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A STEP TOWARDS AGRICULTURE

Agri Roots e-Magazine

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“MAY THIS NEW YEAR SOW THE SEEDS OF PROGRESS, INNOVATION, AND SUSTAINABLE AGRICULTURE FOR A BETTER TOMORROW”

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from the editor

As we step into a brand-new year, I extend my warmest wishes to our readers, contributors, reviewers, and well-wishers. A new year is more than a change in the calendar—it is an invitation to reflect, renew, and reimagine the paths we choose ahead. It offers us a moment to pause, acknowledge how far we have come, and gather the courage and clarity needed to move forward with purpose.

The year gone by has been a tapestry of challenges and achievements. It tested our resilience, sharpened our perspectives, and reminded us of the value of knowledge, collaboration, and compassion. Through every uncertainty, one truth remained constant: progress is possible when curiosity is nurtured and ideas are shared. We are grateful for the trust you have placed in us and for the vibrant engagement that continues to shape our collective journey.

As we welcome this new beginning, we reaffirm our commitment to quality, integrity, and relevance. The year ahead brings fresh opportunities to explore emerging ideas, embrace innovation, and amplify voices that inspire positive change. We aim to deepen conversations, encourage thoughtful inquiry, and provide content that informs, empowers, and connects our community across disciplines and interests.

Let this year be marked by optimism grounded in action—where aspirations are matched with effort, and learning translates into impact. May we approach each day with curiosity, kindness, and the confidence to adapt in a rapidly evolving world. Together, let us turn challenges into stepping stones and ideas into meaningful outcomes.

Thank you for being an integral part of our journey. We look forward to another year of shared growth, insightful dialogue, and purposeful progress. Wishing you good health, continued success, and fulfillment in all your endeavors.

Dr. Deepak Kumar
FOUNDER & EDITOR


EXPLORING
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Epigenetic Modulation of Plant Disease Resistance

ARTICLE ID: 0316

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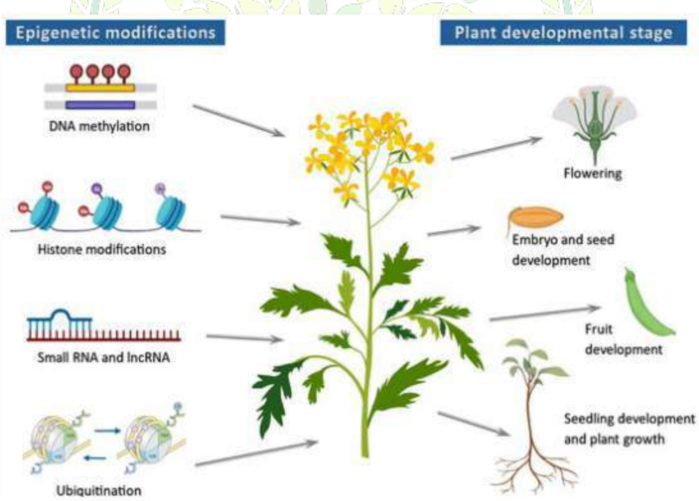
Plants, being sessile organisms, are continuously exposed to a wide range of biotic and abiotic stresses. To successfully repel invading pathogens, plants have evolved an intricate and highly regulated immune system that enables rapid and need-based activation of defence genes. Epigenetics refers to heritable changes in gene function that occur without alterations in the underlying DNA sequence and can be transmitted mitotically and/or meiotically. Epigenetic regulation—mediated through DNA methylation, histone modifications, and small RNAs—plays a critical role in controlling gene expression during stress responses. With advances in molecular tools, epigenome editing has recently emerged as a promising strategy for enhancing resistance against various plant stresses. Stable and heritable epigenetic regulatory mechanisms associated with disease resistance can be effectively exploited in crop-breeding programmes for the development of improved and resilient varieties.



Plants defend themselves against pathogens through sophisticated defence mechanisms that have evolved over time. Pattern-triggered immunity (PTI) is activated when pattern recognition receptors (PRRs) recognize pathogen-associated molecular patterns (PAMPs) or damage-associated molecular patterns (DAMPs). In contrast, effector-triggered immunity (ETI) is initiated when plant resistance (R) proteins detect pathogen-secreted effector molecules (Jones et al., 2016). Both PTI and ETI involve extensive transcriptional reprogramming of defence-related genes; however, they differ in the magnitude and duration of downstream responses.

Many defence-associated genes are located in heterochromatic regions and are transcriptionally inaccessible under normal conditions. Activation of these genes requires coordinated action of epigenetic regulators that modulate DNA methylation patterns, chromatin structure, and histone modifications (Qi et al., 2023).

Types of Epigenetic Mechanisms

Epigenetic mechanisms can be broadly classified into three major categories: DNA methylation/demethylation, histone modifications, and non-coding RNAs.

DNA Methylation

DNA methylation involves the addition of a methyl group to the 5-position of cytosine residues, catalysed by DNA methyltransferases (MTases). It is generally associated with transcriptional repression, particularly when present in promoter regions, and results in heritable methylation patterns transmitted during mitosis and meiosis. DNA methylation is regulated through both methylation (maintenance and de novo) and demethylation (active and passive) processes. Maintenance methylation preserves existing methylation patterns during DNA replication, whereas de novo methylation establishes new methylation marks on previously unmethylated regions, primarily via the RNA-directed DNA methylation (RdDM) pathway. In plants, DNA methylation is controlled by three major families of methyltransferases: maintenance methyltransferases (METs), chromomethylases (CMTs), and de novo DNA methyltransferases (DRMs).

Histone Modifications

Histones are basic proteins rich in lysine and arginine residues, which impart a positive charge and facilitate interaction with negatively charged DNA. The N-terminal tails of histones are subject to diverse post-translational modifications, including methylation, acetylation, ubiquitination, and phosphorylation. Histone methylation is among the most extensively studied modifications and can either activate or repress gene expression depending on the specific residue modified; for example, H3K4 methylation is associated with transcriptional activation, whereas H3K27 methylation is linked to gene repression. Histone acetylation neutralizes the positive charge on lysine residues, reducing histone–DNA affinity and thereby enhancing accessibility of transcriptional machinery such as transcription factors and RNA polymerase II.

Non-coding RNAs

Non-coding RNAs are RNA molecules that do not encode proteins but play crucial roles in gene regulation and genome stability. Major classes include microRNAs (miRNAs) and small interfering RNAs (siRNAs), which mediate RNA interference pathways by promoting mRNA degradation or inhibiting translation, thereby regulating gene expression during plant–pathogen interactions.

Applications in Plant Disease Resistance

Both naturally occurring epigenetic variation and artificially induced epigenetic modifications can significantly influence plant responses to pathogens. These mechanisms offer considerable potential for epigenetic breeding approaches aimed at improving disease resistance. Selected examples of epigenetic regulators implicated in plant disease resistance are summarized in Table 1.

Table 1. Reported use of epigenetic regulators in plant disease resistance

Gene name	Gene function	Role in host–pathogen interaction	Reference
AeDRM2	De novo DNA methyltransferase	Knockdown enhanced resistance of *Aegilops tauschii* to *Blumeria graminis* f. sp. *tritici*	Geng et al., 2019
Xa21G	Resistance to *Xanthomonas oryzae* pv. *oryzae*	Demethylation using 5-azadeoxycytidine improved disease resistance	Akimoto et al., 2007
IR-specific siRNA (24 nt)	Transcriptional gene silencing	Increased methylation of MYMIV intergenic region conferred resistance in soybean	Yadav & Chattopadhyay, 2011
MeSWEET10a	Susceptibility gene in cassava	Targeted methylation of EBE site conferred resistance to bacterial blight	Veley et al., 2023
SlPR1	Defence-related gene	H3K4me3 enrichment enhanced resistance to *Clavibacter michiganensis* ssp. *michiganensis*	García-Murillo et al., 2023

Conclusion

Epigenetic modification represents a promising alternative strategy for developing disease-resistant crop varieties through epi-breeding. Epigenomic variations associated with disease resistance traits can serve as molecular epigenetic markers to support selection and evaluation in breeding programmes. Furthermore, epigenetic modelling may help predict the effects of epigenomic variation on disease resistance and guide targeted epigenome engineering. Future research should focus on elucidating the precise regulatory mechanisms by which epigenetic factors are recruited to defence genes during plant immune responses.

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ICT and Today's Agricultural Extension: Has Extension Truly Adopted ICT, and Does It Reach the Village?

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Agricultural extension has historically played a vital role in enhancing agricultural productivity, food security, and rural livelihoods by facilitating the transfer of knowledge, technologies, and skills from research institutions to farmers. Conventional extension approaches—such as farm and home visits, demonstrations, field days, group meetings, and training programmes—have been effective in building trust and enabling location-specific learning. However, these methods are often constrained by inadequate manpower, limited financial resources, and difficulties in reaching a large and geographically dispersed farming population (Anderson & Feder, 2007; Swanson & Rajalahti, 2010).

In recent decades, rapid advancements in Information and Communication Technologies (ICTs) have transformed communication systems worldwide, including rural areas. Increased penetration of mobile phones, internet connectivity, and digital media has created new opportunities for strengthening extension delivery systems. ICT-based extension is often promoted as a cost-effective, scalable, and time-efficient solution capable of overcoming many limitations of traditional extension systems (Aker, 2011).

In India, ICT has been strongly integrated into agricultural policy frameworks through initiatives such as Digital India, the National e-Governance Plan in Agriculture (NeGP-A), mKisan, Kisan Call Centres (KCCs), e-NAM, Krishi Vigyan Kendra (KVK) portals, mobile applications, and community radio stations. These initiatives suggest that agricultural extension has formally embraced ICT. However, an important question remains unanswered: Has ICT truly been adopted in extension practice, and does it meaningfully reach farmers at the village level?

This article critically examines the concept, adoption, and real-world functioning of ICT in agricultural extension, with a particular focus on village-level realities. It argues that while ICT adoption is evident at institutional and policy levels, its penetration, regular use, and impact at the grassroots level remain uneven and limited.

Concept of ICT in Agricultural Extension

ICT in agricultural extension refers to the systematic use of digital tools, communication technologies, and information systems to generate, store, process, retrieve, and disseminate agricultural information to farmers and other stakeholders (Aker, 2011; FAO, 2019). Unlike traditional extension methods that rely primarily on physical interaction, ICT-enabled extension enables rapid, interactive, and multi-directional communication across distances.

ICT Tools Used In Agricultural Extension Include

- Mobile phones (SMS, voice calls, IVR systems, mobile applications) for weather alerts, pest and disease advisories, market prices, and scheme information
- Internet-based platforms such as agricultural portals, e-extension systems, and social media (WhatsApp, YouTube, Facebook)
- Mass media, particularly community radio and agricultural television, which are highly effective for illiterate and semi-literate farmers
- Digital kiosks and information centres providing access to expert advice and government services
- Decision support systems, GIS, and AI-based advisories for crop planning, precision agriculture, and risk management

The primary objectives of ICT-based extension include timely and accurate information delivery, cost-effectiveness, wider outreach, improved transparency, and farmer empowerment (Davis et al., 2014). ICT also enables feedback mechanisms, allowing extension systems to become more participatory and demand-driven. However, effectiveness depends not merely on technology availability but also on user capacity, content relevance, and local contextualization.

