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Nature's Arsenal: Medicinal Plants as Biocontrol Agents Against Soil Borne Pathogens

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The control of pests and diseases continues to attract interest and requires a high level of attention. Pest control is fundamental to sustainable crop production in terms of both quality and quantity. Environmental protection of ecosystems and biodiversity is now also factored into the equation. Modern pest management utilizes a variety of methods to prevent crop loss and maintain yield quality. Increasingly popular among them is the use of plant extracts and essential oils, known as a natural source of antimicrobials. Plant oils have antibacterial, antifungal, antiviral, antiparasitic, antifeedant, antitermitic and antinematicidal properties; thus these biologically active natural products from essential oils and plant extracts have the potential to replace synthetic pesticides in the management of fungal rotting in fruits and vegetables, suppression of soil-borne plant diseases, and the control of pests in stored product and in the field. The discovery of natural products with low mammalian and environmental toxicity for integrated pest management (IPM) will ensure a safe and reliable food supply into the future.

Introduction:

The escalating pressure on soil health, driven by population growth, increased food demand, and intensive agriculture, is causing land degradation, reduced productivity, and declining yields. Evaluating soil health and quality is crucial for long-term agricultural sustainability, as healthy soil exhibits stability, robust nutrient cycling, resilience to stress, and a thriving, diverse microbial community. Healthy soil is characterized by stability, continuous nutrient cycling, stress resilience, richness, evenness, abundance, and diversity of microbial communities. The interactions between plants and soil-dwelling microorganisms are important drivers of the agroecosystem, as these indigenous microbes can control the development, defense, tolerance, and nutrition of plants. The composition and abundance of microbial communities are heavily influenced by factors like the type of crops grown, environmental changes, and agricultural practices.

Reduced plant productivity and phytopathogen-related disease outbreaks can be considered as indicators of soil instability, poor ecosystem health, and a lack of microbial diversity.Soil-borne pathogens including viruses, bacteria, fungi, protozoa, and nematodes are well known for their socio-economic and ecological impacts on the ecosystem by causing serious losses in the agro-industry. Plant roots and their exudates provide substrates and space for these phytopathogens leading to colonization and infection. Generally, the eradication of these organisms is especially hard in continuous-cropping systems, due to the intensive tillage and cultivation processes.

After World War II, farming shifted towards intensive practices, including shorter rotation periods, more tillage, monocropping (growing the same crop year after year), and widespread use of synthetic pesticides and fertilizers. Despite the availability of diverse control methods, agrochemicals remain the cornerstone of soil-borne pathogen management, owing to their high efficiency and practical application. Besides the positive effects, the indiscriminate use of these chemical agents may induce undesirable changes to the beneficial soil microorganisms and human and animal health.

Bioactive Compounds:

Many medicinal plants contain compounds like alkaloids, flavonoids, and essential oils that exhibit antimicrobial activity. Examples of Plants and their Activity: *Azadirachta indica (*Neem) is known for its broad-spectrum antimicrobial activity. *Cassia fistula, Veronica biloba*, *Hypericum perforated* extracts have shown remarkable activity against bacterial and fungal pathogens. Biopesticide effect of secondary metabolites derived from aromatic and medicinal plants on important soil-borne plant pathogens including bacteria, fungi, and nematodes. Most of the investigated herbs belong to the family of Lamiaceae (e.g., *Origanum spp.*, *Salvia spp.*, *Thymus spp.*, *Mentha spp.*, etc.) and have been associated with potent antimicrobial activity, primarily due to their chemical constituents. The most frequently tested organisms include fungi, such as *Rhizoctonia spp., Fusarium spp., and Phytophthora spp.*, which may be highly persistent in soil. protection techniques, and it also highlights the importance of exploiting the residues generated by aromatic plant-utilizing sectors as part of agro-industrial processes.

Phytopathogens on Soil:

Soil biology is in direct connection with agricultural sustainability , as healthy soil can recycle nutrients, decompose organic matter, support biological activities, suppress the growth of pathogens, and inactivate toxic compounds. It is the habitat of a myriad of organisms (e.g., invertebrate animals, plants, protozoa, fungi, and bacteria) that play an important role in maintaining agro-ecosystem functions and productivity , As for microbial diversity, only a few grams of soil can contain millions of species . In addition to beneficial microbes, however, major and minor pathogens may also be present. Even though the occurrence of microbial plant diseases is a natural part of crop production, the excessive accumulation and epidemic spread of phytopathogens can induce serious crop damages and yield losses.

Soil-borne pathogenic fungi, bacteria, protozoa, viruses, and plant parasitic nematodes can cause negative plant–soil feedback individually or collectively. They usually affect the root system or the stem base of plants, but vascular diseases caused by these organisms have also been reported. Overall, approximately 15% of total crop production is estimated to be lost to different biological threats annually, but microbe-induced diseases may even lead to total crop failure. So we can overcome this negative situation by adopting use of medical extracts in integrated pest management.

Essential Oils:

Essential oils (Eos), biosynthesized, stored, and secreted in various parts of aromatic herbs, e.g., buds, bark, leaves,twigs, wood, stems, seeds, fruits, rhizome, roots, and flowers, are complex mixtures of terpenoids and phenolic compounds that play a critical role in plant defense mechanisms against abiotic and biotic stress factors. These volatile organic compounds can diffuse through water- and gas-filled pores and serve as food sources, infochemicals, chemo-attractants, or antimicrobials. Monoterpenes, as frequent constituents of Eos, are involved in chemical and ecological interactions, and their production may be induced by the attack of pathogens and herbivores. Due to their bioactive potential, Eos and their constituents can be utilized as components of ecological products with nematicidal, antimicrobial, antiviral, insecticidal, repellent, antifeedant, and molluscicidal activity. They can also support the growth of other soil microbes indirectly by killing organisms and providing easily decomposable carbon and energy sources. This was confirmed by, who found that Mentha × piperita EO had an instant antimicrobial effect on soil; however, a fraction of soil microbes survived the treatment and used the killed microorganisms as fresh organic carbon. As a result, an increased microbial biomass and respiration rate were recorded.

As for the efficiency of active substances derived from aromatic and medicinal plants, Eos tend to possess stronger antimicrobial properties than other extracts. Although several studies investigated the biocidal effect of Eos and their constituents on phytopathogens ,the mechanism of their action is complex and not fully understood. Volatile oils containing oxygenated monoterpenes, primarily phenols and aldehydes, tend to be more active against pathogens. This was confirmed by *Wogiatzi et al.*,who found that the thymol-rich EO of *Origanum vulgare* collected from the mountain Olympus in Greece had the strongest antifungal effect on *Verticillium dahliae*, *Pythium* spp., and *Sclerotinia sclerotiorum*. Conversely, the hydrocarbonic fraction of *Salvia pomifera* L. ssp. *Calycina* (Sm.). *Hayek* was less effective against *Sclerotinia sclerotiorum* and *Rhizoctonia solani* than was the oxygenated fraction.The application of EOs can provoke chemical, physical and biochemical changes in the cell including disruption of the permeability barrier and proton pump function, damage of cytoplasmic membrane, increased permeability and leakage of cell contents, decreased ATP synthesis and augmented ATP hydrolysis, cytoplasm coagulation, reduced membrane potential, and inhibition of the production of toxic microbial metabolites. As regards fungi, Eos can inhibit ergosterol biosynthesis leading to the depletion of sterol content in the cell membrane, disruption of cell membrane integrity and permeability, loss of ions, and, eventually, inhibition of fungal growth. The study of *Upadhyay et al.*has shown that a decreased level of methylglyoxal may also be observed that was reported to be in correlation with aflatoxin B1 production in *Aspergillus flavus*. In addition, *Vokou et al.*claimed that volatile oils extracted from *Satureja thymbra* could reduce the spore germination and mycelial growth of *Penicillium citrinum* and *Mucor hiemalis*, respectively. Another study conducted by *Sempere-Ferre et al.*showed that EO constituents, either alone or in combination, inhibited the mycelial growth of *Botryotinia fuckeliana* and *Rhizoctonia solani*, although eugenol exerted a fungistatic effect only. Similarly, testing the antifungal efficacy of various EO constituents, *Marei et al.*found that 1,8-cineole, ®-camphor, ®-carvone, camphene, cuminaldehyde, ®-linalool, geraniol, (1R,2S,5R)-menthol, (S)-fenchone, myrcene, thymol, and (S)-limonene were promising substances against *Fusarium oxysporum*, *Penicillium digitatum*, *Aspergillus niger, and Rhizoctonia solani*. Thymol and (S)-limonene possessed strong inhibitory effect on cellulase and pectin methyl esterase activities. Lee et al. stated that *Origanum vulgare* EO had a broad antifungal spectrum against both postharvest (*Botrytis cinerea*, *Colletotrichum gloeosporoides)* and soil-borne pathogenic fungi (*Fusarium oxysporum*, *Rhizoctonia solani*, *and Pythium ultimum*). *Bi et al.*reported that a 21-day-long soil treatment with Eo's from palmarosa (*Cymbopogon martini*), oregano (*Origanum syriacum*), and red thyme (*Thymus vulgaris)* at concentrations of ≥0.1 µg/mL decreased the population density of *Phytophthora capsici* below the limit of detection.As nematicides, Eo's can reduce gall formation, hinder the hatching of nematode eggs, immobilize juveniles, and, as a result, completely suppress nematode infestation. This is consistent with the findings of *Ntalli et al.*,who reported the Eos of *Origanum vulgare*, *Origanum dictammus*, *Mentha pulegium*, and *Melissa officinalis* to be effective against *Meloidogyne incognita* by irreversibly paralyzing the larvae. In fact, the oxygenated EO constituents were more active than hydrocarbons, including β-caryophyllene, pcymene, and limonene. Overall, the studies presented thus far provide evidence that the biological activity of Eos is usually strongly related to their chemical composition; the synergistic effect of different bioactive components specific seasonal, geographic, and climatic conditions genetic factors; and harvest and postharvest processes.

Antimicrobial Activity Mechanisms of Medicinal Plant-Derived Chemical Compounds:

Although synthetic antimicrobial agents are already approved in many countries, the usage of medicinal plant-derived natural compounds continues to attract the attention of many researchers. Medicinal plants have enormous potential for the discovery of new bioactive compounds which can fight against resistant microorganisms. Medicinal plant-derived chemicals are a wide group of chemical compounds that have been found naturally in plants. They can restore the clinical application of older antibiotics by increasing their potency and therefore, avoid the fact of resistance.Plant-derived bioactive compounds (phytochemicals) of therapeutic value are mostly secondary metabolites used for medicinal purposes. Secondary metabolites are the results of secondary plant metabolism and can occur as intermediate or end products. They have a wide antimicrobial activity range according to the structure, number, and position of substituent groups, presence of glycosidic linkages alkylation of OH groups, and the topography and climate of the country of origin. Indeed, variations in the quality and quantity of bioactive secondary metabolites modify their antimicrobial activity against different microbial strains.

Alkaloids:

Alkaloids are chemically very diverse structures of heterocyclic nitrogen compounds characterized by analgetic, antispasmodic, and antimicrobial effects.In particular, many studies have indicated that these compounds are commonly found to play a significant role in the treatment of many infections .Activity against Gram-negative bacteria and yeast was displayed by indoquinoline alkaloids while the alkaloid quinine is popular for its antiprotozoal activity against the malarial parasite. Most of the alkaloids act through EP inhibitory activity. Berberine, an isoquinoline alkaloid, accumulates in cells driven by the membrane potential and is an excellent DNA intercalator active in several microorganisms and a target on RNA polymerase, gyrase, and topoisomerase IV and on nucleic aci. Thus, berberine disrupts the membrane structure by increasing the membrane permeability of bacteria.

Sulfur-Containing Compounds:

There is extensive literature on the topic of antibacterial, antifungal, antiviral, and antiprotozoal activities of sulfur-containing compounds that are obtained from plants with high concentrations of polysulphides . The most important compounds are allicin, ajoene, and isothiocyanates. These compounds have been detected to be effective against both Gram-positive and Gram-negative bacteria including Helicobacter pylori. Antimicrobial mechanisms of sulfur-containing compounds may include the inhibition of sulfhydryl-dependent enzymes and partial inhibition of the DNA and protein synthesis as well. some compounds can also damage the cell wall integrity and lead to the leakage of cellular metabolites. Antifungal activities of these compounds might be related to decreased rate of oxygen consumption, intracellular accumulation of reactive oxygen species, and the depolarization of mitochondrial membrane.

Terpenes:

Terpenes are also referred to as isoprenoids and their derivatives that contain additional elements, usually oxygen, are called terpenoids. Terpenes are the main component of essential oils fractions, which carry the peculiar fragrance of plants.Essential oils have exhibited greater antimicrobial activity due to a synergistic effect with some active compounds rather than single compound. They have been showing to possess antibacterial activity against Escherichia coli, *Enterococcus faecalis, Staphylococcus aureus, Salmonella sp., Vibrio parahaemolyticus,* and *Helicobacter pylori.* They also showed varying degrees of antimicrobial activity against various pathogenic fungi. Although antibacterial activity of terpenes remains challenging due to their poor solubility, terpenes show a strong activity especially against Gram-positive bacteria. Several terpenoid derivatives, such as diterpenoids, also exhibit antimicrobial activity against bacterial fungi, viruses and protozoa with the emphasis on *Mycobacterium tuberculosis.*Terpenoids, like diterpenoids, are antimicrobial agents active against bacteria, fungi, viruses, and protozoa, with particular relevance to *Mycobacterium tuberculosis*. The antimicrobial mechanisms of terpenes are closely related to their lipophilic features which facilitate their penetration into the microbial cell wall. Monoterpenes preferentially impact the structures of the membrane by increasing its fluidity and permeability, altering the topology of its proteins, and making disturbances across the respiration chain. Moreover, the mechanism of action of terpenoids is not fully understood but is speculated to involve membrane disruption by the lipophilic compounds, disruption of the protein motive force, and coagulation of cell contents.

