestock sector for sustainability in animal husbandry

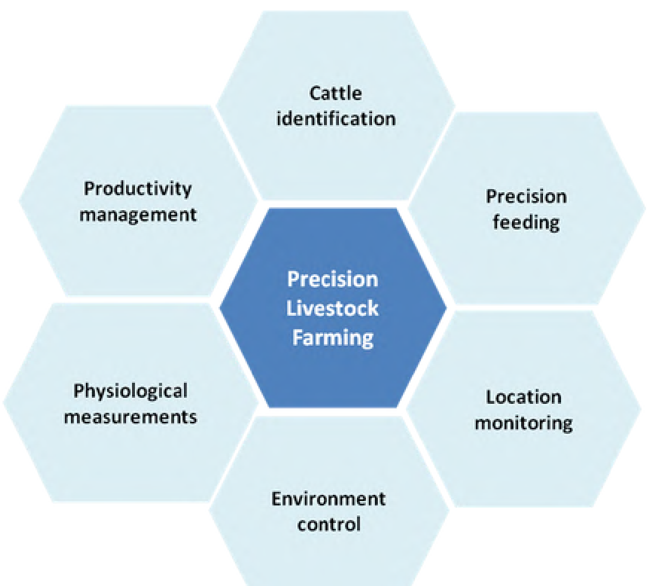


Fig. 1. Components of Precision Livestock Farming

Livestock identification systems

Cattle identification systems include animal recognition, identification of missing cattle, reallocation of livestock, and eradication of false insurance claims.

There are various types of cattle recognition techniques

Permanent identification techniques involve ear tips, tattoos, and freeze branding. Semi-permanent method includes ear tagging and ID collars. Temporary methods include sketching and methods like Radio Frequency identification (RFID) and detection. (Dogan et al., 2023).

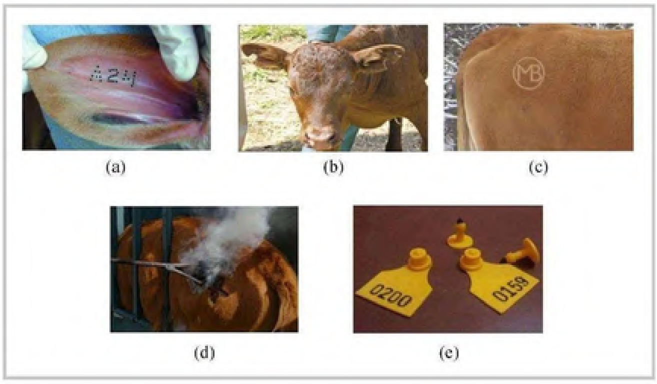


Fig. 2. Traditional animal identification methods. (a) Tattooing, (b) Ear notch, (c) Cold stamping, (d) Hot stamping, (e) Ear Tag (Dogan et al., 2023)

Further, the advanced identification techniques identify the individual cattle using animal biometrics such as muzzle patterns, Facial images, and Iris patterns. (Kumar and Singh et al., 2020)

Fig. 3. A sample of the collected muzzle print images database. The images, from two living animals, show different deteriorating factors: image orientation, blurred images, low resolution images, and partial images (Awad et al., 2016). This type of cattle identification includes two phases viz., training and testing phase. The training phase includes collecting

features like muzzle patterns, facial images, or iris patterns. The next step involves extracting the features, representing each image by one feature vector, and applying a dimensionality reduction to reduce the number of features in the vector and storing them in the database. The testing phase includes collecting the muzzle point image of a particular animal, extracting the features, and applying the machine learning algorithms in classifying the test features and match them with the database.