Extent of ICT Adoption in Today's Extension System

Institutional Adoption

At the institutional level, ICT adoption in agricultural extension has increased significantly. Most agricultural universities, research institutions, line departments, and Krishi Vigyan Kendras (KVKs) maintain websites, digital repositories, and social media accounts. Extension advisories are disseminated through mobile messages, WhatsApp groups, YouTube videos, and online training modules (Davis et al., 2014).

This widespread institutional use indicates that ICT has been structurally integrated into extension systems. Digital reporting, online meetings, and e-learning platforms are now common within extension organizations.

Policy and Programme Support

Government policies strongly promote ICT-based extension. Under Digital India and NeGP-A, emphasis is placed on farmer-centric digital governance, online service delivery, and real-time advisory systems. Programmes such as mKisan, KCCs, soil health card portals, and weather-based advisories reflect this commitment (Government of India, 2020).

From a policy perspective, ICT adoption appears robust and progressive. However, policy enthusiasm does not automatically translate into effective field-level implementation.

Readiness of Extension Personnel

The digital readiness of extension personnel varies widely. Younger professionals and researchers tend to adopt ICT tools more readily, while many field-level extension workers continue to rely on traditional approaches due to limited training, infrastructure constraints, or lack of confidence in digital tools. This uneven capacity significantly affects ICT utilization at the village level.

Real Village Scenario: ICT in Practice at the Grassroots Level

The village-level reality of ICT-based extension presents a mixed and complex picture. While smartphones are increasingly available, their use for agricultural purposes remains limited. Most farmers primarily use mobile phones for voice calls, entertainment, and social communication rather than independently accessing agricultural applications or portals.

In many villages, ICT-based extension functions through intermediaries such as extension workers, KVK scientists, progressive farmers, or input dealers. WhatsApp groups managed by these intermediaries are common, but active participation is limited to a few members. Information often spreads verbally rather than digitally, maintaining the dominance of interpersonal communication.

Community radio and locally produced agricultural videos have shown greater acceptance, especially among women, elderly farmers, and marginal farmers. Collective listening and discussion foster shared learning and trust-building. However, access remains uneven, with progressive and resource-rich farmers benefiting more than smallholders.

Thus, ICT in villages often supports extension rather than replacing traditional methods. Trust, personal interaction, and local experience remain central to farmers' decision-making processes.

Does ICT-Based Extension Truly Reach Villages?

Despite the proliferation of ICT platforms, their reach into villages remains partial and uneven. Infrastructure constraints such as poor internet connectivity, unreliable electricity, and limited access to smartphones restrict ICT use, particularly in remote and tribal areas (Aker, 2011; FAO, 2019).

Digital literacy is another major barrier. Many farmers lack the skills required to navigate mobile applications, portals, or online advisories. Language barriers further limit effectiveness, as content is often technical and insufficiently localized.

Gender disparities also affect reach. Women farmers frequently have limited access to digital devices and fewer opportunities for ICT training, reinforcing existing inequalities (FAO, 2019). Consequently, ICT-based extension has expanded information availability but has not ensured equitable access.

Challenges Limiting Effective ICT Adoption

Several challenges constrain the effective adoption of ICT in agricultural extension:

- Persistent rural–urban digital divide

- Inadequate infrastructure and connectivity
- Low digital literacy among farmers and extension staff
- Generic and non-localized content
- Gender and social inequalities
- Weak feedback, monitoring, and evaluation mechanisms

These challenges create a gap between the availability of ICT tools and their meaningful use at the village level.

Way Forward: Making ICT Truly Reach Villages

To ensure meaningful ICT adoption, digital tools must complement rather than replace conventional extension approaches. A blended extension model that integrates ICT with interpersonal communication is essential for building trust and improving technology adoption.

Key strategies include strengthening digital literacy through village-level training programmes, promoting community-based ICT tools such as community radio and participatory video, and developing localized, need-based content. Capacity building of extension personnel, gender-sensitive inclusion strategies, improved rural infrastructure, and robust feedback mechanisms are also critical for ensuring that ICT-based extension genuinely reaches and benefits village communities.

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Ashwagandha: An Ayurvedic Rasayana

ARTICLE ID: 0318

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Ashwagandha (*Withania somnifera*) is a well-known medicinal herb used for centuries in traditional Ayurvedic medicine. It is classified as a *Rasayana*, meaning a rejuvenator that enhances physical and mental health. In recent years, ashwagandha has gained global recognition as a natural remedy for various health disorders and has become the subject of extensive scientific research.

The ashwagandha plant is a small shrub with yellow flowers, native to India, Africa, and the Middle East. The roots and berries are primarily used for medicinal purposes, with the root being the most important component in Ayurveda.

Ashwagandha is widely known for its adaptogenic properties, helping the body adapt to stress and normalize physiological functions. It is commonly used to reduce stress and anxiety, improve mood, and promote relaxation. Additionally, it exhibits anti-inflammatory and antioxidant properties, which help protect against diseases such as cancer, diabetes, and cardiovascular disorders.

The herb is also known to support immune function, regulate hormones, improve sleep quality, enhance digestion, and support the nervous system. In Ayurveda, ashwagandha is often combined with other herbs like *Shatavari* and *Guduchi* to enhance therapeutic efficacy.

Ashwagandha is available in several forms such as powders, capsules, teas, and extracts. When used in recommended doses, it is generally considered safe and effective.

Ashwagandha And History

Ashwagandha is an ancient medicinal herb with a history spanning thousands of years in Ayurvedic medicine. Its roots, leaves, and berries have been traditionally used to treat stress, anxiety, infertility, weakness, and various chronic ailments.

Native to India, Pakistan, and Sri Lanka, ashwagandha belongs to the family *Solanaceae*. In Ayurveda, it is classified as a *Rasayana* herb, believed to promote longevity, vitality, and resistance to disease.

The name "Ashwagandha" is derived from the Sanskrit words *Ashva* (horse) and *Gandha* (smell), referring to the strong odor of the root and its ability to impart strength like a horse.

Ashwagandha is extensively mentioned in classical Ayurvedic texts such as Charaka Samhita and Sushruta Samhita, where it is praised for its rejuvenating and strengthening properties. It is also used in Unani, Chinese, African, and Arabic traditional medicine systems.

Modern scientific research has validated many of its traditional uses, particularly its anti-stress, anti-inflammatory, and neuroprotective effects.

Ayurveda

Ayurveda is a traditional system of medicine originating in India more than 5,000 years ago. The term *Ayurveda* is derived from *Ayur* (life) and *Veda* (knowledge), meaning "the science of life."

Ayurveda is based on the balance of five elements—earth (*Prithvi*), water (*Jala*), fire (*Agni*), air (*Vayu*), and ether (*Akasha*). It recognizes seven body tissues (*Saptadhatu*) and emphasizes balance among the three *Doshas*: *Vata*, *Pitta*, and *Kapha*.

Diseases are believed to arise from imbalance among these elements. Ayurvedic treatment includes detoxification, herbal remedies, diet, yoga, meditation, and lifestyle modification.

Rasayana

Rasayana refers to rejuvenation therapy in Ayurveda aimed at promoting longevity, vitality, immunity, and mental clarity. Rasayana herbs help slow aging, improve resistance to disease, and restore balance among the doshas.

Ashwagandha is one of the most important and widely used *Rasayana* herbs.

Ayurveda and Ashwagandha

Ashwagandha plays a central role in Ayurvedic therapeutics. It acts as an adaptogen, calming the nervous system, improving sleep, enhancing cognition, and reducing anxiety.

It is consumed in the form of powders, capsules, teas, tinctures, and extracts. While generally safe, it should be avoided during pregnancy and used cautiously alongside sedatives.

Ayurvedic Importance of Ashwagandha

According to Ayurveda, ashwagandha promotes vitality, strength, and mental clarity.

Major benefits include:

- Reduces stress and anxiety
- Improves brain function and memory
- Boosts immunity
- Reduces inflammation and arthritis
- Improves heart health
- Reduces symptoms of depression
- Enhances athletic performance
- Improves fertility in men and women

Side Effects Of Ashwagandha

- Avoid during pregnancy (risk of miscarriage)

- Avoid with sedatives or anti-anxiety drugs
- High doses may cause nausea, vomiting, or diarrhea
- May cause allergic reactions in sensitive individuals

Indications in Ayurvedic Medicine

Ashwagandha is indicated for conditions such as: *Murchha, Apasmara, Shosha, Unmada, Karshya, Arsha, Arbuda, Gandamala, Bhagandara, Vatarakta, Kushtha, Kilasa, Vidradhi, Asthibhanga, Gridhrasi, Yonidosha, and Hrudgraha*, among others.

Chemical Composition of Ashwagandha

Ashwagandha contains several bioactive compounds including:

- Withanolides
- Alkaloids
- Steroidal lactones
- Flavonoids
- Saponins
- Glycowithanolides
- Tannins

These compounds contribute to its adaptogenic, anti-inflammatory, antioxidant, and neuroprotective properties.

Medicinal Parts of Ashwagandha

- **Roots:** Tonic, aphrodisiac, adaptogen
- **Leaves:** Used for inflammation, conjunctivitis
- **Berries:** Digestive and anti-inflammatory
- **Bark:** Used for asthma and skin conditions

Forms of Ashwagandha

- Root powder
- Capsules/Tablets
- Liquid extract
- Tea
- Oil
- Tincture

Conclusion

Ashwagandha (*Withania somnifera*) is one of the most valuable medicinal plants in Ayurveda and holds a prominent place as a *Rasayana* drug. Its long history of use in traditional medicine, supported by growing scientific evidence, highlights its significance in promoting physical, mental, and emotional well-being. The herb exhibits a wide range of therapeutic properties, including adaptogenic, anti-inflammatory, antioxidant, immunomodulatory, neuroprotective, and rejuvenating effects.

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Malabar Spinach: An Underutilized Leafy Green with Immense Potential

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Malabar spinach (*Basella alba* L. and *Basella rubra* L.) is a highly nutritious, climate-resilient leafy vegetable that remains underutilized in many regions of the world despite its excellent food value, adaptability, and low production costs. Native to tropical Asia, Malabar spinach is widely cultivated in India, Sri Lanka, Southeast Asia, China, and parts of Africa. Although commonly referred to as "spinach," it is botanically distinct from true spinach (*Spinacia oleracea*).

Its vigorous growth, tolerance to heat and humidity, and continuous leaf production make it an important alternative leafy vegetable, particularly under changing climatic conditions that threaten conventional vegetable crops.

Botanical Description

Malabar spinach belongs to the family Basellaceae and is a fast-growing, perennial, succulent vine, generally cultivated as an annual crop. Two main cultivated species are recognized:

- ***Basella alba*** – characterized by green stems, petioles, and leaves
- ***Basella rubra*** – characterized by reddish-purple stems, veins, and petioles due to the presence of anthocyanin pigments

The plant produces thick, fleshy, heart-shaped leaves arranged alternately along the stem. Flowers are small, bisexual, white to pink in color, and borne in axillary or terminal spikes. The fruit is a fleshy, dark purple berry containing a single seed.

Its climbing or trailing growth habit allows rapid spread over trellises, fences, or walls, making it well suited for vertical gardening and urban cultivation systems.

Nutritional Value and Health Benefits

Malabar spinach is nutritionally rich and compares favorably with commonly consumed leafy vegetables such as spinach, amaranth, and fenugreek.