Conclusion:

Modern agriculture still relies heavily on the application of synthetic chemicals, even though controversies have arisen regarding their safety. Botanicals, including Eos and phenolic compounds, have been used for decades as non-chemical treatments thanks to their biodegradable nature and high selectivity. Their market is continuously growing; however, they only make up a small percentage of the global market, and just a few of these aromatic plant-based biopesticides are commercially available because of their varying performance and the absence of field studies regarding their efficiency. The cultivation of aromatic herbs can also improve crop production rates and the chemical composition of other plants. Since these wastes may be rich sources of bioactive compounds and beneficial microorganisms, their use as natural biopesticides or organic amendments has also gained popularity. Composting and vermicomposting technologies can offer a meaningful way to produce a mature and stable end product that can improve important soil processes and provide nutrients for the treated crops.

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From Pest Control to Health Promotion: The Miraculous Properties of Cordyceps

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Cordyceps spp., a genus within the Ascomycota phylum, encompasses over 700 species known for their parasitic relationships with insects and arthropods. These fungi produce a variety of secondary metabolites, including cordycepin and adenosine, which exhibit numerous health benefits such as anti-cancer, anti-inflammatory, and immunomodulatory effects. Traditionally utilized in Chinese medicine, particularly *C. sinensis* and *C. militaris*, these fungi are recognized for enhancing energy levels and treating various ailments. The life cycle of Cordyceps involves infection, parasitism, and saprophytism, with a unique ability to thrive in high-altitude environments. Recent studies highlight the potential of *C. militaris* as a biocontrol agent against insect pests and plant pathogens, showcasing its insecticidal properties and mechanisms of interaction with host organisms. The commercial cultivation of *C. militaris* has gained traction due to its pharmaceutical potential, particularly in producing cordycepin. As agricultural challenges increase, the integration of *Cordyceps spp.* into pest management strategies presents a promising avenue for sustainable agriculture, emphasizing the need for further research and commercial production to support farming communities.

Introduction:

Cordyceps spp. is classified within the Ascomycota phylum, specifically in the Pyrenomycetes class, the Hypocreales order, and the Clavicipitaceae family, with over 700 known species. The term "Cordyceps" is derived from the Greek word "kordyle," meaning "club," and the Latin root "ceps," which translates to "head" (Olatunji et al., 2018). Species of Cordyceps are known to infect insects, arthropods, and other fungi, skillfully evading the host's immune response by synchronizing their life cycle with that of their host to ensure survival and reproduction. This interaction leads to the production of various secondary metabolites (Olatunji et al., 2018), including cordycepin, adenosine, guanosine, cordymin, γ-aminobutyric acid (GABA), exopolysaccharides, and cordysinin A-E, among others (Liu Y et al., 2015).

Various species of Cordyceps exhibit a range of beneficial properties, including anti-cancer, anti-proliferative, anti-angiogenic, anti-metastatic, apoptosis-inducing, anti-inflammatory, antioxidant, anti-fibrotic, anti-arteriosclerotic, anti-hypertensive, anti-thrombotic, antimalarial, antifungal, hypolipidemic, antidiabetic, hypoglycemic, anti-asthmatic, steroidogenic, spermatogenic, anti-aging, and immunomodulatory effects (Liu Y et al., 2015). The efficacy of these properties is dependent on their concentration, and generally, no adverse effects have been reported. However, it is advisable to evaluate isolated compounds, such as cordycepin, for a more thorough assessment.

Habitat and Range of Cordyceps Species:

From the more than 700 species of mushrooms recognized on the genus Cordyceps, around 20 species parasitize on the genus *Elaphomyces*, meanwhile the remaining species do parasitize on insects and arthropods belonging to *Arachnida, Hymenoptera, Isoptera, Coleoptera, Hemiptera and Lepidoptera classes*. This diversity of species includes the *C. sinensis, C. ophioglossoides, C.militaris, C.gracilis, C.sobolifera, C.subsessilis., C.cicadae, C.tuberculate, C. scarabaeicola, C.minuta, C. myrmecophila, C. canadensis, C. nutans, C. agriota., C. ishikariensis, C. sphecocephala, C.konnoana, C. nigrella, C. pruinosa, C. tricentri.*

These species display a variety of characteristics, including notable pharmaceutical properties, which have made them appealing to traditional Chinese medicine (TMC) since the 1990s, with *C. sinensis* being the most extensively researched and utilized. Their geographic distribution largely correlates with that of their hosts; however, they are capable of thriving in high-altitude environments ranging from 3,600 to 4,000 meters above sea level. Consequently, *Cordyceps spp.* have been identified in North America, Europe, and Asia, particularly in countries such as China, Japan, Nepal, Bhutan, Vietnam, Korea, and Thailand. In **India**, they are predominantly found in subalpine areas, specifically in the **Kumaun** and **Garhwal Himalayas** at elevated altitudes (Maity, 2013; Chakraborty et al., 2014). Additionally, it has been documented that species like *C. gunnii* (Berk.) Berk. have been discovered in Australia (Olatunji et al., 2018). The unique composition of their metabolites enables them to withstand the harsh conditions typically encountered at high elevations, including low temperatures, reduced oxygen levels, and increased UV radiation exposure.

Life Cycle:

Conversely, the distribution of this unique and valuable medicinal mushroom occurs via air, rainfall, and insects, progressing through three distinct phases in its life cycle: **infection**, **parasitism**, and **saprophytism** (Pal and Misra, 2018). In the initial phase, *Cordyceps spp.* infects the host during its larval stage through ascospores, which are released into the air from mature fruiting bodies in the summer and early autumn, leading to germination. In certain instances, infection may also occur through the consumption of food contaminated with *Cordyceps spp.* mycelia. Following the infection, the parasitic phase begins, during which *Cordyceps spp*. derives nourishment from the host's intestines. The fungal cells disseminate throughout the host's body and multiply rapidly during winter, consuming all internal organs of the larva while leaving the exoskeleton intact. Subsequently, the fungal cells transform into a white mass within the larva's body, known as endosclerotium (Tuli et al., 2013a; Baral et al., 2015). Throughout this period, the environmental conditions are harsh, requiring the mushroom to endure snow and cold temperatures. As spring arrives and temperatures rise, the endosclerotium germinates and emerges through the host's oral cavity, maturing during the summer to form the fruiting body, which subsequently begins to release ascospores (saprophytic stage). This is also the season when the fungus is harvested.

Ethnopharmacy and Traditional Uses of *Cordyceps spp.*

For centuries, *Cordyceps* has been a staple in traditional Chinese medicine (TCM), recognized for its tonic properties in addressing various ailments, including respiratory issues, liver and kidney disorders, hyperglycemia, and cancer-related conditions. Additionally, *Cordyceps spp.* is known for enhancing energy levels and endurance, improving aerobic performance, and strengthening cellular immunity. It was officially recognized as a medicinal substance in the Chinese Pharmacopoeia in 1964, with *C. sinensis* and *C. militaris* (L.) Fr. being the most commonly utilized species. (Shashidhar et al., 2013).

In regions such as China, the Tibetan plateau, Bhutan, Nepal, and India, the dosage and administration of *C. sinensis* are guided by the expertise of local practitioners, often employing a trial-and-error approach (Maity, 2013). For instance,some community dissolves the fungus in milk, and alcohol or hot water, to drink it as an enhancer of the desire and sexual potency or as a morning tonic, respectively (Panda and Swain, 2011). Furthermore, the synergistic effects of the mushroom combined with other bioactive substances have also been documented. For example, certain traditional healers recommend a mixture of *Cordyceps spp.* with taxus leaves and ginseng roots as a treatment for cancer.

C. sinensis is regarded as a nutritious food source by the Chinese community, likely due to its rich composition that includes essential amino acids, vitamins (such as B1, B2, B12, and K), and carbohydrates, among other nutrients. Notably, this species of fungus serves as a dietary supplement that meets the standards set by the U.S. Food and Drug Administration (FDA), making cordyceps a sought-after product in various countries (Wu et al., 2015).

Additionally, *Cordyceps spp.* has been utilized as a treatment for fatigue and weakness, alleviating symptoms associated with altitude sickness and providing an energy boost to patients. As individuals age, they often experience a reduction in aches and pains. Traditional Chinese Medicine (TCM) practitioners also advocate for the regular consumption of *C. sinensis* to prevent infections, colds, and flu, owing to its effectiveness in reducing cough, phlegm, asthma, and bronchial conditions (Lo et al., 2013). Consequently, *Cordyceps spp.* has been employed in the treatment of lung fibrosis, particularly in patients affected by severe acute respiratory syndrome (SARS). According to TCM principles, these benefits are attributed to *C. sinensis* capacity to enhance lung yin and yang (Chiu et al., 2016a). The advantages of *Cordyceps spp.* have also been noted among athletes, as it improves energy levels by increasing cellular ATP, which releases energy in muscle cells.

Like *C. sinensis*, *C. militaris* (L.) Fr., which is found in China, Japan, Korea, and East Asia, is recognized for its applications as an energy booster, aphrodisiac, and treatment for respiratory ailments. Additionally, this species is noted for its hypoglycemic, anti-inflammatory, antitumor, antibacterial, antifungal, antioxidant, and immuno-protective properties. Consequently, it ranks as the second most commercially utilized species in China, Japan, and Korea, often regarded as a more affordable alternative to *C. sinensis* (Chou et al., 2014). (Chou et al., 2014).

Other species employed by traditional healers include *C. pruinosa Petch*, *C. bassiana*, *C. cicadae S.Z. Shing*, *C. gunnii (Berk.) Berk.*, *C. guangdongensis* T.H. Li, Q.Y. Lin, and B. Song, as well as *C. ophioglossoides (T. ophioglossoides)*. *C. pruinosa Petch* is primarily used for treating stomach ailments and inflammatory disorders. *C. bassiana* Z.Z. Li, C.R. Li, B. Huang, and M.Z. Fan is utilized for skin issues such as dermatitis and eczema, and it also serves as a biological insecticide for pest management (Wu et al., 2015; Olatunji et al., 2018). In Traditional Chinese Medicine (TCM), C. cicadae S.Z. Shing is employed to address infantile convulsions, elevated body temperature, and tremors, with additional therapeutic benefits including antitumor,immunoregulatory, and reno-protective effects (Olatunji et al., 2018). Similarly, C. gunnii (Berk.) Berk. demonstrates immunomodulatory properties, enhances memory, and may delay aging (Zhu et al., 2012b; Zhu Z-Y et al., 2014). *C. guangdongensis* is used to combat fatigue, avian influenza, inflammation, renal failure, and oxidative stress (Yan et al., 2013). Conversely, *C. ophioglossoides (T. ophioglossoides)* is consumed as food and is associated with antitumor, estrogenic, and anti-aging effects, in addition to its use during childbirth to prevent excessive bleeding in women (Kawagishi et al., 2004; Olatunji et al., 2018).

The conventional use of ***Cordyceps spp.*** has primarily been in the form of herbal products, with significant marketing efforts commencing in the early 2000s. In numerous countries, it is utilized as a **dietary supplement** owing to its various health benefits. Currently, it remains a highly coveted item, with its popularity bolstered by scientific research. The price for wild *C. sinensis* can reach as high as $20,000 per kilogram, establishing it as the most expensive mushroom globally.

A New Biological Approach for Crop Protection:

As previously noted in the introduction, cordyceps fungi exhibit parasitic behavior towards insects and possess entomopathogenic characteristics that can aid in pest management. This section provides a concise overview of the metabolites generated, the entomopathogenic effects, the mechanisms of interaction, and the commercial cultivation of ***Cordyceps militaris.***

Cordyceps militaris is recognized for its production of various secondary metabolites, which include bioactive substances such as polysaccharides, adenosine, cordycepin, ergosterol, and myriocin (de Bekker et al., 2013). The primary active constituents of *C. militaris* are cordycepin, cordymin, and adenosine (Shrestha et al., 2004). Cordycepin, in particular, has demonstrated antibacterial and antiviral effects, enhancing multiple immune responses in humans (Paterson, 2008). Additionally, adenosine is involved in modifying cellular responses, influencing processes such as cell differentiation and apoptosis (Szentmiklosi et al., 2015; Yang et al., 2010).

Among the secondary metabolites produced by *Cordyceps militaris*, cordycepin is significant for its role as an active agent in insect control. However, its effectiveness in managing plant diseases remains inadequately understood. Conversely, cordymin is recognized for its ability to combat various plant pathogens, including *Mycospharella arachidicola*, *Rhizoctonia solani*, and *Bipolaris maydis*. The polysaccharides found in *C. militaris* are known to function as bioactive compounds, interacting with the host immune system to combat various insect pests and diseases.