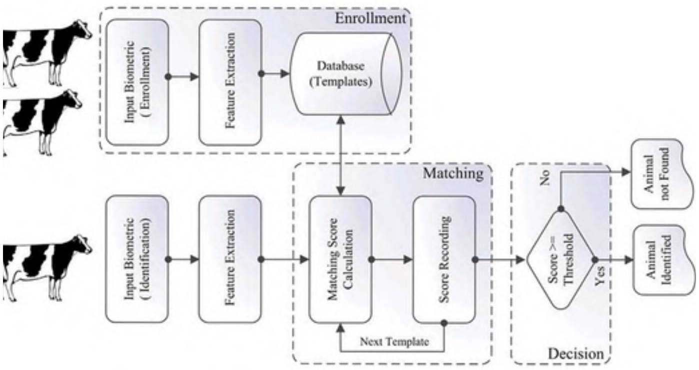


Fig. 4. A block diagram of a complete biometric-based animal identification system (Awad et al., 2016)

Precision feeding

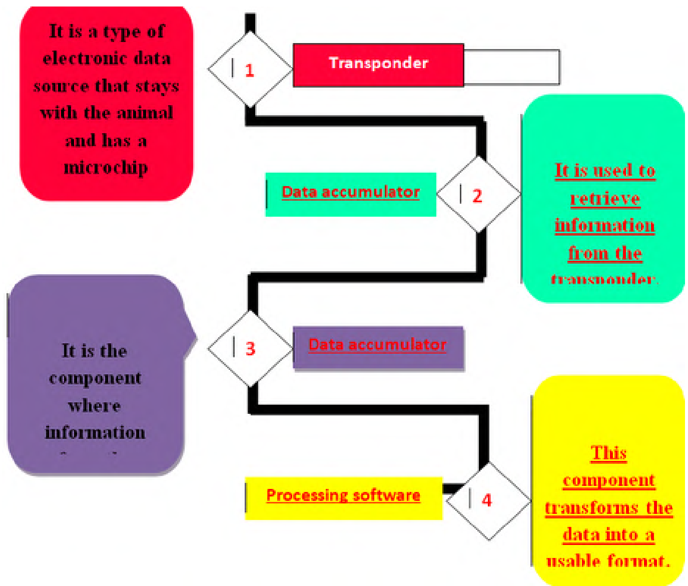
Precision feeding techniques are important for tracking and optimizing the feed intake of an individual animal. Feeding less than the preferred quantity may result in a lack of nutrient requirements. On the other hand, overfeeding should also be avoided as it reduces profit, increases feed costs, and may result in metabolic disorders. Precision feeding enables feeding at the right time, right composition, and right amount, resulting in improved nutrient utilization.

The tools of precision feeding include precise estimation of nutrient requirements, precise nutrient analysis (use of feed additives and supplements, feed processing techniques, proper weighing and mixing of nutrients), and ration formulation on a nutrient availability basis.

The feeding management practices include phase feeding and split-sex feeding. Precision feeding is determined by animal factors such as genotype, sex, age, body weight, etc., and external factors such as health status, environment, stress, water intake, etc., and also the availability of nutrients vitamins, and mineral contents.

Location monitoring

Traceability of animals for safer food, supply, and control of diseases is very important. Global positioning systems (GPS) with RFID wifi networks enable easy monitoring of the animals. Research has proven that RFID-based tracking is more promising. RFID tracking includes active and passive modes. The four basic components of RFID tracking are given below



GPS is an important solution for cattle localization and management. Various Low Power Wide Area Networks are also available for the tracking of animals.

Environment control

Climate is the main factor in reducing the efficiency of the animals. Environmental control involves improved air and water quality, utilization to minimize waste, and so on. An increasing population puts increasing demand on livestock production. There is a need for continuous real-time monitoring of the physical environment of the animal.

An effective precision environment requires continuous sensing at the appropriate frequency, room temperature, humidity, air speed across the animal, solar radiation, and air circulation. Based on the complexity of the system, some behavioral and physical responses are noted.

For example, the dry –bulb temperature can be measured using thermocouple, resistance temperature detector or thermistor, the dew point temperature measured by chilled mirror hygrometer, the relative humidity can be measured b capacitance hygrometer, absolute humidity can be measured be thermal conductivity sensor, Solar radiation can be measured using Pyranometer or black globe radiation, air speed can be measured by propeller anemometer, pitot tube and orifice plates, or hot wire anemometer. (Fournel et al., 2017)