Nutrient Composition

- **Vitamin A (β-carotene):** Essential for vision, immune function, and skin health

- **Vitamin C:** Acts as an antioxidant and enhances iron absorption
- **Iron:** Helps prevent iron-deficiency anemia
- **Calcium and Magnesium:** Important for bone health and metabolic functions
- **Dietary Fiber:** Improves digestion and supports gut health

In addition, Malabar spinach contains bioactive compounds such as phenolics, flavonoids, and anthocyanins (particularly in *B. rubra*), which exhibit strong antioxidant activity and may help reduce the risk of chronic diseases.

The mucilaginous nature of cooked leaves provides a soothing effect on the digestive tract and is traditionally used to relieve gastric irritation and constipation.

Culinary Uses

Malabar spinach is widely used in traditional cuisines across Asia and Africa. Although its texture differs from that of true spinach, its mild flavor makes it highly adaptable to various dishes.

Common Culinary Applications

- Stir-frying with garlic, onion, and spices
- Inclusion in soups, stews, and curries
- Cooking with lentils, pulses, or coconut-based gravies
- Light steaming or sautéing as a side vegetable
- Consumption of tender leaves and shoots raw in salads

When cooked, the leaves become soft and slightly slippery, similar to okra, a texture appreciated in many traditional food systems.

Agronomic Advantages

Malabar spinach exhibits several agronomic traits that make it ideal for low-input and climate-resilient agriculture.

Key Agronomic Benefits

- Thrives under high temperatures and humid conditions
- Performs well in marginal and low-fertility soils
- Shows resistance to many common pests and diseases
- Requires relatively less irrigation compared to conventional leafy greens
- Suitable for home gardens, pots, rooftop gardens, and urban agriculture
- Provides continuous harvest over an extended growing period

Unlike true spinach, which bolts rapidly under warm conditions, Malabar spinach maintains vegetative growth throughout the summer, ensuring a consistent supply of leafy vegetables.

Role as an Underutilized Crop

Despite its nutritional and agronomic advantages, Malabar spinach remains underutilized and poorly commercialized.

Reasons for Underutilization

- Limited consumer awareness beyond traditional growing regions
- Market preference for familiar leafy vegetables
- Lack of organized seed production and distribution systems
- Limited research and breeding efforts
- Consumer unfamiliarity with its mucilaginous texture

Nevertheless, underutilized and neglected crops such as Malabar spinach are increasingly recognized for their importance in sustainable agriculture, climate adaptation, and nutritional security.

Importance in Food and Nutritional Security

Malabar spinach holds considerable potential for enhancing food and nutritional security, particularly in tropical and subtropical regions.

Potential Contributions

- Diversification of diets and improved micronutrient intake
- Year-round availability of leafy vegetables
- Support for kitchen gardens and smallholder farming systems
- Inclusion in school feeding and community nutrition programs
- Reduced dependence on high-input, resource-intensive crops

Its rapid growth and ability to provide multiple harvests make it especially suitable for household-level food production.

Medicinal and Traditional Uses

In traditional medicine systems, Malabar spinach has been used for various therapeutic purposes, including:

- Relief from constipation due to mild laxative properties
- Improvement of digestion and gut health
- Cooling effect on the body in hot climates
- Support for skin and eye health
- Use of leaf paste for treating wounds, burns, and skin inflammations

Although these uses are well documented in ethnobotanical literature, further pharmacological and clinical research is required for scientific validation.

Conclusion

Malabar spinach is a classic example of an underutilized leafy vegetable with immense potential for improving nutrition, agricultural sustainability, and climate resilience. Its rich nutrient profile, adaptability to adverse environmental conditions, and ease of cultivation make it an excellent candidate for wider promotion and integration into modern food systems. Increasing consumer awareness, strengthening seed systems, and incorporating Malabar spinach into nutrition-sensitive agricultural programs can help unlock the full potential of this valuable yet neglected crop.

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Climate Change and Biochemistry: Molecular and Metabolic Responses of Living Systems

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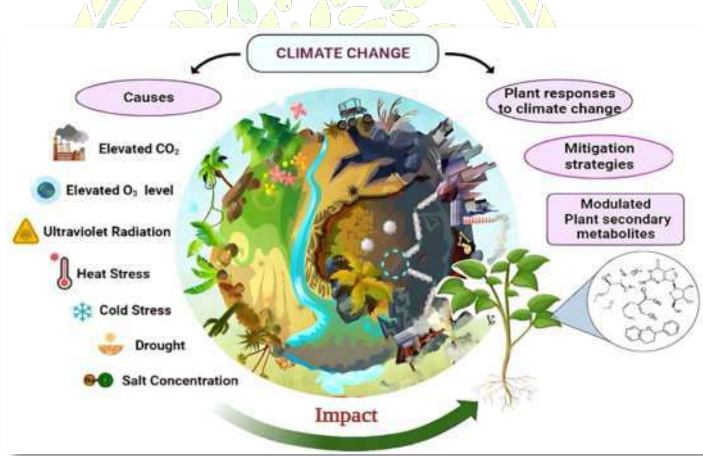
Climate change is one of the most pressing global challenges, profoundly affecting biological systems at molecular, cellular, and ecosystem levels. Rising temperatures, increased atmospheric carbon dioxide concentrations, altered precipitation patterns, and intensified environmental stresses directly influence the biochemical processes that sustain life. Since metabolism, enzyme activity, and redox balance form the biochemical foundation of all living organisms, climate change exerts its effects primarily through biochemical mechanisms. Understanding these molecular and metabolic responses is essential for explaining how plants, microorganisms, animals, and humans adapt to—or succumb under—changing climatic conditions (Zandalinas et al., 2023).



Biochemical Basis of Climate Change Effects

Biochemical reactions are highly sensitive to environmental parameters such as temperature, pH, water availability, and gas concentrations. Climate change alters these parameters, thereby affecting enzyme kinetics, membrane fluidity, and metabolic regulation. Elevated temperatures may initially accelerate reaction rates but can also result in protein denaturation and enzyme inactivation. Similarly, changes in atmospheric CO_2 levels influence carbon assimilation and metabolic efficiency. These effects demonstrate that climate change disrupts cellular homeostasis by directly targeting the biochemical machinery of living systems (Lushchak & Storey, 2024).

Carbon Metabolism and Photosynthesis under Climate Change

The global carbon cycle is driven by biochemical processes including photosynthesis, respiration, and decomposition. Photosynthesis, mediated by ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), converts atmospheric CO_2 into organic compounds. Elevated CO_2 concentrations may temporarily enhance photosynthetic rates; however, increased temperatures reduce RuBisCO specificity and promote photorespiration, thereby limiting net carbon fixation (Fernie & Bauwe, 2024; Roy, 2024). Concurrently, higher temperatures stimulate plant respiration and microbial decomposition, increasing CO_2 release and generating positive feedback loops that further intensify climate change.

Oxidative Stress and Redox Homeostasis

One of the most universal biochemical responses to climate change is enhanced oxidative stress. Environmental stresses such as heat, drought, salinity, and pollution lead to excessive production of reactive oxygen species (ROS), including superoxide radicals, hydrogen peroxide, and hydroxyl radicals. When ROS generation exceeds cellular detoxification capacity, oxidative damage to lipids, proteins, and nucleic acids occurs. To maintain redox homeostasis, organisms activate enzymatic antioxidants—such as superoxide dismutase, catalase, and glutathione peroxidase—as well as non-enzymatic antioxidants including glutathione and ascorbate. These antioxidant systems not only protect against oxidative damage but also regulate redox signaling essential for stress perception and adaptation (Hasanuzzaman et al., 2023; Lushchak & Storey, 2024).

Metabolic Reprogramming under Climate Stress

Climate change induces extensive metabolic reprogramming to ensure survival under adverse conditions. Primary metabolism is modified through alterations in carbohydrate, amino acid, and lipid pathways. Accumulation of osmoprotectants such as proline, soluble sugars, and polyols stabilizes proteins and cellular structures under drought and heat stress. Membrane lipid composition is adjusted to maintain fluidity under temperature extremes. Additionally, secondary metabolism is often upregulated, resulting in increased synthesis of phenolics, flavonoids, and other protective compounds that function as antioxidants and signaling molecules (Bulut et al., 2025; Kumar et al., 2023).

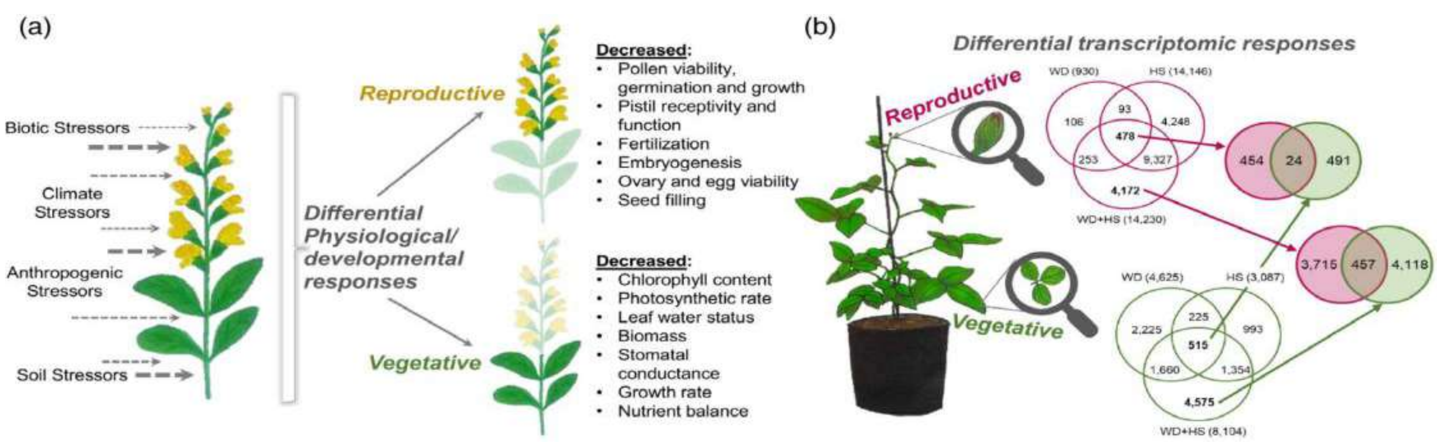


Figure 1. *Differential responses of vegetative and reproductive tissues to combined abiotic stresses.*

Plant Biochemical Responses to Climate Change

Plants exhibit complex biochemical adaptations to climate change due to their sessile nature. Heat shock proteins, antioxidant enzymes, and stress-responsive metabolites are strongly induced under climate-related stresses. Alterations in nitrogen and sulfur metabolism influence protein synthesis and redox balance, ultimately affecting growth, yield, and nutritional quality. These biochemical responses play a decisive role in crop resilience and productivity, making plant biochemistry central to food security under changing climatic conditions (Bulut et al., 2025; Zandalinas et al., 2023).