Entomopathogenic Activity of *Cordyceps militaris.*

Cordyceps militaris is recognized in nature for its ability to infect various insect species, with its fruiting body developing over the infected host to a height ranging from 1 to 8 cm. As the infection progresses, the mobility of the affected insects diminishes, leading to a mummified state. The mycelium of *C. militaris* proliferates intercellularly within the insect, ultimately resulting in the host's death. Subsequently, the fruiting body of *C. militaris* emerges from the deceased insect, characterized by its striking bright orange, club-like appearance. Over time, researchers have gradually come to understand the entomopathogenic properties of this fungus.

Berdy (1989) discovered that the secondary metabolites of *Cordyceps militaris* possess insecticidal properties, making them suitable for environmentally friendly insect control. In a study assessing the toxicity of the metabolic compound cordycepin from *C. militaris* through a leaf dipping method, it was observed to exhibit insecticidal effects against the larvae of the Diamondback moth (*Plutella xylostella*) by inhibiting chitin synthesis (Kim et al., 2002). Bioassays and qPCR analyses conducted on the effects of cordycepin on the Greater wax moth, *Galleria mellonella*, and the Fruit fly, *Drosophila melanogaster*, indicated that cordycepin could diminish the insects' immune response by suppressing the expression of immune-related genes. Furthermore, cordycepin, both alone and in conjunction with entomopathogenic fungi, was found to enhance the mortality rate of the Diamondback moth, *Plutella xylostella* (Anonymous, 2018). Various doses of *Cordyceps militaris* were shown to reduce survival rates, development time, molting, total hemocyte counts, and the activity of cuticular enzymes in the potato Colorado beetle, *Leptinotarsa decemlineata* (Kryukov et al., 2014).

Mechanism of Interaction:

In any biocontrol strategy, understanding the interaction between a biocontrol agent and its host is essential. The mechanisms underlying host-pathogen interactions are crucial for assessing the effectiveness of any biocontrol organism. The successful management of target insects or pathogens is directly influenced by the action mechanisms of the biocontrol agent. In insects, the primary mode of infection involves the invasion of the precutaneous area by fungal spores, followed by growth within the haemocoel and subsequent dissemination throughout the host's tissues. These agents penetrate host insects and compromise their innate immune systems while extracting nutrients necessary for their survival and reproduction (Das et al., 2021). This interaction leads to the production of various components, such as cordycepin, adenosine, and gamma-aminobutyric acid (Liu et al., 2015). Under natural conditions, insect mortality typically occurs within seven days of infection, whereas in vitro conditions may extend this duration to at least seven days (Chandler, 2017). Additionally, *Cordyceps militaris* is recognized for inducing apoptosis, a form of programmed cell death characterized by specific features such as cell membrane shrinkage, externalization of phosphatidylserine, formation of apoptotic bodies, and chromatin condensation. Apoptosis is a widely observed form of cell death across various cell types (Wyllie et al., 1980; Jin and El-Deiry, 2005; Bai and Sehu, 2018). Under favorable environmental conditions, the fungus emerges from the deceased insect to seek new hosts or produce ascospores or conidia, which are then acquired by other insects. This behavior of *Cordyceps militaris* exerts selection pressure on traits that enhance virulence, thereby optimizing pathogen fitness (Roy et al., 2006). Numerous research studies provide evidence confirming the immune disruption caused by various entomopathogenic fungi.

Commericial Production of *Cordyceps militaris:*

The commercial cultivation of *Cordyceps militaris* commenced soon after its pharmaceutical potential was recognized. However, its agricultural value has only been capitalized on in recent years. The growth conditions and nutritional needs of *C. militaris* are notably distinct from those of other biocontrol agents. In its natural habitat, this fungus thrives exclusively in cooler climates at high altitudes. Under laboratory settings, the production of the fruiting body of *C. militaris* occurs only when specific growth parameters are adjusted. Notably, the fruiting body is induced in the absence of light. Research indicates that brown rice media or other solid substrates, such as oatmeal agar, are optimal for the cultivation of *C. militaris* fruiting bodies (Wen et al., 2014). An investigation into the *Cordyceps militaris* isolate CGMCC 2909 revealed that a medium containing yeast extract at 10.33 g/L, sucrose at 27.24 g/L, and KH2PO4 at 5.06 g/L, with a pH of 6 and a temperature of 25°C, yielded a mycelial output of 12.19 g/L (Yang et al., 2014). The fruiting bodies of *Cordyceps militaris* contain an active biometabolite known as cordycepin, a derivative of the nucleoside adenosine. Following its initial isolation from *C. militaris* (Cunningham et al., 1950), cordycepin is now produced commercially due to its insecticidal, antibacterial, and antifungal properties (Paterson and Russell, 2008). It is widely recognized that the growth and reproduction of fungi are significantly influenced by various abiotic factors, including temperature, pH, and nutrient availability. The optimal temperature for mycelial growth has been identified as between 15 to 20°C, while 25°C is ideal for cordycepin production; at 30°C, neither mycelial growth nor cordycepin production occurs (Hung et al., 2009).

Conclusion:

As we conclude our journey into the fascinating world of Cordyceps, it's clear that this miraculous mushroom holds the key to unlocking nature's secrets. With its incredible range of health benefits, from boosting energy and endurance to enhancing immune function and combating cancer, Cordyceps is a natural wonder that deserves our attention.As we continue to explore the depths of Cordycep's potential, we may uncover even more surprising benefits and uses of this incredible fungus. Whether you're an athlete looking to enhance your performance, a health enthusiast seeking to boost your wellbeing, or simply someone curious about the natural world, Cordyceps is definitely worth exploring.

In recent years, the management of plant diseases has largely relied on various agricultural chemicals. However, these chemicals have proven to be less effective against pathogenic microbes, leading to the emergence of numerous new pathogen strains. Additionally, the use of these chemicals has negatively impacted soil health by disrupting the population dynamics of many beneficial microbes present in agricultural soils. Furthermore, options for crop rotation and the availability of resistant cultivars have become increasingly limited. These challenges have prompted the need for new management strategies, particularly biological control. While several biological control agents, such as *Trichoderma harzianum*, *Pseudomonas sp.*, and

Bacillus subtilis, are commercially available, the potential of *Cordyceps militaris* as a biocontrol agent against both insect pests and plant pathogens is significant. Therefore, it is essential to utilize this biocontrol agent on a larger scale and to promote its commercial production to assist the farming community in combating crop threats in a safe and effective manner.

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Artificial Intelligence in Pig Farming: A New Frontier

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The integration of Artificial Intelligence (AI) in pig farming marks a significant advancement in addressing the limitations of traditional farming practices. This paper explores how AI technologies including computer vision, sound recognition, and intelligent sensing are applied to monitor pig behaviour, detect health issues, and enhance overall farm management. Vision-based systems enable precise tracking and behaviour analysis, while sound-based models assist in identifying respiratory diseases and oestrus signs. Despite challenges such as harsh environmental conditions, equipment maintenance, and skill gaps among farmers, AI presents promising opportunities for precision pig farming. The study highlights the potential of AI-driven systems to improve animal welfare, optimize productivity, and support sustainable livestock production.

Key words: Artificial Intelligence, Behaviour, Computer Vision, Pig Welfare, Precision

Introduction

Traditional pig farming faces numerous challenges across different regions. In Asia, key issues include limited land and feed resources, prevalence of small-scale farms, environmental pressures, infectious diseases, and climate challenges. Similar problems are observed in Nagaland, India, where farmers struggle with high feed costs, inadequate veterinary care, disease outbreaks, and lack of quality breeding stock. In Botswana, commercial pig production is hindered by high feed costs, insufficient slaughter facilities, unorganized marketing, and inadequate extension services. These traditional monitoring methods are becoming increasingly difficult as pig farming scales up, impacting both pig welfare and economic productivity. To address these challenges, the integration of artificial intelligence in pig farming is emerging as a promising solution, offering continuous monitoring of biometric data for early health issue detection and improved production efficiency (Shukla *et al.*, 2023).

The emergence of digital technologies is transforming agriculture and livestock practices, ushering in the era of Agriculture 4.0. Key innovations include artificial intelligence, block chain, precision agriculture, IoT, robotics, and machine learning. These technologies enable data-driven decision-making, automation, and improved efficiency across various sectors, including crop production, livestock breeding, and supply chains. Benefits include increased productivity, enhanced animal welfare, and improved sustainability. However, the future of Agriculture 4.0 is uncertain, with potential challenges in realizing expected benefits. Responsible innovation requires collaboration among stakeholders, including policymakers, farmers, consumers, and technology developers, to create balanced transition pathways that consider both desirable and undesirable consequences (Pletsch *et al.*, 2024).

"Understanding Artificial Intelligence"

What is A.I.?

Artificial Intelligence (AI) is defined as the ability of machines or computer systems to simulate and perform tasks typically requiring human intelligence, such as reasoning, learning, and problem-solving (Nagendraswamy & Salis, 2021).

AI-Based Intelligent Equipment for Precision Pig Farming

AI-powered smart equipment plays a crucial role in precision pig farming and serves as a key foundation for implementing advanced farming practices. In today's modern pig industry, such equipment not only facilitates the collection and transmission of data but, when integrated with edge AI capabilities, can also process and analyse information directly at the source. This enables rapid decision-making for effective farm management. These intelligent devices are capable of executing actions based on real-time monitoring results, either autonomously or by coordinating with other devices. As a result, the farming environment can be optimized scientifically—leading to better disease control and improved profitability (Banhazi et al., 2012).

AI-Based Vision for Pig Detection and Tracking

Vision-based detection and tracking, which operates without direct contact, is essential for continuously monitoring pig behaviour and welfare. In modern pig monitoring systems, identifying and tracking individual pigs is a fundamental step toward shifting from group-level management to personalized care and detailed activity analysis. By accurately detecting and following key body parts of each pig, it becomes possible to assess their behaviour more precisely, enabling better health management and welfare assessment (Zhang *et al.*, 2019).

- **Pig Detection:** Accurate pig detection is a fundamental requirement for tracking pig movements, observing behaviours, and ensuring continuous data collection. The precision of detection significantly influences the effectiveness of both tracking systems and behavioural analysis. Traditionally, machine learning techniques have been applied to identify and locate pigs within an environment. These methods often combined tools such as image difference analysis with median background subtraction, the Laplacian operator, pseudo-wavelet features, ellipse fitting algorithms, and Gaussian mixture models to determine the position of pigs effectively (Zhang *et al.*, 2019).
- **Pig Tracking:** Pig tracking algorithms enable the assessment of individual animal activity, which has been found to be inversely related to environmental factors like temperature, humidity, and ammonia levels. Conventional image analysis techniques have relied on color and contour features to capture various types of pig movements. For instance, Gao *et al*. developed a method that segmented the head and tail of pigs and applied Hough clustering along with roundness recognition algorithms to trace individual pig trajectories. While this approach showed effectiveness in separating closely grouped pigs, further refinement is still required to enhance its tracking accuracy (Gao *et al*., 2017).

AI-Based Vision Pig Behaviour Recognition

Pig behaviour serves as a key indicator of their productivity, health status, and overall welfare. Recognizing both normal and abnormal behavioural patterns is essential for enhancing animal well-being, particularly through improvements in housing and nutrition. In the context of modern, large-scale pig farming, real-time monitoring and behavioural analysis have become crucial not only for ensuring animal welfare but also for reducing labour demands and gaining a competitive edge in the industry (Pedersen, L. J. 2018). Pigs exhibit various behaviours depending on their environment, and under normal conditions, common activities include drinking, mounting, aggression, and resting. These routine behaviours are vital markers for evaluating dietary health and early signs of illness (Fernandes *et al*., 2021)

- **Recognition of Pig Drinking Behaviour:** Water plays a vital role in a pig's daily routine and is a key component of its diet. The quantity of water consumed by an individual pig is closely linked to its feed intake and can also serve as an early indicator of potential health issues. Currently, one of the commonly used methods for monitoring drinking behaviour involves RFID technology, where a transmitter is attached to the pig's ear and receivers are positioned near the drinking stations. This setup enables the tracking of drinking patterns, which can then be analysed through linear regression models to explore correlations with health status. However, this approach is somewhat invasive, as it requires the insertion of electronic tags into the pigs' ears, which may cause discomfort or injury (Chen *et al*., 2020).
- **Recognition of Aggressive Pig Behaviour:** In intensive, confined farming systems, pigs are more prone to display aggressive behaviours. Such aggression can lead to issues like unequal access to feed, skin injuries, and infections, ultimately affecting pig welfare and causing economic setbacks. As a result, there is growing interest in applying computer vision and artificial intelligence technologies to detect and monitor aggressive behaviour in pigs. Traditional machine learning approaches, which rely on manual feature extraction, face limitations such as limited feature diversity, complex feature selection processes, and poor generalization capabilities. However, with recent advances in deep learning and machine vision, AI techniques have greatly improved behavioural recognition. These methods eliminate the need for manual feature engineering by learning directly from data, leading to higher accuracy and better adaptability across different farming conditions (Lee *et al*., 2016).
- **Recognition of Pig Nursing, Lying Down and Other Behaviours:** In commercial pig production, productivity is closely tied to the number of piglets successfully weaned per sow. One of the leading causes of high piglet mortality before weaning is starvation. Additionally, behaviours such as lying down and other activity patterns serve as vital indicators for assessing nutritional health and detecting early signs of disease (Zhu *et al*., 2015). In earlier studies, Yuan et al. employed Zernike moments combined with support vector machines to identify four different pig postures. However, traditional machine learning methods often struggle with the complexity involved in recognizing diverse poses and behaviours. With advancements in artificial intelligence, a range of deep learning techniques has emerged, offering more effective solutions for monitoring pig behaviour. These AI-driven models are typically trained using various types of data including images, video, and 3D inputs to accurately identify feeding habits, postures, and other behaviour patterns, ultimately supporting better animal welfare and improved farm productivity (Yang *et al*., 2018).
- **Recognition of Pig Mounting and Oestrus Behaviours:** Mounting behaviour in pigs is commonly observed in overcrowded housing conditions and is often associated with an increased risk of injuries due to physical strain and aggressive interactions. Additionally, enhancing sow reproductive efficiency is important for reducing both management and feeding costs per pig (Yang *et al.,* 2021). In natural mating systems, sows typically undergo at least three mating events to maximize the chances of successful fertilization. During oestrus, boars display specific behaviours such as climbing and mounting. Therefore, accurately detecting mounting and oestrus-related behaviours is crucial not only for improving breeding outcomes but also for supporting overall pig

health, welfare, and reproductive success (Whittemore *et al*., 1996).