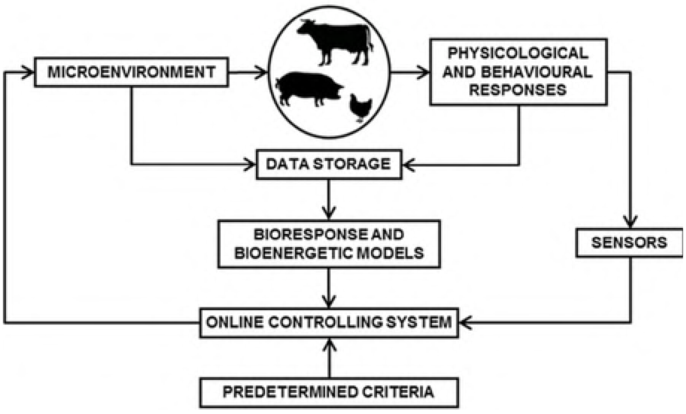


Fig. 5. Schematic overview of the key components of environment control through precision livestock farming. (Fournel et al., 2017)

The data are then stored and the interpretations of the measurements are done using response simulations such as animal comfort indices or bio-energetic models. These will enable the online controlling systems.The environmental control of livestock buildings includes analysis of heat and moisture production rates using models, thermal stress through multifactor animal comfort indices, and animal behavioral response to the changing environment.

Physiological measurements

The collection of body temperature data, movement patterns, and behavioral data helps in the early prediction of diseases. The dairy cattle-focused platform element comprises a neck count sensor network with neck neck-mountedcollar electronic unit. The collar electronic unit is mounted on the neck of animals with 3 a 3-axis accelerometer to monitor the rumination and feeding details. The energy spent will help in the identification of the physical condition of the cow.

Monitoring the feed intake helps in establishing the overall welfare of the animal. If the animal spends less time eating or ruminating, there are chances of illness. Research implies that a healthy cow ruminates 500 – 600 times per day. Jaw movements are bigger during eating than during rumination.

The other measurements such as dry bulb temperature, dew point temperature, etc., are measured using specified equipment. The internal body temperature can be measured by using the gastrointestinal device, implanted data logger, or implanted radio transmitter.

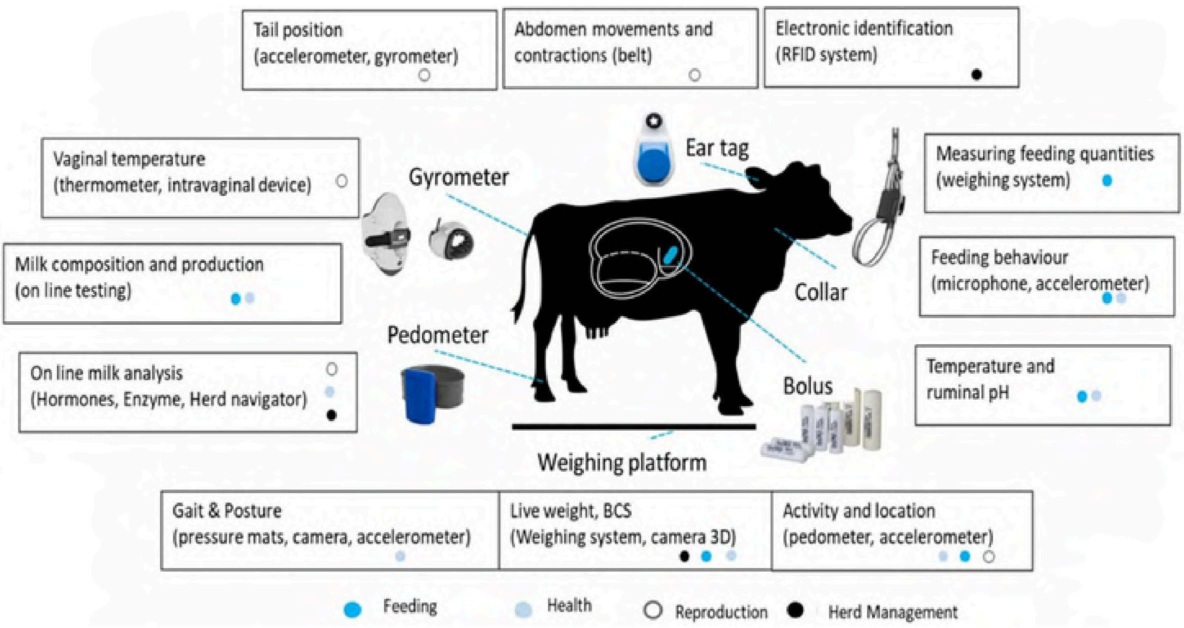


Fig. 6. Overview of currently used devices for measuring physiological measurement of animals