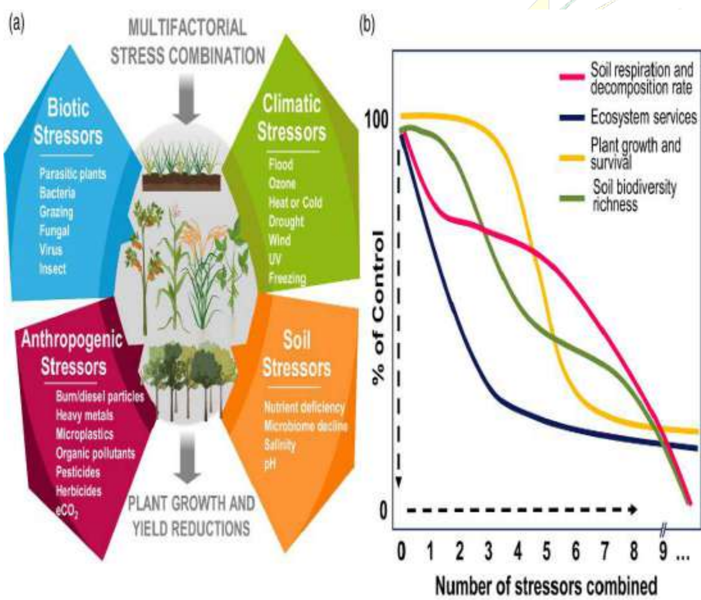


Figure 2. *Impact of multifactorial stress combinations on plants, crops, ecosystems, and soil processes.*

Microbial Biochemistry and Greenhouse Gas Emissions

Microorganisms play a critical role in climate change through their biochemical activities. Microbial pathways such as methanogenesis, nitrification, and denitrification are responsible for the production of methane and nitrous oxide—potent greenhouse gases. Climate-driven changes in soil temperature and moisture significantly influence microbial metabolism, thereby affecting greenhouse gas emissions and nutrient cycling. A detailed understanding of microbial biochemistry is essential for predicting climate feedback mechanisms and developing mitigation strategies (Liu et al., 2024).

Biochemical Impacts of Climate Change on Human Health

Climate change also influences human health by disrupting biochemical and metabolic processes. Heat stress alters enzyme activity, electrolyte balance, and energy metabolism, while air pollution intensifies oxidative stress and inflammatory pathways. Climate-induced changes in agriculture and food systems affect micronutrient availability, with long-term consequences for metabolic health. These biochemical disturbances are increasingly associated with cardiovascular diseases, metabolic disorders, and impaired immune responses (Romanello et al., 2024).

Biochemistry in Climate Change Adaptation and Mitigation

Biochemistry provides essential tools for addressing climate change through both adaptation and mitigation strategies. Advances in enzyme engineering, metabolic regulation, and redox biology facilitate the development of climate-resilient crops, enhanced photosynthetic efficiency, and sustainable bio-based alternatives such as biofuels and bioplastics. Integrating biochemical insights with systems biology and biotechnology is crucial for designing effective and sustainable climate solutions (Fernie & Bauwe, 2024).

Conclusion

Climate change is fundamentally a biochemical phenomenon that alters molecular and metabolic processes across all forms of life. From disrupted enzyme activity and redox imbalance to large-scale changes in carbon metabolism and greenhouse gas production, climate change reshapes the biochemical foundation of living systems. A comprehensive biochemical understanding is therefore essential for predicting biological responses, protecting ecosystems, safeguarding human health, and developing sustainable strategies to cope with a changing climate.

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Bt Cotton in India: Success or Failure? A Genetic Perspective

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Since its commercial adoption in 2002, Bt cotton has reshaped cotton cultivation in India. Engineered to express Cry1Ac and later pyramided Cry2Ab toxins from *Bacillus thuringiensis*, Bt cotton promised reduced pesticide use, increased yields, and improved farmer incomes. However, over time, genetic resistance in insect pests—particularly the pink bollworm (*Pectinophora gossypiella*)—has emerged as a major challenge. This review examines the genetic basis of Bt cotton, mechanisms of pest resistance, and evidence of field-evolved resistance in India. It critically evaluates whether Bt cotton remains a viable technology and provides recommendations emphasizing integrated pest management (IPM), refuge strategies, and advanced breeding approaches to mitigate resistance-related failures.

Bt cotton, genetically engineered to express *Bacillus thuringiensis* (Bt) toxin genes, was introduced to Indian farmers in 2002 and rapidly gained popularity due to its effectiveness against key lepidopteran pests. First-generation Bt cotton expressed the Cry1Ac toxin, while second-generation hybrids were later developed to co-express Cry1Ac and Cry2Ab (pyramided toxins) to delay resistance evolution.

Despite initial success, increasing reports over the past decade indicate the development of resistance in major cotton pests, particularly the pink bollworm (PBW). Genetics plays a central role in this resistance—encompassing the structure and inheritance of Bt genes in cotton, pest adaptation mechanisms, and the effectiveness of resistance management strategies. Therefore, evaluating Bt cotton from a genetic perspective is critical for assessing its long-term sustainability.

Genetic Basis of Bt Cotton and Resistance

Bt Genes in Cotton

Most Bt cotton hybrids commercialized in India contain the Cry1Ac gene or a combination of Cry1Ac + Cry2Ab. These toxins act by binding to specific receptors in the insect midgut, causing cell lysis and larval death. The "high-dose–refuge" strategy, which requires planting non-Bt cotton alongside Bt cotton to delay resistance, remains a cornerstone of resistance management but is poorly implemented in practice.

Additionally, genetic segregation in hybrid cotton contributes to resistance development. Although Bt cotton hybrids are F_1 plants, the seeds formed in the bolls segregate genetically, resulting in variable toxin expression. This variability can allow partially resistant larvae to survive, thereby accelerating resistance evolution.

Mechanisms of Resistance in Pest Populations

Resistance in pink bollworm populations has been well documented. Molecular studies have identified mutations in the *PgABCA2* gene, an ATP-binding cassette transporter involved in Cry2Ab toxicity. Disruptions in this gene reduce toxin binding and confer resistance. Similarly, Cry1Ac resistance has been linked to reduced toxin binding to midgut receptors, as demonstrated in brush-border membrane vesicle (BBMV) assays.

These molecular adaptations reflect intense selection pressure imposed by widespread Bt cotton cultivation in the absence of effective refuge compliance.

Field-Evolved Resistance: Evidence from India

Pink Bollworm Resistance

Large-scale monitoring studies conducted between 2010 and 2017 across 38 cotton-growing districts in India reported clear field-evolved resistance in pink bollworm populations to both Cry1Ac and Cry2Ab. The median lethal concentration (LC_{50}) values increased dramatically—from approximately 0.33 µg/mL to 6.938 µg/mL for Cry1Ac and from 0.014 µg/mL to 12.51 µg/mL for Cry2Ab—representing resistance ratios in the thousands.

A 2023 F_2-screen study from Andhra Pradesh estimated resistance allele frequencies of 0.082 for Cry1Ac and 0.054 for Cry2Ab, with detection probabilities exceeding 97%. A subsequent study in 2025 reported a combined Cry1Ac + Cry2Ab resistance allele frequency of approximately 0.059 across South Indian populations, confirming the widespread nature of resistance.

Cotton Bollworm (*Helicoverpa armigera*)

In addition to pink bollworm, *H. armigera* populations are showing increasing tolerance to Bt toxins. Screening studies from Telangana (2021) estimated Cry1Ac resistance allele frequencies ranging from 0.05 to 0.056, indicating early warning signs of resistance development.

Impacts and Agronomic Realities

Yield, Agronomic Performance, and Farmer Benefits

Initially, Bt cotton significantly reduced pesticide usage, improved pest control, and increased yields, resulting in economic benefits for farmers. However, the increasing prevalence of resistant pest populations threatens these gains. Rising pink bollworm infestations may force farmers to resume intensive pesticide use or suffer yield losses.

Why Has Resistance Evolved?

Key factors contributing to resistance evolution include:

1. **Poor Refuge Compliance:** Limited adoption of non-Bt refuges reduces dilution of resistance alleles.
2. **Segregation of Bt Genes in Hybrids:** Variable toxin expression facilitates survival of partially resistant insects.
3. **High Selection Pressure and Genetic Diversity:** Multiple independent resistance mutations (over 60 *PgABCA2* variants) have been documented.
4. **Regulatory and Management Gaps:** Weak stewardship, insufficient monitoring, and limited farmer awareness accelerate resistance development.

Discussion

From a genetic standpoint, resistance in cotton pests—especially pink bollworm—poses a serious threat to the sustainability of Bt cotton in India. Molecular evidence demonstrates that resistance is deeply embedded within pest populations through heritable genetic changes. While Bt cotton delivered short-term benefits, inadequate resistance management and the genetic limitations of hybrid systems have hastened resistance evolution.

Future Directions and Recommendations

1. **Improved Insect Resistance Management**

- Strict enforcement of refuge planting
- Farmer education and policy incentives

2. **Advanced Breeding and Biotechnology**

- Development of high-dose Bt events
- Exploration of next-generation pyramids and genome-editing tools (with caution)

3. **Integrated Pest Management (IPM)**

- Crop rotation, biological control, pheromone traps, and cultural practices
- Regular resistance allele monitoring

4. **Surveillance and Genetic Monitoring**

- Sentinel monitoring networks
- Transparent data sharing

5. **Seed Quality and Stewardship**

- Certification to prevent substandard Bt seed
- Awareness of hybrid segregation risks

Conclusion

Bt cotton has been transformative for Indian agriculture; however, its long-term sustainability is increasingly threatened by genetically driven pest resistance, particularly in pink bollworm populations. Resistance is measurable, widespread, and growing. Without rigorous resistance management, the benefits achieved over the past two decades may be lost.

Sustaining Bt cotton requires a holistic approach that integrates genetic innovation, strict refuge compliance, integrated pest management, and robust surveillance systems. Only through coordinated scientific, regulatory, and farmer-driven efforts can Bt cotton remain a viable component of India's cotton production system.

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Nature Inside: Indoor Plants for Beauty, Health, and Clean Air

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Indoor plants have become an integral part of modern homes, offices, hospitals, and educational institutions. With increasing urbanization and reduced access to natural green spaces, indoor plants provide an effective means of bringing nature indoors. Beyond their decorative appeal, indoor plants significantly improve indoor air quality, regulate the microclimate, and enhance physical, psychological, and emotional well-being. From a floriculture perspective, indoor and air-purifying plants represent a rapidly expanding and economically important sector.

What Are Indoor Plants?

Indoor plants are ornamental plants grown inside buildings under controlled or semi-controlled environmental conditions. These plants are generally adapted to low or medium light intensity, stable temperatures, and limited air circulation. Most indoor plants are foliage plants valued for their attractive leaves, while some flowering plants are also widely used for interior decoration.

Importance of Indoor Plants

1. Aesthetic and Decorative Value

Indoor plants add colour, texture, and freshness to interior spaces. They soften architectural structures, enhance visual appeal, and create a calm and welcoming environment. Foliage plants with varied leaf shapes and colours are especially popular in interior landscaping.

2. Improvement of Indoor Air Quality

Indoor air often contains pollutants such as formaldehyde, benzene, toluene, xylene, ammonia, and carbon monoxide released from furniture, paints, carpets, and electronic devices. Many indoor plants absorb these pollutants through their leaves and root systems, acting as natural biofilters and improving indoor air quality.

3. Health and Psychological Benefits

The presence of greenery indoors helps reduce stress, anxiety, and mental fatigue. Indoor plants improve concentration, productivity, and overall mood, making them particularly beneficial in offices, classrooms, and healthcare facilities.

4. Regulation of Indoor Microclimate

Through transpiration, indoor plants increase relative humidity and help maintain a comfortable indoor environment. This reduces dryness caused by air conditioning and helps prevent respiratory irritation, dry skin, and eye discomfort.