AI-Based Sound for Pig Disease and Oestrus Diagnosis:

In pig farming, aside from visual monitoring, sound also serves as a key indicator for detecting abnormal behaviours and health issues. Among these, respiratory illnesses are a major concern, with some farms experiencing mortality rates as high as 15%, leading to significant economic losses. Coughing sounds in pigs are especially useful as auditory markers for identifying respiratory diseases. Effective monitoring of such sounds including coughs and vocalizations related to oestrus relies heavily on two main components: data preprocessing and the application of sound recognition models. These technologies help detect health problems early, allowing timely interventions to reduce mortality and improve herd management. (Choi *et al*., 2003). During the data preprocessing stage, one challenge in detecting pig cough sounds is the overlap between the frequency range of environmental noise typically below 5 kHz and that of the cough sounds themselves. This overlap makes it difficult to distinguish pig vocalizations from background noise, such as ventilation fans commonly used in pig housing. To address this issue, Dong et al. developed an enhancement algorithm based on the Discrete Cosine Transform (DCT), which effectively reduces noise and improves the clarity of pig cough signals for more accurate detection and analysis (Wang *et al*., 2022).

Challenges And Development Opportunities:

- While AI technologies based on visual and auditory data have shown promising results in pig detection and behaviour monitoring, several challenges remain in fully implementing precision pig farming. Factors such as the scale of farming operations, the technical knowledge of farm workers, the quality and compatibility of smart farming equipment, and the consistency and reliability of data collection all play a critical role. These limitations present both obstacles and opportunities for further innovation and the broader adoption of AI in pig farming systems.
- One of the key challenges in implementing intelligent systems in pig farming is ensuring their reliability, ease of maintenance, and user-friendliness. In terms of reliability, many sensors and devices must be installed in harsh environments, such as on the roofs of pig houses or other locations exposed to extreme conditions. These areas often experience high temperatures, humidity, dust, and inconsistent power supply, all of which can contribute to wear and deterioration of the hardware components, including sensors (Ariyadech *el al*., 2019).
- The integration of intelligent sensing systems, Internet of Things (IoT), and artificial intelligence technologies—combined with diverse sensor types and expert insights—is driving the pig farming industry toward greater standardization, scalability, and automation (Chlingaryan *et al*., 2018).

Conclusion

Artificial intelligence is revolutionizing pig farming by enabling real-time monitoring, behaviour recognition, and early disease detection. These technologies enhance animal welfare, increase productivity, and reduce labour demands. While challenges such as harsh farm environments and limited technical expertise remain, the integration of AI, IoT, and intelligent sensors offers great potential for more sustainable and efficient pig production. With continued innovation and collaboration, AI can play a key role in transforming traditional pig farming into a smarter, data-driven system.

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"Effect of Climate Change on Livestock Health and Productivity"

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Climate change has emerged as a pressing global issue, significantly impacting livestock health, productivity, and sustainability. Rising temperatures, erratic rainfall patterns, and extreme weather events contribute to heat stress, reduced feed and water availability, and increased prevalence of diseases, ultimately impairing animal performance. These challenges are particularly critical for dairy, meat, and poultry production systems, affecting milk yield, weight gain, reproductive efficiency, and egg quality. Additionally, climate-induced changes in pasture composition and quality threaten fodder availability. This paper highlights the multifaceted effects of climate change on livestock systems and explores adaptation and mitigation strategies such as promoting climate-resilient breeds, improving housing and nutrition, enhancing disease surveillance, and utilizing advanced technologies including ICT tools and genetic innovations. A multidisciplinary and collaborative approach is essential to safeguard livestock productivity, ensure food security, and support sustainable livelihoods in the face of ongoing climate challenges.

Keywords: Climate Change, Impacting, Livestock

Introduction

Climate change poses a significant threat to livestock health and productivity globally. Rising temperatures and extreme weather events negatively impact feed availability, water resources, and animal performance. Heat stress reduces feed intake, milk production, reproductive efficiency, and egg quality in various livestock species (Mittal et al., 2019). Climate change also affects the distribution and abundance of pathogens and disease vectors, increasing the risk of emerging and re-emerging zoonotic diseases. The livestock sector, which employs 1.3 billion people worldwide, is particularly vulnerable to these impacts. Mitigation strategies include improved cooling systems, proper ventilation, and housing management. Addressing climate change's effects on livestock requires multidisciplinary approaches focusing on animal nutrition, housing, health, and developing thermo tolerant breeds. These efforts are crucial for maintaining livestock productivity and ensuring food security in the face of changing climatic conditions (Arora et al., 2024). Climate change significantly impacts livestock health and productivity, posing a major threat to the agricultural sector globally. Rising temperatures and altered rainfall patterns lead to heat stress in animals, reducing feed intake, growth rates, and reproductive performance. These changes also affect the availability and quality of feed and water resources, further compromising livestock productivity. Climate change can increase the prevalence and distribution of pathogens and parasites, potentially exacerbating disease outbreaks. Livestock owners have observed these impacts and are implementing various adaptation strategies, including feed conservation, destocking, and diversification of income sources (Tiruneh & Tegene, 2018).

Understanding Climate Change

Climate change poses a significant threat to ecosystems and livestock production systems worldwide. Greenhouse gases (GHGs), released by both natural and anthropogenic sources, contribute to global warming. The livestock sector is a major contributor to GHG emissions, accounting for 18% of emissions causing global warming. Climate change impacts include increased heat stress, altered feed availability, and changes in disease patterns, affecting livestock health, production, and reproduction (Agbeja et al., 2021). Mitigation strategies focus on management and nutritional approaches, such as improving forage quality, dietary manipulations, and manure management. However, these strategies should not compromise the economic viability of livestock enterprises. A comprehensive and sustainable action plan involving various stakeholders is necessary to address GHG emissions from livestock production (Prasad et al., 2015).

Impact on Livestock Health

Heat stress significantly impacts livestock health and productivity, particularly affecting dairy animals. It reduces feed intake, growth rate, milk yield, and reproductive performance. Heat stress suppresses immune and endocrine systems, increasing disease susceptibility (Das et al., 2016). Reproductive functions are compromised through hormonal imbalances, decreased oocyte and semen quality, and reduced embryo development. Conception rates decline as the temperature-humidity index (THI) increases, with significant reductions observed above THI 72 in cattle and THI 75 in buffaloes. Climate change may also lead to the emergence and re-emergence of vector-borne diseases. Mitigation strategies include environmental modifications, nutritional management, and genetic selection for heat-tolerant breeds. Advanced reproductive technologies and timed artificial insemination may help counter summer infertility in farm animals (Krishnan et al., 2017).

Impact on Livestock Productivity

- **Decline in milk yield due to heat stress in dairy animals:** Heat stress significantly impacts dairy animal productivity, causing reduced milk yield and quality, decreased feed intake, and impaired reproductive performance. The Temperature Humidity Index (THI) is used to measure heat stress, with values above 68-72 negatively affecting milk production. Milk yield decreases by 0.2 kg per unit increase in THI above 72 (Krishnan, 2020).
- **Reduced weight gain and feed conversion efficiency in meat animals:** Feed efficiency in meat animals is influenced by various factors, including genetics, nutrition, environment, and management practices. Selection for leanness and growth rate can improve energetic efficiency, as animals farther from mature size exhibit greater relative weight gain and more efficient conversion of food to lean tissue. Environmental stressors, such as heat and parasites, can significantly impact feed efficiency and weight gain. For instance, stable fly infestations can reduce cattle weight gains through both direct and indirect effects, with the latter accounting for a larger proportion of the impact (Wieman et al., 1992).
- **Decreased egg production in poultry:** Climate change and heat stress significantly impact poultry production, particularly egg-laying hens. High ambient temperatures above 32-35°C can lead to decreased egg production and quality. This reduction is attributed to various mechanisms, including disturbances in the reproductive system, reduced intestinal absorption, and hormonal imbalances (Kavtarashvili, 2021).
- **Altered growth rates and performance parameters:** Research on altered growth rates in animals reveals significant impacts on adult performance and life histry traits. Compensatory growth following early-life environmental perturbations can lead to

reduced reproductive investment, decreased swimming endurance, and accelerated senescence in three-spined sticklebacks. The negative effects of accelerated growth are more pronounced when the perceived time until breeding is shorter (Lee et al., 2015).

- **Effect on Feed and Fodder Availability**: Climate change poses significant challenges to fodder production and livestock sustainability. Erratic rainfall, temperature variability, and drought are predicted to negatively impact forage quality and quantity. These factors, combined with increasing CO_2 levels, may alter pasture composition and nutritional value. The scarcity of fodder availability, coupled with rising demand for livestock products, further exacerbates the issue. To address these challenges, various strategies have been proposed, including the adoption of climate-smart forage production techniques, precision agriculture (Sarwar et al., 2021), and the development of drought-resistant crop varieties. Improved irrigation efficiency, altered sowing times, and the introduction of genotypes with higher thermal accumulation efficiency are potential adaptations. However, the implementation of these strategies remains geographically uneven and faces obstacles such as land scarcity and lack of awareness (Diriba Tulu et al., 2023).

Adaptation and Mitigation Strategies

Climate change poses significant challenges to livestock production, affecting animal health, productivity, and sustainability. To address these issues, several strategies have been proposed. Promoting climate-resilient and indigenous breeds can enhance adaptability to harsh conditions. Improved housing and shelter design, along with nutritional interventions and water management, can help mitigate heat stress. Enhanced disease surveillance and health management are crucial for maintaining animal welfare (Sharma et al., 2024). Physiological adaptability, measured through variables such as respiration rate, rectal temperature, and skin temperature, plays a vital role in animals' ability to cope with heat stress. Policy support and farmer awareness programs are essential for implementing these strategies effectively and promoting sustainable livestock farming (Rashamol et al., 2018).

Role of Research and Technology

Early warning systems and ICT tools play a crucial role in managing agricultural risks, particularly for pastoralists and smallholder farmers. Livestock early warning systems provide real-time monitoring of forage, water, and market information, helping pastoralists assess drought risks and make informed decisions. ICT applications are cost-effective for collecting, processing, and disseminating risk-related information, which is essential for smallholders who lack resources to mitigate and cope with risks (Sen & Choudhary, 2017). Genetic technologies offer sustainable solutions for improving livestock production by utilizing naturally occurring genetic variation. These approaches range from breed selection to using genetic markers for enhancing output, product quality, and disease resistance. The integration of information technology with genetic and breeding strategies is crucial for making rational decisions in sustainable livestock production systems, addressing challenges in both developed and developing countries (Bishop & Woolliams, 2004).

Conclusion

Climate change poses a critical challenge to global livestock health, productivity, and sustainability. Its impacts ranging from heat stress and reduced feed efficiency to emerging diseases and declining reproductive performance threaten food security and rural livelihoods. Addressing these challenges requires integrated adaptation and mitigation strategies, including improved animal housing, nutritional management, breed selection, and the use of advanced technologies. Strengthening research, policy support, and farmer awareness is essential to build resilient livestock systems capable of withstanding climate-related risks.

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Backyard Piggery in Nagaland: Cultural Significance, Economic Potential, and Challenges

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Backyard piggery is integral to Nagaland's rural economy and cultural heritage, supporting livelihoods and food security through pork, a dietary staple. Despite its significance, low productivity of indigenous breeds, high feed costs, inadequate veterinary services, and limited market access hinder growth. This article examines the socio-economic and cultural role of pig farming, its reliance on sustainable local feeds and Indigenous Traditional Knowledge, and key constraints. Integrating modern practices with traditional methods, alongside enhanced policy support, can reduce Nagaland's pork production deficit, curb import reliance, and promote sustainable rural development.

Keywords: Backyard Piggery, Economy, Rural, Sustainable

Introduction

Nestled in the northeastern corner of India, Nagaland is a predominantly hilly and mountainous state covering an area of 16,579 sq. km and home to approximately 7,74,930 people. About 80% of the population resides in rural areas, with Christianity being the major religion. The people of Nagaland are traditionally non-vegetarian, with pork serving as a staple protein source alongside rice. In rural areas, pig rearing is more than just a livelihood it is a way of life. Nearly every household, regardless of income level, raises livestock such as pigs, poultry, or dairy animals. Among these, backyard piggery is the most culturally significant and commonly practiced. However, the local pig breeds, though well-adapted to the environment, tend to be small in size, slow-growing, and low in productivity, making them economically less viable.