The respiration rate can be monitored by automated cattle respiration rate or automated dairy cow respiration rate. The heart rate variability can be recorded by a Holter recorder, Polar recorder, or implantable telemetric transmitter. (Fournel et al., 2017)

The body weight can be measured with a scale plate (platform with strain gauge load) or machine vision system (image or video capture from which the weight can be calculated based on the superior area, perimeter, side of abdomen, wide of capture of the animal)

Production management

The key components of production management include all the above-mentioned automated monitoring systems, data-driven decision-making, environmental control, individualized animal care, etc., For example, a dairy cow should be monitored based on the milk production as well as estrus cycle.

Conclusion

By including contemporary technologies like artificial intelligence, machine learning and the internet of things, precision livestock farming is transforming the animal husbandry sector. Some upcoming advancements like AI based disease prediction models, blockchain-based traceability systems may lead livestock farming to achieve greatest advancements. Farmers can utilize these technologies to become successful in their livestock farming sector with more profit and leading to minimize environmental impact and ensuring animal welfare.

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Nematode pests of Coconut-based cropping system and their management

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Abstract

The coconut tree originated from Southeast Asia and is considered Kalpavriksha' – the 'tree of heaven which means all the tree parts are useful. India is the leading producer of coconut in the global market. There are various pests which attack the coconut-based cropping system of which nematodes are also one of the serious pests. The nematodes which attack coconut-based cropping system are burrowing nematode- *Radopholus similis*, root-knot nematode- *Meloidogyne incognita*, and red-ring nematode- *Bursaphelenchus cocophilus*. These nematode pests are significant threats, affecting the root system and leading to poor growth, reduced yield, and in severe cases, plant death. Of these, red ring nematodes are not present in India. Effective management of nematodes in coconut-based cropping system is crucial to ensure healthy palms and sustainable yields.

Keywords: Kalpavriksha, nematodes, quarantine, management

Introduction

The coconut tree (*Cocos nucifera* L.) belongs to the family Arecaceae which is originated in Southeast Asia and transported to America and Africa through ocean currents and by voyagers. It grows well in tropical regions of temperatures around 27± 5^{0}C and does not survive temperatures below 20^{0}C. India is the leading producer of coconut in the global market. From 2022 to 23 the production of coconut is 3.7K MT (Anonymous, 2022). Around 90% of the coconut products are produced in the four main southern states of India: Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh. In the order of production- Karnataka (28.97%) > Kerala (27.4%) > Tamil Nadu (26.4%) > Andhra Pradesh (8.31%) (Figure 1), Karnataka makes up the largest proportion of production in India as per data of CDB (Coconut Development Board), 2022-2023. The following crops, like black pepper, turmeric, betel vine, and ginger, are

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planted as intercrops in coconut plantations. There are numerous pests and diseases of coconut-based cropping system of which nematodes are also one of the serious threats to the coconut plantations. The serious nematode pests of coconut-based cropping systems are the burrowing nematode, *Radopholus similis*, and the root-knot nematode, *Meloidogyne incognita* which are present in India (Anes et al., 2021). Another serious nematode pest is the red-ring nematode *Bursaphelenchus cocophilus* which is a quarantine pest, not present in India (Nisha et al., 2024).