Major Indoor and Air-Purifying Plants

A. Foliage and Air-Purifying Plants

- **Money plant (*Epipremnum aureum*)**: Removes formaldehyde and carbon monoxide; easy to grow and propagate.
- **Snake plant (*Sansevieria trifasciata*)**: Releases oxygen at night; ideal for bedrooms and low-light areas.
- **Spider plant (*Chlorophytum comosum*)**: Effective in removing carbon monoxide and xylene.
- **Areca palm (*Dypsis lutescens*)**: Acts as a natural humidifier and improves air quality.
- **Rubber plant (*Ficus elastica*)**: Large leaves efficiently absorb airborne toxins and dust.
- **Dracaena (*Dracaena marginata*, *D. deremensis*)**: Removes benzene, formaldehyde, and toluene.
- **Bamboo palm (*Chamaedorea seifrizii*)**: Effective against benzene and trichloroethylene.
- **Boston fern (*Nephrolepis exaltata*)**: Improves humidity and removes formaldehyde.
- **English ivy (*Hedera helix*)**: Reduces airborne mold and formaldehyde.
- **Peace lily (*Spathiphyllum wallisii*)**: Absorbs ammonia, benzene, and acetone and produces elegant white flowers.

B. Flowering Indoor Plants

- **Anthurium (*Anthurium andraeanum*)**: Attractive spathes with moderate air-purifying ability.
- **Orchids (*Phalaenopsis* spp.)**: Long-lasting blooms with high ornamental value.
- **African violet (*Saintpaulia ionantha*)**: Compact flowering plant suitable for small indoor spaces.

C. Succulents and Low-Maintenance Plants

- **Aloe vera (*Aloe vera*)**: Removes benzene and formaldehyde; also valued for medicinal use.
- **Jade plant (*Crassula ovata*)**: Drought-tolerant and decorative.
- **ZZ plant (*Zamioculcas zamiifolia*)**: Highly tolerant to low light and irregular watering.

Indoor Plants and Pollutants Removed

Indoor Plant	Botanical Name	Major Pollutants Removed
Money plant	*Epipremnum aureum*	Formaldehyde, CO
Snake plant	*Sansevieria trifasciata*	NO_2, Xylene
Spider plant	*Chlorophytum comosum*	CO, Xylene
Peace lily	*Spathiphyllum wallisii*	Benzene, Ammonia
Areca palm	*Dypsis lutescens*	Toluene, Xylene
Rubber plant	*Ficus elastica*	Formaldehyde

Dracaena	*Dracaena* spp.	Benzene, Trichloroethylene
Boston fern	*Nephrolepis exaltata*	Formaldehyde
Aloe vera	*Aloe vera*	Benzene, Formaldehyde

Role of Indoor Plants in Floriculture

Indoor plants constitute an important segment of the floriculture industry. They are propagated through cuttings, division, and tissue culture, enabling large-scale, year-round production. Interior landscaping, corporate greening, nursery trade, and export of foliage plants generate employment and income. The growing demand for eco-friendly and health-oriented living spaces has further increased the commercial importance of indoor and air-purifying plants.

Conclusion

Indoor plants beautifully combine aesthetics with function. They enhance interior spaces, purify indoor air, improve health, and contribute to emotional well-being. Easy to maintain and adaptable, indoor plants offer natural solutions for cleaner air and healthier living. Promoting their use supports sustainable urban lifestyles while strengthening the floriculture sector.

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Hydroponics: A Modern Soilless Farming Technique for Sustainable Agriculture

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Agriculture has been practiced since ancient times and continues to be the primary source of livelihood for rural populations. Even today, a large proportion of families in villages depend on farming, livestock, and allied activities. However, the question arises: why is modern agriculture necessary in the present era?

Several factors have contributed to the increasing need for modern agricultural practices:

Growing Population And Increasing Food Demand

With the continuous rise in population and shrinking availability of arable land, India has only about 0.12 hectares of agricultural land per capita, which is significantly lower than the global average of 0.21 hectares.

Climate change

Rising temperatures, erratic rainfall patterns, delayed monsoons, droughts, and floods have severely impacted crop productivity. Traditional farming practices often fail to cope with these rapid changes. According to ICAR estimates, climate stress may reduce crop production by 10–25% by 2025.

Depletion of natural resources

Excessive use of land has led to declining soil fertility and productivity. Agriculture in India consumes more than 80% of the country's freshwater resources, while groundwater levels are depleting at an alarming rate.

Due to these challenges, the food requirements of the growing population cannot be fulfilled through traditional soil-based agriculture alone. Hence, adopting modern agricultural concepts has become essential.

Modern agriculture focuses on the use of advanced technologies, scientific approaches, and mechanization to enhance productivity and sustainability. Techniques such as genetically modified crops, precision farming, advanced machinery, and innovative cultivation methods like hydroponics and aeroponics are increasingly being adopted.

Among these, hydroponics stands out as one of the most promising techniques capable of producing crops in areas with limited land, water scarcity, and poor soil conditions.

Hydroponics

The term *hydroponics* is derived from Greek words *hydro* (water) and *ponos* (work), meaning "working with water." Hydroponics is an advanced agricultural technique in which plants are grown without soil, using a nutrient-rich aqueous solution or inert growing media.

In this system, plant roots absorb essential nutrients directly from the nutrient solution, ensuring efficient nutrient uptake. In simple terms, hydroponics refers to the cultivation of crops without soil.

Hydroponics is gaining popularity worldwide due to its ability to produce higher yields, faster growth, and efficient utilization of water and nutrients. It is particularly suitable for urban agriculture, water-scarce regions, and areas with limited fertile land.

Working Principle of Hydroponics

Nutrient solution

Plants are grown either directly in water or in inert media such as coco peat, perlite, or vermiculite. A balanced mineral nutrient solution is dissolved in water, with pH maintained between 5.5 and 6.5 and electrical conductivity (EC) regulated for optimal nutrient uptake.

Resource Management

Hydroponics ensures the efficient use of water, oxygen, and nutrients by providing them directly to the root zone.

Energy Efficiency

Since nutrients are readily available, plants expend less energy searching for food, allowing more energy to be diverted toward growth and yield formation.

Types of Hydroponic Systems

- **Nutrient Film Technique (NFT):** A thin film of nutrient solution continuously flows through channels containing plant roots.
- **Drip System:** Nutrient solution is delivered directly to the base of each plant through drip emitters.
- **Ebb and Flow (Flood and Drain):** The root zone is periodically flooded with nutrient solution and then drained, allowing aeration.
- **Deep Water Culture (DWC):** Plant roots remain submerged in an aerated nutrient solution.
- **Aeroponics:** Roots are suspended in air and supplied with nutrients through fine mist sprays.
- **Wick System:** A passive system where nutrient solution is transported to roots using a wick.

Components of a Hydroponic System

- **Plant Support Structures:** Containers or channels to hold plants
- **Nutrient Solution Reservoir:** Stores nutrient-enriched water
- **Pumps And Aeration Devices:** Ensure circulation and oxygen supply
- **Growing Media:** Coco peat, perlite, vermiculite, etc.
- **Monitoring Instruments:** pH and EC meters

- **Automation And Control Sensors:** Regulate nutrients, temperature, and humidity
- **Artificial Lighting:** LED lights used for indoor cultivation

Advantages of Hydroponics

- Faster growth and 30–50% higher yields
- Significant reduction in water consumption due to recycling
- Freedom from soil-borne diseases and pests
- Year-round crop production
- Efficient utilization of space (rooftops, greenhouses, urban areas)

Disadvantages of Hydroponics

- Requires technical expertise in nutrient and system management
- High initial investment cost
- Limited suitability for long-duration and field crops
- Continuous monitoring of pH, EC, and environmental conditions
- Rapid spread of diseases through contaminated water
- Requires high-quality water with low impurities

Conclusion

Hydroponics is an efficient and innovative method of cultivating crops without soil. It conserves water, optimizes space utilization, and promotes rapid and healthy plant growth. This technique is especially valuable in regions where fertile soil is scarce or environmental conditions are unfavorable. Overall, hydroponics represents a smart, sustainable, and future-oriented solution for modern agriculture.

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Cold-Pressed Groundnut Oil Business Model in India

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The cold-pressed groundnut oil business model in India offers a viable and sustainable approach for enhancing farmers' income and promoting rural entrepreneurship. Cold-pressed groundnut oil is produced through mechanical extraction without the use of heat or chemical treatments, thereby retaining natural nutrients, antioxidants, and flavour. Increasing consumer awareness regarding health, wellness, and chemical-free foods has significantly boosted the demand for cold-pressed oils, particularly in urban and semi-urban markets. Compared to refined groundnut oil, cold-pressed oil commands a premium price, resulting in higher profit margins for producers and processors. This business model can be successfully implemented at small and medium scales with moderate investment and can be effectively integrated with local groundnut cultivation to ensure consistent raw material supply and quality assurance. Furthermore, government initiatives such as MSME and PMFME schemes provide financial and technical support, enhancing its feasibility. Overall, the cold-pressed groundnut oil business demonstrates strong potential for sustainable growth, employment generation, and value addition within the Indian edible oil sector.

Cold-Pressed Groundnut Oil Business Model in India

Cold-pressed groundnut oil (also known as cold-pressed peanut oil) is a premium segment within the Indian edible oil market, gaining momentum due to rising health awareness, preference for natural foods, and expanding market opportunities. Unlike refined oils, cold-pressed oils are extracted at low temperatures without the application of heat or chemicals, thereby preserving essential nutrients, natural flavour, and antioxidants. These attributes make them particularly appealing to health-conscious consumers.

1. What Is Cold-Pressed Groundnut Oil?

Cold-pressed groundnut oil is extracted using mechanical pressing at low temperatures. This method helps retain natural nutrients such as vitamin E and essential fatty acids, which are often lost during high-temperature refining processes. Consequently, the oil is widely preferred for healthier cooking practices as well as for traditional and Ayurvedic applications.

In the Indian retail market, the price of cold-pressed groundnut oil generally ranges between ₹270 and ₹499 per litre, depending on brand positioning, packaging, and certification.

2. Market Potential

S. No.	Parameter	Description / Trend	Source
1	Edible oil market growth	Cold-pressed oil is a rapidly growing segment in India's edible oil sector as consumers increasingly prefer natural and chemical-free oils over refined alternatives.	Nakulya Cold-Pressed Oils
2	Consumer demand trend	Demand is rising among health-conscious consumers, wellness-oriented buyers, Ayurvedic users, and organic food consumers, particularly in urban and semi-urban areas.	Nakulya Cold-Pressed Oils
3	Growth projection	Groundnut-based cold-pressed oils are estimated to grow at an annual rate of 25–30%, significantly higher than conventional refined oils.	Market Analysis
4	Price premium advantage	Cold-pressed groundnut oil is sold at 2–3 times the price of refined groundnut oil, offering higher profitability to farmers and processors.	Market Analysis
5	Rural entrepreneurship scope	The business can be initiated on a small scale in rural areas, leading to local employment generation and increased farm income.	MSME Reports
6	Export opportunity	Growing demand is observed in the USA, UK, UAE, and Southeast Asian countries, especially in ethnic and health-food markets.	Knock 4U Business Idea
7	Government support	Financial assistance and subsidies are available under MSME, PMFME, and food processing schemes.	Government Schemes
8	Future market outlook	Clean-label foods, traceability, and farm-to-bottle models position cold-pressed groundnut oil as a premium niche product in the future.	Market Forecast

3. Business Setup and Cost Structure

A cold-pressed groundnut oil unit can be established at a small scale with moderate capital investment. Major cost components include:

- Cold press expeller and filter press: ₹60,000–₹80,000
- Storage tanks: ₹50,000
- Packaging machinery (optional at initial stage): ₹2,50,000–₹3,00,000
- Licensing and registration (FSSAI, MSME, etc.): ₹1,00,000
- Marketing and miscellaneous expenses: ₹50,000–₹80,000

The total investment for a small-scale unit typically ranges between ₹5–7 lakh, depending on production capacity and packaging facilities.