As per the 19th Livestock Census (GoI, 2012), pigs constitute 55.38% of Nagaland's total livestock, and according to the NSSO (2011–12), the state records India's highest per capita pork consumption. Driven by population growth and rising living standards, pork demand continues to surge. However, indigenous pig breeds cannot keep pace, and to bridge the gap, pigs are routinely imported from other states such as Assam, West Bengal, Uttar Pradesh, Bihar, Haryana, and Punjab. This dependency imposes a heavy financial strain on the state's economy. Nagaland is largely inhabited by tribal communities, where agriculture is the mainstay, and pig farming plays a vital role in both socio-economic and cultural traditions. Despite vast potential for commercial development, the state suffers from a pork production deficit of over 50%. Nationally, the total pig population is around 9.06 million, marking a 12.03% decline from the previous census, and pigs constitute only 1.69% of India's total livestock (Singh et al., 2020). In contrast, Northeast India alone contributes 46.83% to the national pig population, with states like Assam and Meghalaya showing positive growth trends.

Pig production systems in Nagaland are diverse, varying across ethnic groups, geographical areas, and farming systems, but are predominantly small-scale and traditional. These systems focus more on fattening than

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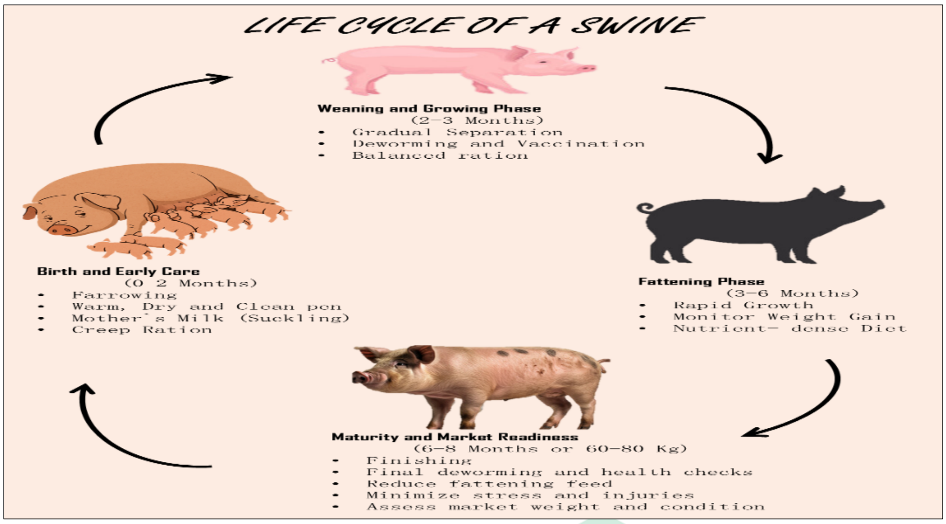
breeding, rely heavily on kitchen waste and local feed resources, and integrate Indigenous Traditional Knowledge (ITK) in daily management, breeding, and healthcare practices. Over time, penning has replaced free-range scavenging, and crossbred pigs have increasingly replaced indigenous breeds (Singh and Mollier, 2016). Due to limited infrastructure, remoteness, and inadequate veterinary services, most farmers continue to rely on their traditional knowledge systems throughout the pig's lifecycle. Yet, there is scant scientific documentation on these valuable ITKs. To address this, researchers undertook a study to document commonly used medicinal plants and tribal practices in pig farming for scientific validation and future standardization (Singh et al., 2019). The article aims to highlight the role of backyard piggery in Nagaland's rural economy and culture, explore existing challenges, and emphasize the need for improved practices and policy support to boost local pork production.

Why to Go for Backyard Piggery in Nagaland?

- **Cultural and Traditional Value:** Backyard piggery is a cornerstone of Naga traditions, deeply embedded in the rural lifestyle. It is not just an economic activity, but a cultural practice that connects families to their heritage. Pigs are an essential part of festivals, feasts, and ceremonies, making pig farming an integral part of Naga identity.
- **Affordable and Accessible Livelihood:** With minimal initial investment, backyard piggery offers an accessible livelihood for many rural households. It allows families, regardless of wealth, to maintain a source of income through the sale of pigs and pork, which remains a crucial part of their diet and economy.
- **Sustainability and Resource Efficiency:** Backyard piggery relies on locally sourced feed, including kitchen scraps, crop residues, and other organic waste. This low-input, high-output system promotes sustainability and reduces the environmental footprint of commercial farming. It helps recycle waste, improving the efficiency of rural resource use.
- **Meeting Rising Demand for Pork:** As the demand for pork grows due to population increase and rising incomes, backyard piggery can bridge the gap between local production and consumption. By enhancing local production, Nagaland can reduce dependency on imported pork, ensuring fresher and more affordable meat for the community.
- **Nutritional Benefits:** Pork is a key protein source in the Naga diet, and local pig farming ensures a constant, affordable supply of fresh meat. By increasing local production, food security improves, and rural communities are better able to meet their nutritional needs without relying on costly imports.
- **Job Creation and Economic Growth:** Beyond farming, backyard piggery creates economic opportunities in areas like meat processing, feed production, and transportation. It stimulates local markets and creates jobs, contributing to broader economic development in rural areas.
- **Low-Cost Entry with High Potential:** For aspiring farmers, backyard piggery is an ideal entry point into livestock farming. It requires low capital investment compared to other farming ventures and offers the potential for steady growth. With proper training and improved management practices, farmers can increase their productivity, leading to greater profitability and sustainability.
- **Improvement Through Innovation:** While the local pig breeds have limitations in terms of growth rate and productivity, there is tremendous potential for improvement through the introduction of better breeding techniques, better healthcare, and improved feed management. By incorporating modern scientific practices alongside traditional knowledge, pig farming can become more efficient and economically viable.



Commonly Used Plants as Feed for Pigs:

Backyard piggery in Nagaland relies heavily on locally available plants, which are cost-effective and sustainable. Table 1 lists commonly used plants, their scientific names, parts used, and preparation methods.

Common Name	Scientific Name	Part Used	Method of Use
Cassava/ Tapioca	*Manihot esculenta*	Root and leaves	Raw/ Cooked
Colocasia	*Colocasia esculenta*	Leaves and petiole	Cooked
Sweet Potato	*Ipomoea batatas*	Root, leaves, and vines	Raw/ Cooked
Banana	*Musa spp.*	Pseudostem (mostly), leaves, and plantain	Raw/ Cooked
Water Hyacinth	*Eichhornia crassipes*	Whole plant excluding roots	Raw/ Cooked
Papaya	*Carica papaya*	Fruit (mostly) and leaves	Raw/ Cooked
Chinese Gooseberry	*Saurauia nepaulensis*	Leaves	Cooked
Toothache Plant	*Spilanthes acmella*	Leaves	Cooked
Kalijiri, Somraj	*Vernonia anthelmintica*	Leaves	Cooked
Paper Mulberry	*Broussonetia papyrifera*	Leaves	Cooked
Pumpkin	*Cucurbita pepo*	Fruit	

(Source: Singh et al., 2020)

Key Constraints Hindering the Growth of Backyard Piggery in Nagaland:

Backyard piggery in Nagaland, despite its cultural relevance and contribution to rural livelihoods, faces multiple constraints that hinder its transformation into a medium-scale commercial enterprise. According to Patr et al., (2014), the major challenges include the high cost of concentrate feed (81.08%), non-availability of medicines, vaccines, and veterinary healthcare services (72.97%), high initial investment costs in housing and piglet procurement (60.36%), frequent disease outbreaks and piglet or adult stock mortality (46.85%), lack of availability of good breeding boars (45.95%), and limited market linkage (45.04%). These challenges are compounded by poor veterinary infrastructure in remote areas, limited awareness and training among farmers regarding scientific pig husbandry, reliance on inbred and unproductive breeding stock, and lack of access to institutional credit and organized marketing channels. As a result, farmers continue to struggle with low productivity, high input costs, and minimal profit margins, which ultimately limits the sustainable growth of pig farming in the region.

Conclusion

Backyard piggery farming is a vital component of Nagaland's rural economy and cultural fabric, offering sustainable livelihoods, food security, and economic opportunities. Despite its potential, challenges like low productivity, disease outbreaks, and limited support systems hinder its growth. By blending traditional knowledge with modern practices, improving access to resources, and fostering policy support, Nagaland can reduce its pork production deficit, decrease import dependency, and strengthen its rural economy. Investments in training, infrastructure, and market linkages are critical to transforming backyard piggery into a thriving, sustainable industry that preserves Naga heritage while driving economic progress.

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Geospatial Assessment of Water Streams for Smart Farming: A Remote Sensing and GIS Approach

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The use of remote sensing and GIS offers a reliable and structured method for analyzing surface water patterns through stream network mapping. This research employs DEM data to develop an accurate stream layout using essential GIS tools like Fill, Flow Direction, Flow Accumulation, and Stream Order. The workflow supports detection of flow paths, water collection points, and drainage features across varied terrain. This study highlights a targeted area in Jalpaiguri district, West Bengal, to showcase its practical relevance. The final stream layout supports agricultural strategies by improving irrigation plans, controlling erosion, and managing water efficiently. This approach ensures a scientific base for sustainable land and farm decision.

Keywords: Digital Elevation Model (DEM), fill, flow direction, stream order, stream network

Introduction

The integration of remote sensing technologies with Geographic Information Systems (GIS) has transformed land and water resource studies by enabling advanced capabilities for real-time monitoring, spatial analysis, and strategic management (Mondal, 2012). Remote sensing plays a key role in efficiently acquiring and interpreting land use and land cover data essential for hydrological modeling and planning (Parece & Campbell, 2015). Conventional approaches to water resource evaluation often lack the spatial coverage and temporal resolution needed for large-scale or remote areas. In contrast, remote sensing provides consistent, multi-spectral observations of the Earth's surface, effectively addressing these challenges and supporting detailed environmental assessments (Xie et al., 2016).

What is Water Stream Network?

A stream network in any region signifies the connected layout of surface water bodies, including rivers, streams, and tributaries, that together define the area's drainage system. It plays an essential role in channeling runoff and rainfall toward major water bodies like lakes, reservoirs, or seas, thus maintaining the natural water cycle. The form of a stream network depends on various environmental elements such as terrain, gradient, soil characteristics, rock structure, vegetation, and climate (Jenson & Domingue, 1988). To extract a precise stream layout from a DEM, the process starts with a fill function to remove sinks or low spots that could disrupt flow paths. This ensures the model accurately reflects water movement. Next, flow direction is established using elevation to determine the slope-based path water will follow (Tarboton, 1997). Afterward, flow accumulation is computed to locate gathering points for runoff, which help identify stream courses

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(O'Callaghan & Mark, 1984). These steps are vital for water modeling, flood analysis, watershed planning, and land management, enabling efficient resource planning and development.

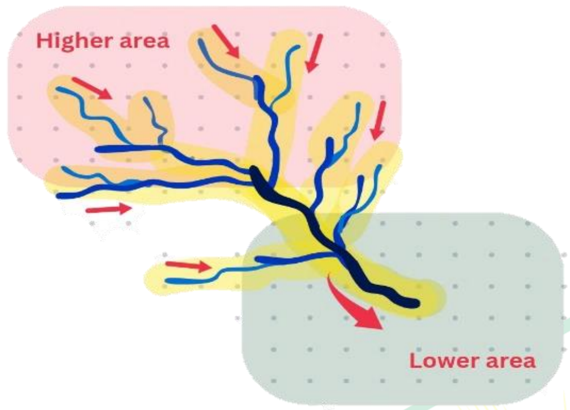

Fig 1. General Diagram of Water Stream Network

Methodology

Water naturally travels from higher elevations to lower terrains. To analyze the direction and pattern of stream flow, we first need to obtain Digital Elevation Model (DEM) data from trusted platforms like the Shuttle Radar Topography Mission (SRTM), ASTER, or LiDAR-derived sources. These elevation datasets are accessible via the USGS website. After downloading, the DEM should be imported into GIS software such as ArcGIS for further analysis. Initially, the study region must be clipped from the DEM layer. Then, within the toolbox, we navigate to Spatial Analyst Tools and choose the Hydrology section to initiate stream network extraction. The first function to apply is 'Fill', where the extracted DEM is used to eliminate any pits or depressions that could hinder water flow across the surface. Following this, the 'Flow Direction' tool is used to calculate flow paths, taking the filled raster as input. This tool uses the D8 algorithm to define the steepest descent path from each cell to one of its eight neighbors—whether vertically, horizontally, or diagonally—indicating the expected direction of runoff.

Table.1. Direction symbol and code value for each direction use in flow direction process

Flow Direction	Direction Symbol	Code Value
East	→	1
Southeast	↘	2
South	↓	4
Southwest	↙	8
West	←	16
Northwest	↖	32
North	↑	64
Northeast	↗	128

Following this, the 'flow accumulation' is computed using the flow direction raster. This identifies areas where small streams converge to form larger channels. Higher accumulation values indicate areas of stronger water flow, effectively distinguishing between flowing and non-flowing zones within the study area. Using the flow direction and flow accumulation raster,

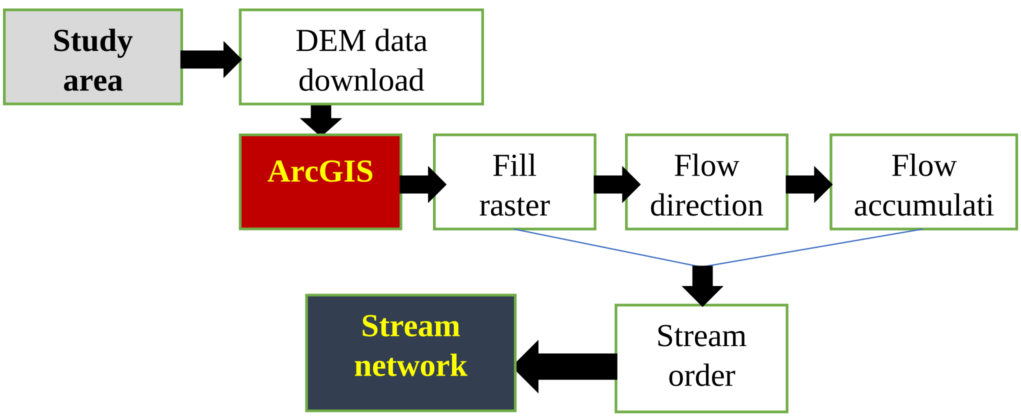

Fig.2. Flow chart foe creation of stream network of study area.