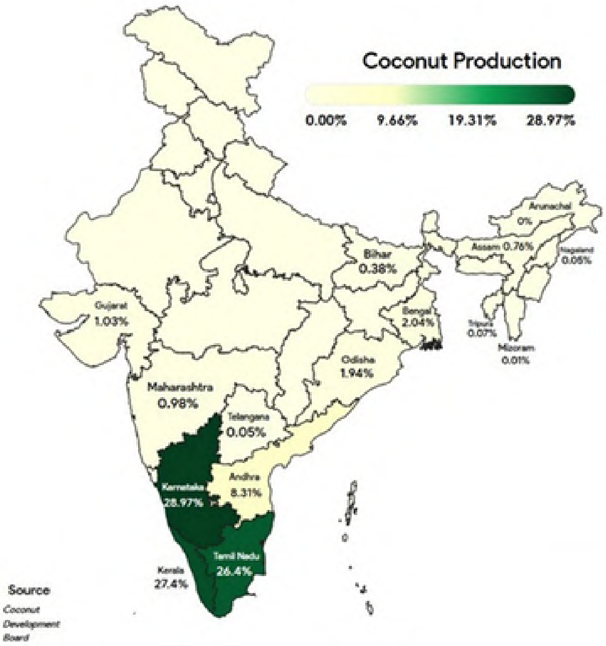

Fig. 1. Coconut production in India 2022-23

Burrowing nematode, *Radopholus similis*

It is the migratory endoparasite that completes its life cycle within 25 days inside the coconut roots (Geetha et al.,1991). All the larval stages and females are infective except males. The typical identification characters for *Radopholus similis* are the females with lip region sometimes set off and hemispherical, well-developed oesophagus with overlapping dorsally, vulva postmedian, gonads paired, outstretched, tail elongate conoid while the male has the oesophagus which is degenerated and bursa covers two-third of the tail (Sekora and crow et al., 2012).It causes general nonspecific symptoms such as yellowing, stunting, reduction in the number and size of leaves and leaflets, delay in flowering, button shedding and yield reduction. Their infestation is more severe in the roots of nursery seedlings. They produce small, elongated, orange-coloured lesions on the creamy-white roots is the typical symptom (Figure 2). Burrowing nematode is a parasite of more than 300 plant species. It also infests major crops like banana, black pepper, betel vine, ginger, turmeric etc. This nematode also causes the toppling disease of banana.

Fig. 2. Necrotic lesions caused by burrowing nematode in coconut root (from right to left) (Photograph by V.K. Sosamma.)

Root-knot nematode, Meloidogyne incognita

It is a sedentary endoparasite with a broad host range. Its life cycle is completed within 24-30 days (Mhatre et al., 2020). This nematode causes damage to coconut-based cropping systems such as ginger, turmeric, black pepper, and betel vine which are planted as intercrops but not the main crop of coconut (Nampoothiri et al., 2019).The identification of this nematode is done based on examining the perineal pattern of melon-shaped females which has a high dorsal arch, no distinct lateral lines and punctations (Figure 3). Whereas in vermiform males bursa is absent, and second-stage juveniles have elongated conoid tail with pointed (Eisenback et al., 1985).

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Symptoms include the formation of rounded or irregular galls in the roots and stunting and yellowing are above-ground symptoms caused by this nematode. This nematode infestation aggravates many other pathogens like *Phytophthora capsici* which causes slow decline or slow wilt in black pepper (Rai and Upadhyay et al., 2023), and *Fusarium oxysporum* in the roots of black pepper (Ramana et al., 1992). In turmeric this nematode acts as predisposer for secondary pathogen like *Pythium sp*. (Jalaluddin et al., 2024).