4. Processing Workflow

The cold-pressed groundnut oil production process involves the following steps:

1. **Procurement and cleaning:** Sourcing high-quality groundnuts from farmers or local markets.
2. **Drying:** Reducing moisture content to prevent fungal growth and improve oil yield.
3. **Cold Pressing:** Mechanical extraction of oil without heat.
4. **Filtering and Settling:** Multi-stage filtration to enhance oil clarity.
5. **Packaging:** Bottling in food-grade containers for retail distribution.
6. **Oil Cake Utilization:** The residual oil cake can be sold as animal feed or organic fertilizer, generating additional income.

5. Profitability and Revenue Streams

Profitability depends on production volume, raw material costs, and value addition. Industry estimates indicate profit margins of approximately 35–40% at retail price levels, though actual returns may vary.

Additional revenue streams include:

- Sale of oil cake as cattle feed or organic manure
- Premium pricing through health-focused branding and organic certification
- Diversified packaging options such as 500 ml, 1 L, and gift packs

6. Challenges and Growth Strategies

Key Challenges

- Volatility in raw material prices
- Competition from refined oils and large branded players
- Compliance with quality standards and FSSAI regulations

Growth Strategies

- Attractive branding and premium packaging
- Contract farming and direct sourcing from farmers
- Online and e-commerce sales channels
- Introduction of value-added products such as flavoured or organic variants

Strategic partnerships with farmers, stringent quality control, and diversified product portfolios can substantially improve long-term profitability.

Conclusion

The cold-pressed groundnut oil business in India represents a high-growth niche within the edible oil sector. With moderate initial investment, increasing health awareness among consumers, and opportunities for premium pricing and product diversification, it offers a sustainable and profitable business model for rural entrepreneurs. Strategic sourcing, efficient processing, and effective marketing are critical determinants of success in this emerging industry.

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Organic Farming for Sustainable Agriculture

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After independence, India faced a major challenge in producing sufficient food to meet the needs of its rapidly growing population. To overcome this problem, agriculture adopted high-yielding crop varieties along with modern inputs such as irrigation, chemical fertilizers, and pesticides. Although these technologies significantly increased agricultural productivity, they also resulted in adverse effects such as deterioration of soil health, environmental pollution, pesticide toxicity, and sustainability concerns. Consequently, scientists and policymakers are reconsidering farming practices that rely more on organic inputs rather than synthetic chemicals.

Organic farming offers the potential to produce healthy and high-quality food without harming soil health or the environment. However, concerns remain regarding the ability of organic farming to meet the food demands of a large population like India. India produces a wide range of certified organic products, including basmati rice, pulses, honey, tea, spices, coffee, oilseeds, fruits, grains, herbal medicines, and value-added products. Non-edible organic products include cotton, textiles, cosmetics, health foods, and personal care items. The present review discusses the role of organic farming in sustainable agriculture with special reference to northern India.

At present, rising levels of pollution in all sectors of life pose a serious challenge to sustainable environmental development. Increasing population pressure, growing demands, and changing lifestyles have accelerated environmental degradation. Agriculture, a critical sector for human survival, has also contributed to pollution through the excessive use of chemical fertilizers and pesticides to enhance crop yields. These practices disrupt soil nutrient balance, reduce soil fertility, and negatively affect ecosystems.

Organic farming is an effective and promising approach to environmental sustainability, as it ensures crop stability, improves soil health, minimizes environmental hazards, and promotes the production of organic food. While several agricultural practices aim to reduce environmental damage, organic farming remains one of the most scientifically proven methods for maintaining ecological balance in agriculture.

Organic farming relies on various components such as organic fertilizers, crop rotation, vermicomposting, nitrogen-fixing microorganisms, crop residues, biofertilizers, biopesticides, kitchen waste, sludge, and biogas. These inputs enhance soil structure, fertility, and biological activity while remaining environmentally friendly. The use of synthetic chemicals is avoided, and eco-friendly inputs are preferred. Organic cultivation of vegetables and other crops ensures the availability of safe and nutritious food in the market.

Therefore, it is essential to formulate and implement organic farming policies with active participation of stakeholders. Proper monitoring, ground-level implementation, impact assessment, and public awareness are crucial for policy success. Effective policies promote sustainable development and contribute to environmental conservation.

What Is Organic Farming?

The term *organic* was coined by Northbourne in 1940 in his book *"Look to the Land."* Organic farming is an agricultural system that relies on biological fertilizers and environmentally based pest control methods derived from plant and animal residues and nitrogen-fixing cover crops. Modern organic farming developed as a response to environmental damage caused by chemical-based conventional agriculture.

Compared with conventional farming, organic agriculture uses fewer pesticides, reduces soil erosion, minimizes nitrate leaching into groundwater, and recycles animal waste within the farm. However, organic farming often results in lower yields—approximately 25% less than conventional systems—though this varies depending on crop type and management practices. The future challenge of organic agriculture lies in maintaining natural resources, increasing productivity, reducing costs, and addressing climate change and population growth.

Need for Organic Farming

- Excessive use of chemical fertilizers reduces soil fertility
- Chemical inputs cause soil, water, and air pollution
- Conservation and maintenance of ecosystems
- Promotion of sustainable agricultural development
- Low-input and cost-effective farming practices
- Increasing consumer demand for safe and quality food

Effect of Organic Nutrition on Crop Productivity

The addition of organic matter to soil is a well-established practice for improving crop productivity. Sharma and Mitra reported increased grain and straw yield of rice with organic matter application. Ranganathan and Selvaseelan observed that spent mushroom compost and rice straw compost increased rice grain yield by 20% compared to NPK fertilizers.

Singh *et al.* reported that application of 7.5 t FYM ha^{-1} significantly improved grain and fodder yield in degraded soils.

Green manuring with *Sesbania aculeata* significantly enhanced grain yield in rice and chickpea. Stockdale *et al.* highlighted multiple benefits of organic farming, including environmental protection, biodiversity conservation, and reduced energy consumption in developed countries, while supporting sustainable resource use and improved yields in developing nations.

Effect of Organic Nutrition on Soil Fertility

Application of NPK fertilizers tends to lower soil pH, making soils acidic, whereas organic manures increase soil pH. Organic fertilizers increased soil nitrogen content by approximately 17%, while NPK treatments showed little improvement. Available phosphorus increased by more than 50% under organic treatments, and exchangeable potassium levels doubled with organic manure application.

Organic manures also enhanced calcium and magnesium levels, unlike NPK fertilizers, which reduced calcium content. Electrical conductivity increased under both organic and inorganic treatments, with the highest values observed under combined application.

Effect of Organic Nutrition on Crop Quality Parameters

Studies on *Amaranthus* revealed that crops grown with organic manures exhibited superior nutritional quality compared to chemically fertilized crops. Poultry manure enhanced iron and calcium content, while vermicompost improved iron availability, carotenoids, crude fibre, vitamin C, and zinc content. Overall, organic fertilizers proved more effective in improving crop nutritional quality than chemical fertilizers.

Effect of Organic Nutrition on Soil Biological Properties

The application of FYM, vermicompost, and coir pith compost along with biofertilizers significantly improved soil physical, chemical, and biological properties. The combined use of vermicompost and *Azospirillum* enhanced soil organic carbon, nitrogen availability, and microbial populations. Among organic nitrogen sources, 75% vermicompost combined with *Azospirillum* was most effective in improving soil health.

Conclusion

Organic farming provides high-quality food while preserving soil health and environmental integrity. It is more eco-friendly than conventional farming and supports long-term sustainability. Identifying region-specific organic crops and products can help meet global market demands while ensuring food security. Organic farming can generate employment, promote rural prosperity, and contribute to environmental conservation. Integrated research and policy support are essential to enhance productivity and sustainability in organic agricultural systems.

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Organic Farming: A Sustainable Alternative to Conventional Agriculture

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Agricultural development policies in developing nations must prioritize increasing land productivity while reducing production costs and minimizing adverse impacts on human health and the environment. In recent years, organic farming has gained considerable attention as a viable solution to many challenges faced by modern agriculture. This approach offers several advantages, including environmental conservation, efficient utilization of non-renewable resources, and improved food quality.

Organic agriculture has become a societal necessity, valued not only by consumers seeking safe and nutritious food but also by farmers striving for sustainable and long-term agricultural growth. It plays a vital role in transforming rural farming systems into more resilient and eco-friendly models by improving soil health, reducing land degradation, and compensating for the ecological costs of conventional agriculture.

Although India accounts for nearly 30% of the world's organic producers, it represents only 2.59% (1.5 million hectares) of the global organic farming area, which totals 57.8 million hectares, as reported in *The World of Organic Agriculture (2018)*.

Organic Farming

The term *organic farming* was first introduced by Lord Northbourne in 1940. However, the roots of organic agriculture date back to the early nineteenth century. In 1840, Justus von Liebig proposed the mineral theory of plant nutrition, suggesting that nutrients supplied through manure could be replaced by specific mineral salts. While this idea laid the foundation for chemical agriculture, concerns over soil degradation and environmental pollution later revived interest in organic practices.

Objectives of Organic Farming

The major objectives of organic farming focus on sustainability, ecological balance, and human health:

1. **Improve Soil Quality and Fertility:** Enhance soil productivity through composting, green manuring, crop rotation, and biological activity.
2. **Provide Safe and Nutritious Food:** Produce chemical-free food that is wholesome and safe for consumption.
3. **Ensure Environmental Protection:** Reduce pollution and conserve natural resources using eco-friendly practices.
4. **Promote Biodiversity:** Encourage diverse cropping systems and beneficial organisms for ecosystem resilience.
5. **Reduce Dependence on Synthetic Inputs:** Minimize or eliminate chemical fertilizers and pesticides.
6. **Strengthen Rural Livelihoods:** Support sustainable income and long-term economic stability for farmers.

Organic Farming in India

The benefits of the Green Revolution, led by Dr. M. S. Swaminathan, have gradually reached a plateau with diminishing returns. Excessive use of chemical fertilizers and synthetic growth regulators has contributed to environmental pollution and declining soil health. Consequently, there is a growing need for alternative farming techniques that maintain a natural balance essential for sustainable agriculture.

With fossil fuels being non-renewable and rapidly depleting, environmentally friendly and organic farming practices have gained importance. During 2023–24, India produced approximately 3.6 million metric tonnes of certified organic products, including oilseeds, sugarcane, cereals, millets, cotton, pulses, medicinal and aromatic plants, tea, coffee, fruits, spices, vegetables, dry fruits, and processed foods.