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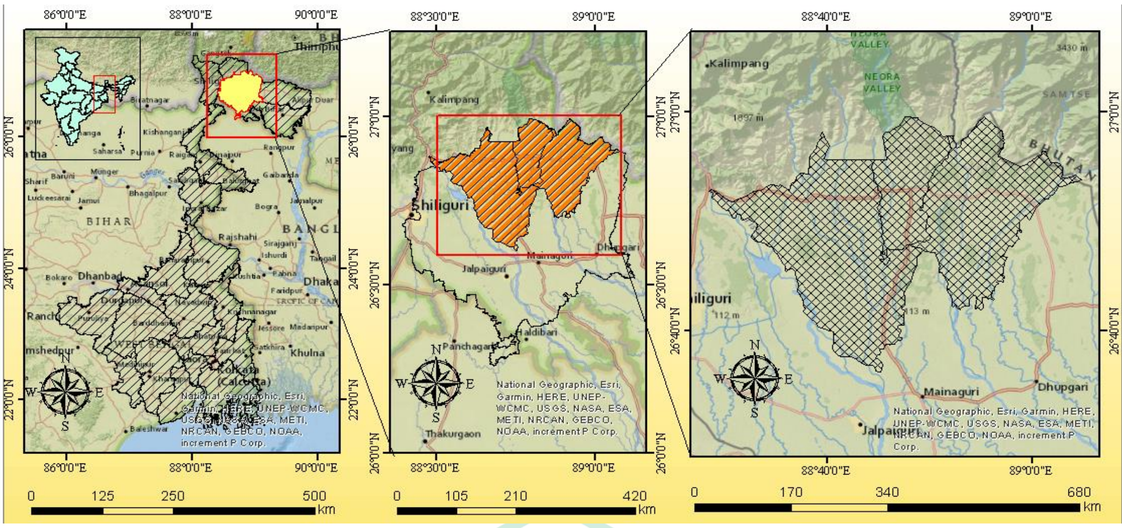


Fig.3. Selected Study Area

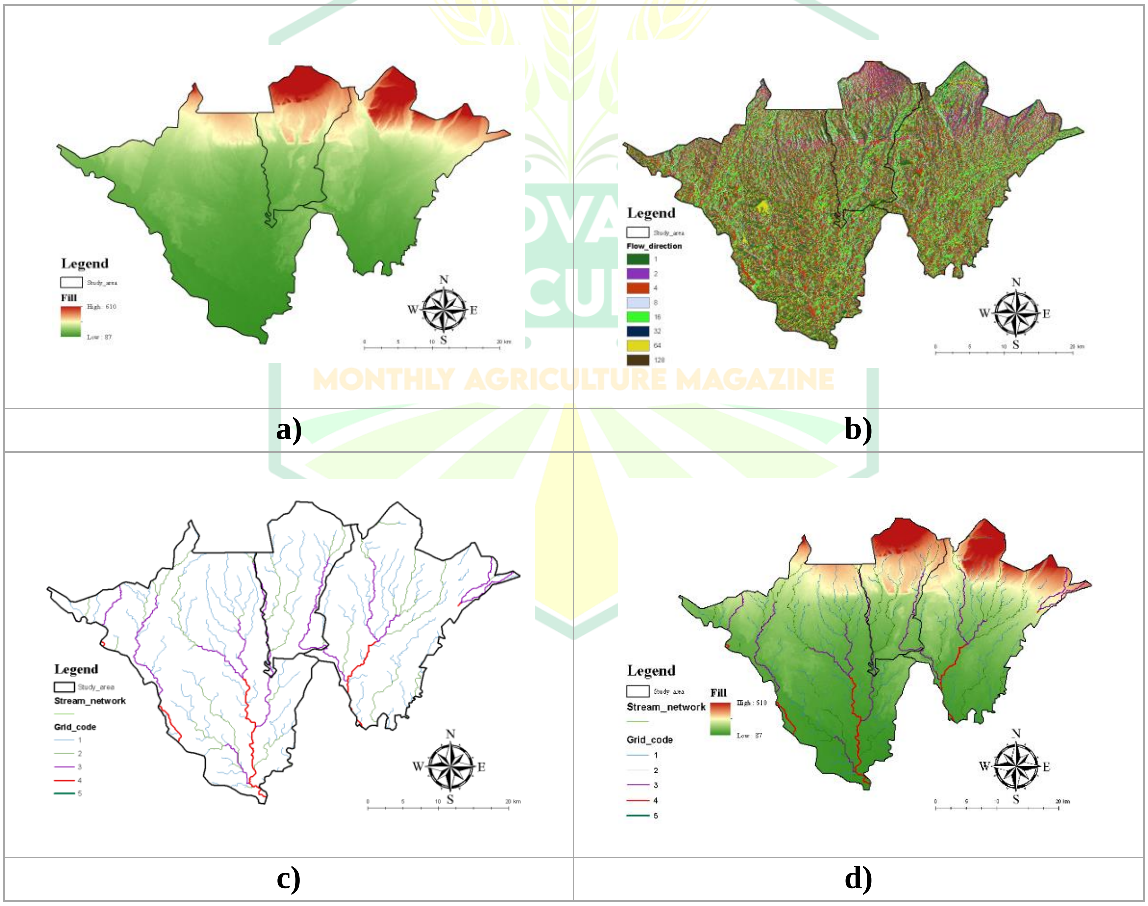


Fig.4. a) Fill, b) Flow direction, c) Stream order and d) Stream network of study area

we can now extract the stream network by applying the 'stream order' and 'stream feature' tools. The resulting stream network should be labelled, starting from the main stream down to the smaller tributaries. This involves assigning grid codes to the previously accumulated raster and arranging the streams in order from the widest (highest flow) to the narrowest, based on their accumulated flow values. Finally, we can visualize the complete stream network of the study area, including its flow characteristics, water distribution pattern, and the overall structure of the main and sub-streams across the experimental zones.

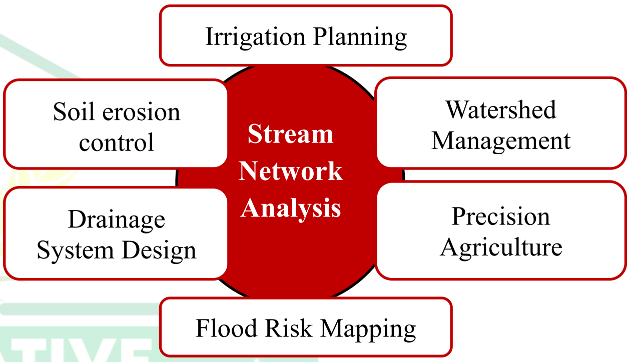
Result

By this technique a complete stream network and water distributional map of any area can be gained. This map will indicate the possible flow accumulation at any point of study area and its distance from any effective stream flows also. As an example, we have taken a portion of Jalpaiguri district of West Bengal as a study area, has explored the hydrological map using SRTM imagery and GIS software.

Now according to the methodology, after downloading the DEM data set from USGS software we have fill the raster, extract the flow directions, flow accumulation and ultimately the stream order or stream network. The resulted output has given at Fig.3.

Relative Impact in Agriculture

Mapping and analyzing the stream network within agricultural landscapes is essential for sustainable water resource management and optimized land use. By understanding the natural flow paths of water, farmers and land planners can make informed decisions regarding the placement of irrigation channels, drainage systems, and soil conservation structures. This knowledge helps reduce waterlogging in low-lying fields, minimizes runoff and soil erosion in sloped areas, and ensures efficient water use across the farm (Ghayoumian et al., 2007). Furthermore, the stream network supports precision agriculture techniques by identifying areas that may require varied input application—such as fertilizers or pesticides—based on how water accumulates and moves through the land (Mulla, 2013). Proper stream flow analysis also allows for effective watershed management by delineating zones that contribute to downstream pollution or sedimentation, thereby encouraging environmentally responsible farming practices (Jain & Das, 2010). Overall, integrating hydrological stream network data into agricultural planning enhances productivity, preserves soil health, and supports long-term sustainability of the ecosystem.



Conclusion

Understanding and mapping stream networks through DEM and GIS tools offers invaluable insight into the natural movement of water across agricultural landscapes. This approach not only aids in efficient irrigation and erosion control but also supports sustainable land use planning. By integrating flow direction and accumulation data, farmers can make informed decisions that enhance productivity while preserving natural resources. The combination of hydrological analysis and agricultural planning ensures long-term environmental and economic benefits. Ultimately, it empowers land managers to work in harmony with the landscape rather than against it.

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Stubble Burning in Punjab: Challenges and Potential Solutions

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As the Kharif harvesting season begins, Punjab and Haryana face the ongoing issue of stubble burning. Due to management challenges, many farmers continue to burn crop wastes even though the government has advised them to handle them on-site. Farmers are receptive to alternatives as they grow more conscious of the negative effects stubble burning has on their health and the environment. Small-scale farmers are most impacted by the exorbitant prices and restricted supply of necessary equipment, such as mulchers and happy seeders. The Pusa Bio Decomposer is a good choice because it can turn leftover straw into manure for plant growth.

Keywords: Stubble burning**,** sustainable agriculture, Pusa Bio Decomposer, government initiatives,

Introduction:

The entire area of Punjab devoted to rice farming is over 2646000 hectares. In addition to stubble burning, paddy farming is a major contributor to the region's groundwater depletion. Setting agricultural remains on fire in order to prepare fields for the following planting is known as stubble burning. In regions that use combination harvesting techniques, this technique is frequently employed. The quickest and least expensive way. An official assessment states that the nation produces around 500 million tonnes of parali (agricultural residues) a year, of which 70 percent comes from cereal crops like rice, wheat, maize, and millets. The majority of this residue is burned on fields, with rice accounting for 34% and wheat for 22%. About 80 percent of the 20 million tonnes of rice stubble produced annually in Punjab alone is burned. In Punjab, burning paddy straw has several detrimental effects on the environment and human health, especially as farmers use this technique to swiftly. In this article, we will discuss how stubble burning affects the environment and soil health, as well as explore alternative methods to address these challenges for future conservation efforts.

Fundamental Reason for the Occurrence of Stubble Burning

It is anticipated that the 25.81 lakh hectares of Punjabi farmland planted with non-basmati paddy this year will have produced 16 million tonnes of residue. Farmers find it difficult to control a significant amount of stubble, which leads them to start fires. The most likely causes of stubble burning in Punjab are as follows:

A. **Lack of period between two successive crops:**Because farmers have little time to prepare their fields for the following planting cycle and because there is usually only a two- to three-week gap between harvesting rice and planting wheat, they burn stubble. The wheat crop may suffer from any postponement in the planting process. The desire for short-duration two-paddy rice cultivars is being driven by the government. The increase in acreage of short-duration varieties, which went from 32.6% in 2012 to 69.8% in 2021, In 2022, nearly 66 per cent of surveyed farmers grew short-duration Parmal Rice (PR) varieties.

B. **Unlikely for cattle:** Because of its low protein level (2–7%) and higher silica and lignocellulose content, rice straw is not

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recommended as cattle feed in the northern regions. This eliminates the possibility of transporting rice straw to the dairy. However, due to its excellent palatability, cattle seem to prefer basmati rice fodder.

C. **Lack of awareness:** Farmers might not be aware that burning stubble has detrimental consequences on the environment and human health. Through community engagement and peer-to-peer interactions, stakeholders like Krishi Vigyan Kendras (KVKs), NGOs, and model farmers can help dispel myths by educating the public and offering training on efficient crop residue management (CRM) techniques.Send out yearly CRM program updates to make sure farmers are promptly notified of the benefits that are available. Make the CRM campaign more.

Stubble Burning in Punjab has Many Negative Effects on the Environment, Human Health, and Soil Fertility

Effect on Environment: releases toxic chemicals into the environment, including methane, carbon monoxide, nitrogen dioxide, and sulfur dioxide.These gasses can produce smog and a poisonous atmosphere that are harmful to people's health.Just 20% of the organic and elemental carbon in the northwest region of India comes from burning residue, which accounts for the whole national budget of pollution caused by burning agricultural waste. It was discovered that burning rice and wheat straw produced CO2, CO, N2O, and NOX emissions of roughly 2.306. The air is polluted by toxic gases and particles (PM) that are emitted from agricultural remnants that contain 100% carbon, 80–90% nitrogen, 25% phosphorus, 20% potassium, and 50% sulfur. The Central Pollution Control Board (2014) states that the air quality index, or AQI, is a scale of 0-500 categorical measures of pollution levels that aid in explaining the condition of the air in each location. The majority of Northern India has beyond the AQI level, which is dangerous for the atmosphere, particularly during the months when burning is at its worst.