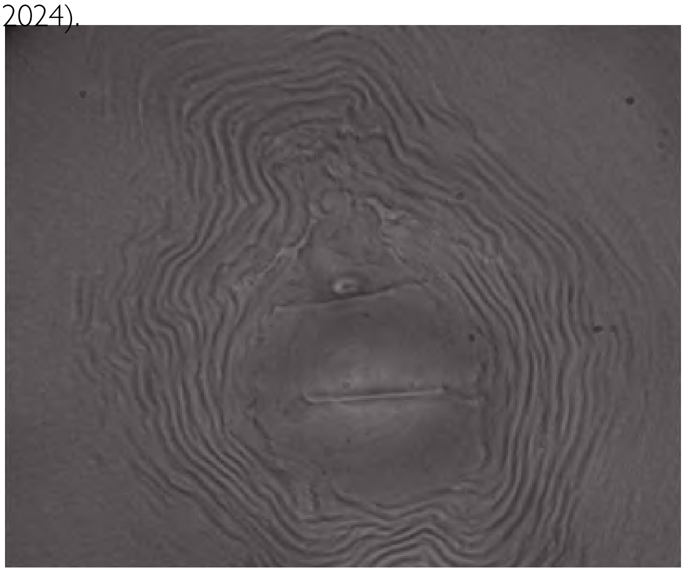

Fig. 3. Perineal pattern of *Meloidogyne incognita*

Red-ring nematode, *Bursaphelenchus cocophilus*

It is the aerial plant parasite, transmitted by palm weevil (*Rhynchophorus palmarum* L.). Nematodes are injected into the tissues of young coconut palms aged 2.5 to 10 years by insects while depositing their eggs. Nematodes first occur intercellularly and later found in both intercellularly and intracellularly. Symptoms include initial chlorosis appearing in the older leaves, and premature shedding of nuts, in cross-section the stem appears orange to brick red colour ring of 2 to 4 cm wide (Figure 4). The disease-affected trees will not recover after attack by this nematode because there will be an imbalance in the water uptake by the plant (Griffith et al., 2018). It is a quarantine pest that occurs in the West Indies and Latin America, which is not present in India (Figure 5). The plant materials such as seed nuts, seedlings, pollens, and tissue cultures etc., where import is prohibited and are subjected to quarantine inspection.

Fig. 4. Red ring symptom caused by *Bursaphelenchus cocophilus* in cross-section. (Photograph by Society of Nematologists slide collection)

Fig. 5. Distribution map of Bursaphelenchus cocophilus

Management

- Use of nematode-free planting materials from certified nurseries.
- Avoid planting intercrops such as banana, black pepper, turmeric, betel vine, and ginger in coconut plantations or nurseries.
- Remove the infected roots of the seedlings before planting.
- Use of less susceptible cultivars such as dwarf cultivars Kenthali and Klappawang, tolerant cultivar such as Indonesia 6 (VTL-11), Mahuva 8 and Andaman-5 (VTL-29e) and hybrids such as Java Giant x Malayan Dwarf Yellow, San Ramon x

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SGangabondam, Kulasekharam Dwarf Yellow × Java Giant, Java Giant × Kulasekharam Dwarf Yellow, and Indonesia-6 (VTL-11) × Singapore (VTL 17) are resistant against R. similis. (Sosamma et al., 1980, 1988; Sosamma et al., 1984; Griffith et al., 2018).

- Growing antagonistic crops like marigold as intercropping or as border planting will reduce the nematode population.
- Incorporation of bioagents such as AMF (Arbuscular Mycorrhizal Fungi), *Pasteuria penetrans* and *Paecilomyces lilacinus* in potting mixture
- Application of organic amendments like neem cakes at 2-4 kg/palm/ year.
- ·Apply 3 kg of enriched FYM per pit before planting and apply at an interval period of six months and it is prepared by mixing with 2 kg of each of *Pseudomonas fluorescens* + *Trichoderma harzianum* + *Paecilomyces lilacinus* formulation under shade. It has to be covered with mulch and optimum moisture of 25 - 30% has to be maintained for a period of 15 days.

Conclusion

The management of nematodes in coconut-based cropping system requires a holistic approach, balancing cultural, biological, and chemical methods. By adopting these integrated strategies, farmers can protect their coconut palms from nematodes, ensuring higher yields and long-term sustainability. Regular monitoring and adaptive management are key to keeping nematode infestations under control and maintaining the health of coconut plantations.

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Best Article of the First Issue

NATURE'S HELPERS: HOW BIRDS' ACOUSTIC SIGNALS INFLUENCE STOMATAL OPENING?

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Email: abhishreeramachandra@gmail.com

Abstract

Stomata are minute epidermal openings on leaf surfaces regulating the vital process of photosynthesis and transpiration in plants. The opening and closing of stomatal apertures are regulated by many factors including turgor pressure changes, influenced by environmental

What are Stomata?

The stomata are minute openings on the leaf surfaces that regulate photosynthesis and transpiration, crucial for overall plant health. Stomata consist of a pair of specialized guard cells present in aerial surface of leaves covering

With Dr. H. Shivanna, Ex-VC of UAS, Bangalore

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