Madhya Pradesh ranks as the leading organic producer in India, followed by Maharashtra, Karnataka, Uttar Pradesh, and Rajasthan. Oilseeds account for the largest share of organic production, followed by sugar crops, cereals and millets, tea and coffee, fiber crops, pulses, medicinal plants, and spices.

India's organic exports were valued at approximately ₹4,686 crore (USD 689 million). Major export destinations include the USA, European Union, Canada, Switzerland, Australia, Japan, Israel, UAE, New Zealand, and Vietnam. Processed foods—particularly soybean meal—dominate exports, followed by oilseeds, plantation crops, cereals, and millets.

Principles of Organic Farming

Organic farming is guided by four core principles:

1. Principle of Health

Organic agriculture promotes the health of soil, plants, animals, humans, and the planet as a single interconnected system. Healthy soil leads to healthy crops and, ultimately, healthy people. Synthetic fertilizers, pesticides, and harmful additives are avoided to maintain biological integrity.

2. Principle of Ecology

Organic farming works in harmony with natural ecosystems and biological cycles. It emphasizes biodiversity conservation, ecological balance, and responsible farm design while protecting air, water, soil, and climate.

3. Principle of Fairness

Fairness involves equity, respect, and justice for all stakeholders. Organic agriculture should ensure food security, reduce poverty, and minimize social and environmental costs.

4. Principle of Care

This principle stresses precaution and responsibility in adopting farming practices. Organic farming avoids technologies with unpredictable risks, such as genetic engineering, and promotes transparency and inclusive decision-making.

Techniques of Organic Farming

i. Soil Management

Soil management is the foundation of organic farming. Natural methods such as compost application, green manuring, and microbial activity from animal manure help restore soil fertility and structure.

ii. Weed Management

Weeds are controlled without chemical herbicides through:

- Manual or mechanical removal
- Mulching using crop residues or biodegradable materials

iii. Crop Diversity

Polyculture and crop rotation are widely practiced to enhance soil fertility, reduce pest incidence, and improve farm resilience.

iv. Chemical Management

Organic farming minimizes chemical usage by relying on natural inputs and careful ecosystem management to control harmful organisms.

v. Biological Pest Control

Natural enemies such as predators, parasites, and beneficial microorganisms are used to regulate pest populations, reducing reliance on synthetic pesticides.

Advantages of Organic Farming

- High domestic and international demand with premium prices
- Lower production costs due to reduced dependence on external inputs
- Environmentally friendly and energy-efficient
- Improved soil fertility and nutrient retention
- Reduced pollution and enhanced ecosystem protection
- Sustainable use of natural resources for future generations

Limitations of Organic Farming

1. Labor-intensive and time-consuming
2. Initial yield reduction during conversion period
3. Limited availability and higher cost of organic inputs
4. Price instability of organic produce
5. High certification costs and complex procedures
6. Difficulty in understanding regulatory frameworks
7. Shorter shelf life due to absence of preservatives

Challenges Faced by the Organic Sector in India

1. Producer-Level Challenges

- Complex certification procedures
- Inconsistent standards
- Limited pre-certification markets
- Inadequate incentives and research support

2. Processor-Level Challenges

- Weak supply chains
- Poor infrastructure in remote areas

- Limited global competitiveness
- Inadequate branding and packaging

3. Consumer-Level Challenges

- Low awareness
- Higher prices
- Limited availability

Conclusion

Organic farming is a holistic and sustainable agricultural system that relies on locally available natural resources. Its long-term success requires coordinated efforts among farmers, policymakers, researchers, processors, and consumers. Investment in eco-friendly technologies, marketing infrastructure, and financial support is essential. As an environmentally responsible approach, organic farming can conserve natural resources, enhance soil health, and safeguard biodiversity for future generations.

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Water Management in Agriculture in India

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Water is a critical resource for agriculture that has not been efficiently managed in India. This paper discusses issues related to irrigation in India, their effects, and institutional arrangements addressing water scarcity for irrigation. The study finds that the problems are largely institutional, structural, and administrative in nature, and overcoming them is crucial for agricultural development. Irrigation is both an art and a science. While science has provided concepts and methods for measuring the various processes involved in irrigation, farmers' knowledge of their fields and crops, along with practical experience in applying scientific principles, remains central to achieving effective and efficient irrigation.

"Irrigation is everything in India; water is even more valuable than land," remarked Sir Charles Trevelyan decades ago. Wolff similarly observed that if the monsoon fails, agricultural activity comes to a standstill. Today, there is a general consensus that the problem is not an absolute shortage of water but poor management—particularly in utilisation, augmentation, and conservation.

India is endowed with about 183 million hectares of cultivable land, 115.6 million farming families, and nearly 400 million hectare-metres of annual precipitation, along with a conducive agro-climatic environment for cultivating a wide variety of crops. About two-thirds of the country's population is engaged in agriculture, feeding more than one billion people. Yet, a large proportion of farmers remain trapped in poverty, debt, and hunger (Hans, 2010).

Micro-level studies on rural poverty consistently identify irrigation as a key explanatory factor. Gurunathan (2008), using linear regression analysis for Tamil Nadu over 37 years (1964–2000), found that rural poverty could be reduced by 1.54 per cent through an increase of one hectare of groundwater irrigation per thousand rural population. Hans (2007), in a study of Belthangadi and Mangalore taluks of Dakshina Kannada district, Karnataka, showed that households with better access to irrigation infrastructure were more likely to move above the poverty line, with average household income almost doubling when irrigation was utilised.

Indian agriculture remains heavily dependent on monsoons, with nearly 70 per cent of the net sown area being rainfed. Problems of Indian agriculture are intricately linked to per capita availability of water in a cost-effective manner. Demand for food is increasing, yet a vast proportion of arable land remains fallow during the dry season (Zaman, 2009). The water problem is thus a triple challenge—related to supply, demand, and quality.

By 2030, India will need to produce about 60 per cent more rice with fewer resources. To sustain growth, careful economic valuation of inputs, including irrigation, is essential (Kiran et al., 2009). Despite advances in high-tech agriculture, sustainable farming and livelihood security will continue to depend on efficient management and conservation of natural resources, particularly water.

Objectives of the Study

- To present the problems and challenges related to water use in Indian agriculture.
- To highlight key areas requiring intervention for improved water management.
- To examine selected initiatives undertaken in India to conserve water.

Effects of Water Management on Agriculture

Productivity improvements in agriculture arise both from area expansion and from the combined use of inputs such as irrigation, fertilisers, and plant protection measures. Although irrigated land constitutes only about 46 per cent of the cropped area in India, it contributes nearly 56 per cent of total agricultural output, and around 60 per cent of food grain production comes from irrigated areas.

Farm efficiency is closely linked to water availability, whether through rainfall or irrigation. Under modern farming systems, irrigation is a critical component of integrated farm management. Total Factor Productivity analyses assign significant importance to irrigation in explaining yield variations and technical efficiency across crops and farms.

Challenges and Opportunities in Water Management

One of the most significant challenges facing Indian agriculture is climate change. Global climate change, driven by rising concentrations of carbon dioxide and other greenhouse gases, has increased uncertainty in water availability, making it difficult to optimise irrigation decisions and timing. Natural resources have become increasingly vulnerable, placing agriculture in a situation of growth accompanied by heightened risk.

A substantial portion of annual variation in India's GDP growth is attributable to fluctuations in rainfall. Rising sea levels, depletion of potable water, and declining irrigation potential pose serious concerns. Estimates suggest that by 2080–2100, increases in temperature could lead to crop production losses ranging from 10 to 40 per cent.

In several coastal regions, sand mining has led to declining groundwater tables, forcing farmers to increase pump horsepower, thereby raising cultivation costs and reducing irrigation efficiency. Although programmes such as the Command Area Development Programme have expanded irrigation infrastructure, challenges remain due to inadequate awareness of the scarcity value of water, political interference, and unreliable electricity supply affecting institutions like Water Panchayats.

Water Supply Management

On-farm water management systems can be analysed through three components: primary water supply, farm-level irrigation systems, and drainage. Successful farming requires a reliable, flexible, affordable, and good-quality water supply. Efficient irrigation systems and sound farm management practices are essential for effective water application, while adequate drainage is necessary to maintain soil structure and salinity balance.

Seasonal water requirement analysis forms the foundation of crop planning. Comparing crop water needs with available supplies helps determine whether existing water resources are sufficient or whether crop rotations and management practices need adjustment. Farm water budgeting—covering the crop year and water year—assists in planning monthly and field-level water requirements.

Conclusion

This study analysed the impact of water management on agricultural output, labour, and capital growth in a developing, agriculture-based economy, using government agricultural and economic data spanning 30 years (1977–2006). The findings highlight that improved use and optimal combinations of inputs—particularly water, improved seeds, and fertilisers—are essential for sustaining output growth.

To enhance overall efficiency, irrigation technologies that prioritise water-use efficiency must be developed, disseminated, and adopted widely. Effective water management remains central to achieving sustainable agricultural growth and ensuring food security in India.

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The Impact of Dairy Hormones and Chemical Contaminants on Early Puberty

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The age of pubertal onset has been steadily declining worldwide. In the United States, the average age of breast development in girls has decreased by approximately one year over the past three decades. Although rising obesity rates are a major contributing factor, increasing attention is being directed toward the endocrine-disrupting potential of dairy products. Milk is not merely a nutrient source; it also functions as a complex hormonal delivery system. This article examines how naturally occurring hormones and chemical contaminants present in dairy products may influence the human endocrine system, potentially contributing to early or precocious puberty.

Puberty is the biological process through which a child's body matures into an adult body capable of sexual reproduction. The normal age of pubertal onset is:

- **Girls:** 10–13 years
- **Boys:** 11–14 years

Precocious puberty is defined as the onset of pubertal changes before the age of 8 in girls and 9 in boys. This condition is not merely a physical phenomenon; it is associated with long-term psychological, metabolic, and endocrine consequences. While genetics and nutrition play key roles, environmental and dietary endocrine disruptors are increasingly implicated.

2. Hormonal Profile of Modern Dairy and the Crisis of Precocious Puberty

In modern dairy farming, cows are often milked during pregnancy to maximize yield. This practice significantly alters the biochemical and hormonal composition of commercial milk compared with milk from non-pregnant animals.

2.1 Steroid Hormones (Estrogens and Progesterone)

Commercial cow's milk contains measurable levels of estrone, estradiol, and progesterone.

- **Pregnancy Influence:** Milk obtained from pregnant cows may contain estrogen concentrations

20–30 times higher than milk from non-pregnant cows.

- **Bioavailability:** These steroid hormones are lipophilic (fat-soluble) and resistant to degradation during digestion.
- **Physiological Impact:** A study published in *Pediatrics International* (Davaakhuu et al., 2010) demonstrated that consumption of cow's milk led to significant increases in serum estrone and progesterone levels in children, accompanied by suppression of endogenous gonadotropins (LH and FSH).

2.2 The IGF-1 Axis (Growth Factor)

Insulin-like Growth Factor-1 (IGF-1) is a powerful mediator of growth and development.

- **Mechanism:** IGF-1 stimulates the hypothalamic GnRH pulse generator, effectively priming the brain to initiate pubertal processes.
- **Evidence:** A meta-analysis published in the *American Journal of Clinical Nutrition* reported a consistent positive association between milk intake and circulating IGF-1 levels in children.

3. Chemical Contaminants and Endocrine Disruptors in Dairy

Beyond naturally occurring hormones, dairy products can serve as carriers for endocrine-disrupting chemicals (EDCs) that accumulate in animal fat.