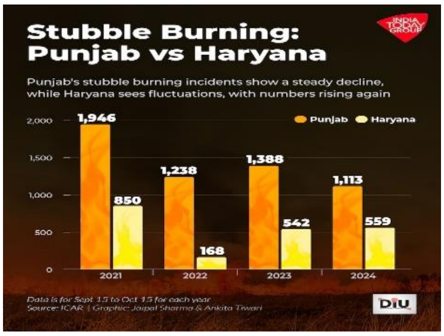
Soil degradation The heat from burning paddy straw penetrates 1 centimeter into the soil, raising the temperature to 33.8 to 42.2 degrees Celsius, killing the bacterial and fungal populations essential for a fertile soil. One tonne of stubble burning, according to a report, results in the loss of 5.5 kilograms of nitrogen, 2.3 kilograms of phosphorus, 25 kilograms of potassium, and more than 1 kilogram of sulfur—all soil nutrients, aside from organic carbon. It also reduces the amount of nutrients in the soil, making it less fertile.

a. **Health effects** Burning stubble can cause coughing and wheezing, as well as irritation of the eyes, nose, and throat.Additionally, it can worsen heart problems and asthma and impair lung function.These pollutants spread throughout the environment after being released into the atmosphere, where they may change chemically and physically before having a negative impact on human health. 18.0% of respondents experienced wheezing, and 41.6% reported coughing or an increase in coughing.

b. **Economic impact** People in rural Punjab spend an estimated Rs 7.6 crore each year on treatment for ailments caused by stubble burning.

Alternatives of Burning Stubble

Over the past four years, Punjab has made strides in reducing stubble burning. From September 15 to October 15, 2021, 1,946 fire incidents were reported in the state. In 2022, it fell to 1,238. With 1,388 instances in 2023, this downward trend persisted, and in 2024, it dropped to 1,113 cases. Over the course of four years, that is a 42.8%



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decrease. Incidents of stubble burning are somewhat declining, but resolving them necessitates comprehending the intricate obstacles that farmers continue to encounter.

Bio Enzyme-PUSA Decomposer: This microbial spray aids in the quick breakdown of crop residues, preparing the ground for the following crop. Researchers from Delhi, India's Indian Agricultural Research Institute (IARI) created it. It is made with fungal strains and comes in capsule form (one package contains four capsules). Microorganisms flourish in temperatures between 30 and 32 degrees Celsius, which are common during paddy harvest. The crucial enzymes that cause agricultural leftovers to decompose more quickly than usual are synthesized by fungal activity. These Recently, Delhi Government has taken the initiative to use it and also suggested other states to adopt it.

Stepwise Procedure to Make Pusa Bio Decomposer Capsule

After adding five liters of water to 150 grams of jaggary, Bring the jaggary to a vigorous boil, then use a sieve to remove any remaining dirt. In a deep square tray or tub, cool the jaggary solution until it is just beginning to warm up, and then Mix in 50g of besan. Break apart four capsules and combine them well. Keep in a warm location and cover with a thin cloth. It will begin to grow in two days. A multicolored mat will be set up. Mix well after ten days, then add one ton of garbage. After the culture has fully grown, you can add five more liters of good medium, mix it.When composting is complete, say 100 kg of compost is ready, take 20 kilogram and mix it with the remaining 100 kg to make another batch. Continue doing this until you receive compost in the same amount of time as the first step. Accordingly, if your compost is ready in 90 days, continue mixing compost starter until it is, but if it takes longer than 90 days, please add fresh compost inoculum.

Dosage: 5 litres -1 ton of agri-waste and 10 litres/acres for paddy field.

Benefits: Because the stubble serves as compost and manure for the crops and reduces the need for fertilizer later on, the decomposer increases the soil's fertility and production. This method of preventing stubble fire is practical, affordable, and efficient. It is an environmentally beneficial and eco-friendly technology that will help fulfill the Swachh Bharat Mission.

a) Palletisation

Drying and turning paddy straw into pellets allows it to be combined with coal for use as fuel in thermal power plants and other industries. This can lower carbon emissions and conserve coal. Approximately 32 million tonnes of stubble and straw are produced jointly by Punjab and Haryana. Of this, just 1.5 million come from Punjab and are used to generate energy. The government and farmers will benefit if more of this stubble can be used in biomass-based power generation facilities and waste-to-energy facilities.

b) Chhattisgarh Innovative Mode

Compost can be made by combining enzymes, animal excrement, and paddy straw. The government of Chhattisgarh has launched an inventive project that entails the installation of gutans. Each town has five-acre plots known as Gauthans, where leftover stubble, or parali, is gathered through donations from the public (parali daan) and converted into organic fertilizer by combining cow manure with natural enzymes.

Manage Crop Residues Effectively by Employing Agricultural Machines Like:

1. **Turbo Happy Seeder (THS)** which is a tractor-mounted device that can drill wheat seeds into freshly cleared soil in addition to cutting and uprooting stubble. In order to

create a mulch cover, the straw is poured over the seeds at the same time.

2. **Happy Seeder**(sowing of crop in standing stubble), **Rotavator** (land preparation and incorporation of crop stubble in the soil).
3. **Zero till seed drill** (land preparations directly sowing of seeds in the previous crop stubble).
4. **Baler** (collection of straw and making bales of the paddy stubble).
5. **Paddy Straw Chopper** (cutting of paddy stubble for easily mixing with the soil).
6. **Reaper Binder** (harvesting paddy stubble and making into bundles).However,these devices are excessively expensive, and state governments ought to step up and offer stronger subsidies so that farmers can purchase them. According to former Agriculture Minister Radha Mohan Singh, the government is subsidizing crop residue management equipment at a rate of 50–80%.Under this initiative, states like Punjab, Haryana, Uttar Pradesh, and the National Capital Region will receive a two-year allocation of Rs 1,151.80 crore.

Government Initiatives

A Rs 1,151-crore plan to provide subsidized THS equipment and encourage in-situ management of agricultural residue was authorized by the Center in March. After their applications are approved, consumers are expected to submit the reduced price amount with the agriculture department. Punjab has planned 30 paddy stump-based power plants, the most of which would be located in the state's paddy-growing regions. These seven facilities, which have a combined 62.5 megawatt generation capacity, will use 44 lakh tonnes of paddy stubble.

Punjab has taken Several Initiatives to Reduce Stubble Burning, Including

The Punjab government prohibits the burning of agricultural residue. Violating this prohibition can result in a criminal complaint under the Air (Prevention & Control of Pollution) Act, 1981. **Penalties** In order to protect the parali (crop residue), the state government has not implemented the National Policy for Management of Crop Residues. On December 10, 2015, the National Green Tribunal (NGT) banned burning crop residue in the states of Rajasthan, Uttar Pradesh, Haryana, and Punjab. Burning crop residue is illegal under Section 188 of the IPC and the Air and Pollution Control Act of 1981. The Commission for Air Quality Management (CAQM) Act of 2021 imposes fines for stubble burning; the fines are Rs 5,000 for farmers with less than

The Delhi high court had also ordered against burning residues, while Punjab government imposed a penalty of Rs 73.2 lakh farmers in 2016 for burning of crop residue. Although the actual number of fines charged was not available; farmers continue to burn residues every season — this making both the soil and air poisonous.

Crop Residue Management Loan Scheme: The **state launched an app** called i-khet to help farmers rent farm machinery.Crop Residue Management (CRM) machines are given to farmers at a 50–80% subsidy under this scheme. **Short-duration paddy varieties** are promoted to help extend the window for stubble management, and the state offers financial incentives to industries to create a **market for biomass. Custom Hiring Centers (CHCs)** are established to help small and **marginal farmers access** CRM machinery, and **the state appointed approximately 8,000 nodal officers** in villages to check stubble burning in 2020. Information, Education, and Communication (IEC) activities are

Challenges

Only roughly 500 THS computers were supplied to end users who had paid the relevant discounted rates, despite the Punjab government's goal of supplying 25,000 devices. Due to purchasers, particularly farmers, not depositing even subsidized price money, deliveries are occurring slowly.

Conclusion

Due to its detrimental consequences on the environment and human life, stubble burning has been one of the most contentious topics in recent years. One of the main causes of stable burning in India is a lack of time between the harvest of the rice crop and the planting of the next wheat crop. For this reason, the government and agricultural universities frequently advise farmers to plant rice crops in nurseries ten days earlier than they have in the past. There are many alternatives available to farmers for handling straw. One of the best technologies that.In order to protect the planet from harm caused by stubble burning, farmers are now responsible for managing their agricultural leftovers in any of the aforementioned methods other than burning.

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CARBON SEQUESTRATION BENEATH THE WAVES

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Carbon sequestration, the long-term storage of carbon in various reservoirs, is a fundamental strategy for mitigating climate change. While terrestrial ecosystems have historically received much of the attention in carbon studies, marine ecosystems are emerging as critical carbon sinks. The term "blue carbon" encapsulates the carbon sequestered in marine and coastal ecosystems such as mangroves, seagrasses, salt marshes, and macroalgae. These ecosystems, although occupying a small fraction of Earth's surface, contribute significantly to global carbon storage due to their rapid carbon uptake and efficient burial processes. This paper explores the mechanisms of carbon capture in marine ecosystems, highlights the substantial role of macroalgae and algae-driven carbon pumps, and emphasizes the importance of conserving blue carbon ecosystems for sustainable climate change mitigation. Through reviewing scientific literature and integrating ecological insights, this paper underlines both the potential and the pressing need to prioritize marine carbon sequestration in global environmental strategies.

Keywords: Carbon Sequestration, Blue Carbon, Marine Ecosystems, Macroalgae, Seagrass Meadows, Salt Marshes, Mangroves, Biological Pump, Algae, Climate Change Mitigation

1. Introduction

Anthropogenic climate change, primarily driven by greenhouse gas emissions such as carbon dioxide (CO_2), is one of the greatest environmental challenges of our time. Over the past two centuries, atmospheric CO_2 concentrations have increased drastically, mainly due to industrial activities, deforestation, and fossil fuel combustion. This rising carbon load in the atmosphere intensifies global warming and ocean acidification, leading to catastrophic impacts on ecosystems and human societies. Carbon sequestration — the process of capturing and storing atmospheric CO_2 — is increasingly being recognized as a viable mitigation tool. While forests and soils are traditionally highlighted for their sequestration capabilities, marine ecosystems have recently gained attention for their unique and powerful role in long-term carbon storage. Marine ecosystems offer a multifaceted approach to carbon capture. Unlike terrestrial systems that store carbon primarily in biomass and soil, marine systems capture carbon both in biomass and in deep sediments or waters, often with more permanence and resilience. Coastal vegetative habitats, commonly referred to as blue carbon ecosystems, such as mangroves, seagrasses, and salt marshes, are among the most effective natural systems for sequestering carbon per unit area. The role of macroalgae, although underrepresented in earlier research, is now emerging as a critical factor in understanding marine carbon dynamics. Moreover, microalgae contribute to the "biological pump," a mechanism that transfers surface carbon to deep ocean waters, thus maintaining global carbon balance.

This paper provides a comprehensive analysis of marine carbon sequestration, focusing on ecosystem processes, potential contributions, and future research needs.

2. Carbon Sequestration: A Conceptual Overview

Carbon sequestration refers to the long-term storage of carbon in plants, soils, geologic formations, and the ocean. It can be categorized into:

- **Terrestrial sequestration** – in forests, wetlands, and soils.
- **Geologic sequestration** – in underground rock formations.
- **Oceanic sequestration** – in the form of blue carbon.

The process reduces the amount of CO_2 in the atmosphere, slowing the pace of global climate change. It occurs naturally and can be enhanced through artificial or managed strategies.

3. Blue Carbon: Definition and Ecosystem Scope

Blue carbon refers to the carbon captured and stored by oceanic and coastal ecosystems. The primary blue carbon habitats include:

- **Mangrove forests**
- **Seagrass meadows**
- **Salt marshes**
- **Macroalgae beds**

These ecosystems play a dual role by:

- Acting as carbon sinks via photosynthesis and organic carbon burial.
- Offering resilience to climate effects like sea-level rise and coastal erosion.

Despite covering less than 2% of the ocean area, these habitats store more than 50% of oceanic carbon.

4. Role of Macroalgae in Marine Carbon Sequestration

4.1. Overview

Macroalgae, including kelp and seaweeds, are dominant coastal autotrophs that were long overlooked in marine carbon models due to their limited direct carbon burial. However, recent evidence indicates their carbon is often transported offshore, contributing to long-term sequestration in deep-sea sediments.

4.2. Mechanisms of Sequestration

Krause-Jensen et al. (2016) identified two main pathways:

- **Submarine canyons** transport detached algae to the deep ocean.
- **Negative buoyancy** causes direct sinking of algae to sediment layers.

Certain study estimated that macroalgae could contribute significantly—potentially comparable to seagrasses and mangroves—in global carbon storage when indirect sequestration is accounted for.

4.3. Challenges in Measurement

Macroalgal sequestration is less straightforward to quantify due to:

- Offshore transport variability
- Lack of root structures for sediment entrapment
- Difficulties in tracking detached biomass

Despite these, macroalgae are now being increasingly recognized for their biosequestration potential.

5. Carbon Sequestration by Coastal Marine Habitats

5.1. Mangrove Ecosystems

Mangroves store carbon in:

- Biomass (above and below ground)
- Peat-rich sediments

They can sequester up to **174 g C m^{-2} yr^{-1}**, with long-term carbon burial lasting for millennia due to anoxic conditions.