Agent	Source	Primary Endocrine Effect
Estrogens	Milk from pregnant cows	Mimics female sex hormones; accelerates breast development
IGF-1	Natural presence / rBST use	Stimulates pubertal initiation signals
Phthalates	Plastic tubing and processing equipment	Anti-androgenic; disrupts male hormone signaling
Zearalenone	Contaminated animal feed	Potent estrogenic activity; linked to premature thelarche
Oxytocin	Illegal injections	Potential disruption of the HPA axis and reproductive signaling

- **Persistent Organic Pollutants (POPs):** Compounds such as dioxins and PCBs are lipophilic, bioaccumulate in dairy fat, and may mimic estrogen or interfere with thyroid function.
- **Phthalates:** Commonly used in plastic processing equipment, these chemicals can leach into high-fat dairy products and may impair testosterone signaling in boys, contributing to gynecomastia or pseudo-pubertal changes.

4. Sex-Specific Impact of Dairy Consumption

4.1 Effects in Girls: Accelerated Maturation

Girls exhibit heightened sensitivity to exogenous estrogens.

- **Evidence:** The Harvard *Growing Up Today Study (GUTS)* followed 5,583 girls and reported that those consuming more than 1.5 servings of dairy per day experienced earlier menarche compared with those consuming less than 0.5 servings. This effect is attributed to the combined influence of estrogen intake and IGF-1 stimulation.

4.2 Effects in Boys: A Paradoxical Response

- **Growth Promotion:** High protein intake and IGF-1 may enhance linear growth and muscle development.
- **Estrogenic Interference:** Excess estrogen exposure and phthalates may suppress LH secretion, potentially delaying masculinization during puberty.

5. Socio-Economic and Long-Term Health Risks

- **Socio-Economic Vulnerability:** In regions where unregulated or "loose" milk is commonly consumed, illegal oxytocin use to stimulate milk let-down poses a major health concern due to lack of residue testing.
- **Long-Term Health Risks:** Early puberty is associated with increased lifetime risks of breast and ovarian cancers in women and prostate cancer in men, likely due to prolonged exposure to estrogen and elevated IGF-1 levels.

6. Recommendations and Risk Mitigation Strategies

6.1 Government and Regulatory Measures

- Strict enforcement of bans on non-therapeutic oxytocin and recombinant bovine somatotropin (rBST).
- Mandatory ELISA or mass-spectrometry-based testing at milk collection centers for synthetic hormone residues.

6.2 Consumer-Level Strategies

- Preference for certified organic dairy products, which prohibit synthetic growth hormones.
- Promotion of A2 milk and milk from indigenous cattle breeds.
- Moderation of dairy intake and incorporation of plant-based calcium sources to reduce cumulative hormonal exposure.

7. Conclusion

Hormonal residues and chemical contaminants in dairy represent a silent but significant public health concern. While milk remains an important nutritional resource, the unchecked use of hormonal and chemical stimulants in dairy production may be altering the biological timing of puberty in children. Protecting future generations requires a transition toward ethical, hormone-free dairy systems that prioritize biological safety over industrial productivity.

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The Potential Role of Herbal Medicines in the Treatment and Management of Polycystic Ovary Syndrome (PCOD/PCOS)

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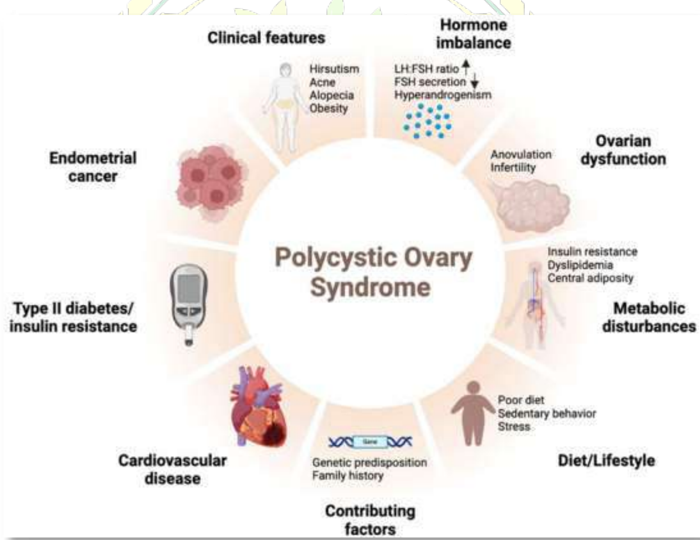
Polycystic ovary syndrome (PCOS/PCOD) is a common endocrine disorder characterized by hormonal imbalance in women of reproductive age. It is often associated with irregular menstrual cycles, anovulation, infertility, and hyperandrogenism. If left untreated, PCOS may lead to serious long-term health complications such as type 2 diabetes mellitus, cardiovascular diseases, and metabolic syndrome (Kapoor & Hasan, 2025).



Most women with PCOS exhibit multiple small cysts in the ovaries, giving rise to the term *polycystic ovary syndrome*. These cysts represent immature antral follicles that fail to develop properly, resulting in anovulation. In a normal menstrual cycle, a dominant follicle matures and releases an ovum, whereas in polycystic ovaries, follicular arrest prevents ovulation. Elevated levels of androgens such as testosterone and androstenedione contribute to clinical symptoms including hirsutism, acne, and menstrual irregularities.

The exact prevalence of PCOS remains uncertain due to variations in diagnostic criteria. According to the World Health Organization, over 116 million women worldwide were affected by PCOS in 2012 (Yadav et al., 2020). In India, PCOS affects approximately one in five women. Ultrasonographic studies indicate that 8–25% of asymptomatic women may have polycystic ovaries, while nearly 14% of women using oral contraceptives show similar features. Menstrual irregularities such as amenorrhea and menorrhagia are reported in 14.6–22.8% of Indian women with PCOS. Insulin resistance, a key etiological factor of PCOS, is particularly prevalent among the Indian population, thereby increasing disease susceptibility.

Herbal Medicines for the Treatment of PCOD/PCOS

Herbal medicines have shown promising potential in the management of PCOS by improving insulin resistance, regulating hormonal imbalance, restoring ovulation, and alleviating metabolic disturbances (Figure 1).

1. Ginger (*Zingiber officinale*)

Zingiber officinale belongs to the family Zingiberaceae. Its rhizome contains bioactive compounds such as 6-gingerol, shogaol, zingiberene, zingiberone, and gingerenone. Ginger has demonstrated significant anti-inflammatory and antioxidant properties. Studies indicate that ginger improves insulin sensitivity, reduces body weight, and enhances lipid profiles. Experimental studies on PCOD-induced Wistar rats revealed that 6-gingerol lowers sex hormone levels and improves ovulation, suggesting its role as an adjunct therapy in PCOD management.

2. Coconut Palm (*Cocos nucifera*)

Cocos nucifera (family Arecaceae), commonly known as coconut, exhibits strong antioxidant and estrogenic properties. Flower extracts of *C. nucifera* have been shown to reduce letrozole-induced PCOD in rats by restoring FSH and LH levels, increasing ovarian weight, improving lipid profiles, and normalizing blood glucose levels. These effects are attributed to its flavonoid content and hypoglycemic activity.

3. Turmeric (*Curcuma longa*)

Curcuma longa, a member of the Zingiberaceae family, is widely used in traditional Indian medicine. Curcumin, the principal bioactive compound, possesses antioxidant, anti-inflammatory, antihyperlipidemic, and hypoglycemic properties. Curcumin has been reported to lower blood glucose, regulate elevated hormone levels, improve lipid metabolism, and promote ovulation, making it beneficial in PCOD management.

4. Liquorice (*Glycyrrhiza glabra*)

Glycyrrhiza glabra (family Leguminosae) contains glycyrrhizic acid, liquiritin, isoliquiritin, and glabridin. These compounds exhibit estrogen-like activity and lipid-lowering effects. Licorice has been shown to enhance oocyte fertilization and embryonic development. Combined therapy with spironolactone has demonstrated improved outcomes in women with PCOS.

5. Cinnamon (*Cinnamomum zeylanicum*)

Cinnamomum zeylanicum belongs to the Lauraceae family and contains cinnamaldehyde, polyphenols, and procyanidins. Cinnamon exhibits antioxidant, anti-inflammatory, and hypoglycemic activities. Clinical studies suggest that cinnamon improves insulin sensitivity, reduces low-density lipoprotein levels, and helps regulate menstrual cycles in women with PCOD.

6. Peppermint (*Mentha piperita*)

Mentha piperita (family Lamiaceae) contains essential oils such as menthol, limonene, and flavonoids. Peppermint has been shown to reduce testosterone levels and body weight in PCOS models. Its antioxidant properties aid in restoring ovarian morphology, improving ovulation, and normalizing endocrine hormone secretion.

7. Pomegranate (*Punica granatum* L.)

Pomegranate is rich in vitamins, minerals, ellagitannins, ellagic acid, and flavonoids. Obesity being a major risk factor for PCOD, pomegranate leaf extract has demonstrated significant reductions in body weight, triglycerides, blood glucose, and free testosterone levels in PCOD-induced animal models.

8. Aloe vera (*Aloe barbadensis* Mill.)

Aloe vera contains phytosterols, anthraquinones, chromones, polysaccharides, and enzymes with antioxidant and hypoglycemic properties. Studies show that aloe vera improves insulin sensitivity, restores estrous cyclicity, enhances steroidogenesis, and improves lipid profiles in PCOD-induced rats.

9. Bamboo (*Bambusa bambos*)

Bambusa bambos (family Poaceae) exhibits strong antioxidant activity. Bamboo seed consumption has been shown to lower blood glucose, triglycerides, and LDL cholesterol while restoring estrous cyclicity, thereby aiding in PCOS management.

10. Fenugreek (*Trigonella foenum-graecum*)

Fenugreek, a member of the Fabaceae family, possesses hypolipidemic, antioxidant, anti-inflammatory, and hypoglycemic properties. Clinical studies suggest that fenugreek, when combined with metformin, improves menstrual regularity and ovarian morphology in PCOS patients.

11. *Gymnema sylvestre*

Gymnema sylvestre is widely used in Ayurveda for diabetes management. It also exhibits antiandrogenic activity. Ethanolic leaf extracts have been shown to reduce elevated androgen levels and correct menstrual irregularities in PCOS animal models.

Figure 1. *Medicinal plants used in PCOS management: (a) Gymnema sylvestre, (b) Fenugreek (Trigonella foenum-graecum), (c) Coconut palm (Cocos nucifera), (d) Aloe vera, (e) Cinnamon (Cinnamomum zeylanicum), (f) Liquorice (Glycyrrhiza glabra), (g) Turmeric (Curcuma longa), (h) Peppermint (Mentha piperita), (i) Pomegranate (Punica granatum L.), (j) Bamboo (Bambusa bambos), (k) Ginger (Zingiber officinale).*

Conclusion

PCOS is one of the most prevalent hormonal disorders affecting women from adolescence to pre-menopause. It is associated with infertility, metabolic dysfunction, cardiovascular risks, and long-term health complications. Although conventional pharmacological therapies are effective, their adverse effects limit long-term use. Herbal medicines offer a safer, cost-effective, and holistic alternative for managing PCOS by addressing both metabolic and reproductive abnormalities, thereby improving patient compliance and quality of life.

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