5.2. Seagrass Meadows

Seagrasses trap sediments and organic carbon. Kennedy et al. (2010) showed that **seagrass sediments** have an average carbon burial rate of **83 g C m^{-2} yr^{-1}**.

Seagrasses also export organic material to deep-sea environments, enhancing their sequestration footprint.

5.3. Salt Marshes

Salt marshes, dominated by halophytic grasses, sequester carbon by accumulating plant detritus in anaerobic sediments. Their carbon burial rate is estimated at **218 g C m^{-2} yr^{-1}**, among the highest of any ecosystem.

6. The Biological Carbon Pump in Algal Ecosystems

6.1. Algal Contribution to Global Carbon Cycle

Algae are highly efficient in converting CO_2 into organic matter via photosynthesis. Despite representing less than 1% of the photosynthetic biomass, they produce nearly 50% of Earth's oxygen.

6.2. Mechanisms of Algal Sequestration

Two key mechanisms define the biological carbon pump:

- **Organic Carbon Pump**: Transfers photosynthetic carbon to deep ocean layers via dead biomass and fecal pellets.
- **Calcium Carbonate Pump**: Operated by calcifying algae like coccolithophores, it affects carbon flux and ocean chemistry.

Sengupta et al. (2017) emphasized that algae are central to natural CO_2 sequestration and form a critical element of aquatic carbon cycling.

7. Seagrass Sediments as a Global Carbon Sink

7.1. Global Importance

Seagrasses are now being recognized as a global carbon sink. However, accurate estimation is challenged by:

- Limited mapping of global seagrass cover
- Variability in species and regional conditions

7.2. Data Limitations and Knowledge Gaps

Most sequestration estimates are derived from Mediterranean species like *Posidonia oceanica*, limiting generalizability. Kennedy et al. (2010) urged a more global approach to determine carbon burial rates and lateral transport effects.

8. Climate Implications and Carbon Dynamics

8.1. Ocean-Atmosphere Carbon Exchange

The ocean absorbs roughly 25% of anthropogenic CO_2 emissions annually. However, increased uptake leads to:

- **Ocean acidification**
- **Altered marine food webs**
- **Decreased carbonate availability for shell-forming organisms**

8.2. Future Climate Scenarios

Failure to protect marine carbon sinks can accelerate climate feedback loops. Conversely, enhancing their capacity may buffer global warming effects.

9. Conservation and Policy Integration

9.1. Ecosystem Threats

Marine carbon sinks are threatened by:

- Coastal development
- Pollution
- Overfishing
- Climate change-induced sea level rise

9.2. Policy Recommendations

- Integrate blue carbon into national climate strategies
- Protect and restore degraded marine habitats
- Promote community-based conservation of coastal ecosystems
- Fund long-term carbon monitoring programs

9.3. International Efforts

Programs like the Blue Carbon Initiative, UNFCCC REDD+, and Ramsar Convention now emphasize marine ecosystem conservation as a climate action tool.

10. Conclusion

Marine ecosystems offer an indispensable, natural solution to carbon sequestration. Mangroves, seagrasses, salt marshes, and macroalgae-rich areas serve as potent carbon sinks, collectively storing millions of tons of CO_2 annually. Algae-driven biological pumps further enhance deep ocean sequestration, reinforcing the global carbon balance. Despite these ecological services, marine carbon sinks are under threat and remain underrepresented in climate policy. Advancing scientific understanding and integrating marine systems into mitigation strategies is essential. Protection, restoration, and sustainable management of blue carbon habitats can significantly contribute to achieving climate goals while maintaining biodiversity and coastal resilience. Prioritizing marine carbon sequestration is no longer an option—it is a necessity for a sustainable climate future.

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Mussel Culture in India: Green and Brown Mussel Cultivation

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Mussel farming has emerged as a sustainable aquaculture practice, particularly in coastal regions of India. The green mussel (*Perna viridis*) and brown mussel (*Perna indica*) are two prominent species cultivated for their nutritional value and economic significance. This article provides a comprehensive overview of mussel culture, focusing on species characteristics, farming techniques, environmental considerations, and socio-economic impacts. Emphasis is placed on practices in Kerala, India, where mussel farming has flourished due to favorable environmental conditions and community engagement.

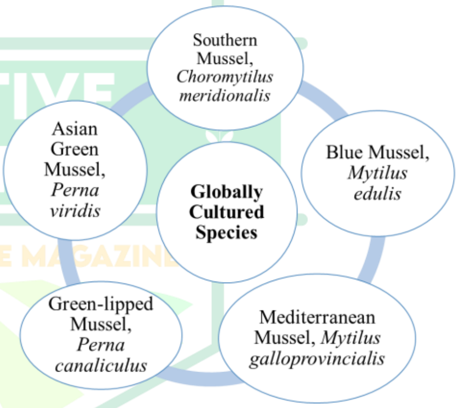
Keywords: Green mussel, Brown mussel, Mussel farming, Sustainable aquaculture

Introduction

In the wild, mussels are predominantly found in the littoral zone, attaching clusters to various substrates. As filter feeders of phytoplankton and detritus, mussels are regarded as the most efficient converters of nutrients and organic matter produced by marine organisms in aquatic ecosystems into palatable and nutritious animal protein. Their exceptionally short food chain, resilient nature, rapid growth rate, and low incidence of catastrophic mass mortalities caused by parasitic microorganisms enable large-scale production at a relatively low cost (Korringa, 1976). Additionally, their ability to adhere to substrates via byssal threads makes them an ideal species for aquaculture, adaptable to diverse culture systems.

Mussels are bivalve mollusks that play a crucial role in marine ecosystems by filtering water and contributing to the biodiversity of coastal habitats. In India, mussel farming has become an alternative livelihood for coastal communities, offering economic benefits and promoting sustainable aquaculture practices. The green mussel (*P. viridis*) and brown mussel (*P. indica*) are the primary species cultivated, each with distinct ecological and economic characteristics. Mussel culture is the most productive form of saltwater aquaculture and its proliferation is virtually a certainty (Bardach *et al.*, 1974).

1. Major Species of Mussel Cultured



Source: FAO, 2022; Gosling, 2003

2. Mussel Cultured in India

2.1. Green Mussel (*Perna viridis*)

The green mussel is characterized by its greenish shell and is widely distributed along the coasts of India, particularly in Kerala. It thrives in estuarine and marine environments with salinity ranging from 27 to 35 ppt and water temperatures between 26°C and 32°C. Green mussels are filter feeders, relying on phytoplankton and organic particles for nutrition. They exhibit rapid growth, reaching harvestable size in approximately 4 to 6 months under optimal conditions (Newell *et al.*, 2021).

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Fig. 1 Green Mussel (*Perna viridis*)
(Source: NFDB, 2022; CMFRI, 2023)

2.2. Brown Mussel (*P. indica*)

Brown mussel, originally identified as *Perna indica*, is a marine bivalve now recognized as *Perna perna* (Gardner *et al.*, 2016). Its uniformly brown, elongate shell features a pointed anterior and robust byssus threads anchoring it to rocky coastal substrates. Thriving in intertidal and shallow subtidal zones, it spawns externally during warm months, undergoing rapid larval development (Singh, 1981). Economically, it supplies vital protein and supports local fisheries, while ecologically, it competes with native species. Advances in aquaculture enable controlled spawning and sustainable cultivation. These insights drive future multidisciplinary coastal studies. Recent investigations consistently highlight its rising economic role and significant ecological influence along global, dynamic coastlines (Singh, 1981).

Fig. 2 Brown Mussel (*P. indica*)
(Source: NFDB, 2022; CMFRI, 2023)

3. Culture Techniques

The process begins with meticulous site selection. Ideal areas are coastal or estuarine regions with clear waters, moderate currents (approximately 0.17- 0.35 m/s), salinity between 27-35 ppt, and temperatures ranging from 26°C to 32°C. These conditions support a rich concentration of phytoplankton (17- 40 µg/l chlorophyll) that fuels rapid growth (Lagan, 2013).

There are two dominant culture techniques: bottom culture and suspended culture.

3.1 Bottom Culture (Broadcast Method)

In this traditional approach, spat (larval mussels) naturally settle on prepared substrates laid on the seabed. Materials such as laminated shells or synthetic substrates are provided to boost settlement. Once these juveniles reach a seeding size, they are directly harvested from the sea bottom. This method is particularly suitable for shallow, intertidal zones that experience minimal sedimentation. Although bottom culture is cost-effective, it can be vulnerable to environmental disturbances and predation, necessitating careful management of the surrounding habitat (Aypa, 1980; Lagan, 2013).

3.2 Suspended Culture Techniques

To overcome some of the limitations of bottom culture, suspended systems are widely used. These include:

1. **Long line systems:** Ropes or nets are suspended from rafts or floating frames in deeper waters. The collectors, fitted with appropriate settlement substrates, ensure that mussels have constant access to nutrient-rich water. Regular cleaning of the lines minimizes the build-up of sediment and biofouling, which can otherwise inhibit growth.

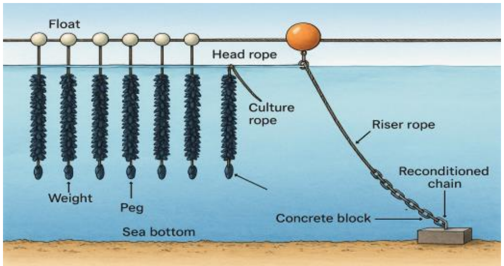

Fig. 3 Long line method of mussel culture

2. **Raft culture:** This method uses a stable raft structure from which multiple long lines are deployed. Raft culture allows for organized spatial distribution and easy harvesting while reducing physical stress on the mussels and increasing flesh yield.
3. **Pole or Bouchol culture:** Borrowed from traditional European methods, this technique utilizes vertically placed poles (often made of robust materials like oak) in intertidal zones, with horizontal ropes attached for spat settlement. The poles are partly submerged, providing protection from predators such as crabs and benefiting from optimal light and water flow. This technique is adaptable and particularly useful where natural spat densities are high.

4. Spat Collection and Development

Spat collection is a critical step in both methods. Specialized collectors made from natural or synthetic materials are deployed in areas of high spat density during peak spawning periods. Mussel seeds (spat) naturally settle on hard surfaces from Jan – March. Collected using coir ropes, nylon nets, or seed collectors. Once the spat reaches a critical size, they are either left to develop further in situ or are transferred to more controlled, suspended systems for enhanced growth management. Farmers monitor key parameters such as water temperature, plankton concentration, and mussel density to optimize production and reduce losses. ICAR-CMFRI is set to establish the first mussel hatchery for *P. viridis* in the world for the State Government of Kerala. These management practices not only bolster yield but also help maintain balance within the coastal ecosystem (Han *et al*., 2024).

5. Economic Benefits and Livelihoods in Mussel Culture

Mussel aquaculture is a sustainable and economically dynamic industry that revitalizes coastal economies and enhances livelihoods by providing both direct employment through activities such as spat collection, maintenance, harvesting, and processing and indirect benefits via supportive sectors including boat building, equipment manufacturing, transportation, and marketing. Community based self-help groups, which frequently empower women as well as marginalized populations, harness mussel farming to generate stable income throughout the year and improve local infrastructure such as harbor facilities, cold storage, and processing plants, thereby mitigating the seasonal fluctuations inherent in traditional fisheries. Furthermore, the industry's low capital investment, efficient resource utilization, limited environmental footprint, and ongoing technological innovations not only ensure food security and bolster export potential but also drive significant regional development (Kumar, 2005).

6. Challenges in Mussel Culture (India)

Mussel culture in India faces multiple challenges that affect both production efficiency and the long term viability of the industry. One major challenge is disease incidence caused by various bacterial, viral, and parasitic agents that lower growth rates and elevate mortality rates in cultured green mussels (Parappurathu *et al*., 2021). Environmental factors such as fluctuating water quality in coastal backwater regions and estuaries also contribute significantly. For instance, sudden freshwater influx during the monsoon season may alter water salinity and temperature, thereby stressing mussel populations and predisposing them to infections (Silas, 1980). In addition, many cultivation sites suffer from infrastructural constraints and a limited transfer of modern technology.

6. Conclusion

Mussel farming is a sustainable, low-cost livelihood for coastal communities. Development of hatchery based seed supply, cold chain, depuration units, and value addition is crucial for consistent production and better returns. Promoting research, training, women's participation, eco-friendly practices, and improving quality and certifications can boost domestic growth and exports.

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Chickpea Production Technology: Advancing India's Pulse Potential

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Chickpeas, locally known as '***Chana***', are a vital pulse crop in India, underpinning food security, nutrition, and rural livelihoods. As the world's leading producer, contributing over 65% of global chickpea output, India cultivates this crop across states like Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, and Andhra Pradesh during the *rabi* season (October–March). Despite their significance, challenges such as climate variability, pest pressures, and low yields persist. Modern production technologies offer solutions to boost yields and sustainability. This article explores advanced chickpea cultivation practices, focusing on India's unique agricultural context, and provides practical guidance for farmers, researchers, and stakeholders.

Importance of Chickpeas in India

Chickpeas (*Cicer arietinum*) are a nutritional cornerstone, offering 18–24% protein, dietary fiber, and essential micronutrients like iron, zinc, and folate. They are a staple in Indian diets, used in dishes like *chole*, *dal*, and *besan*-based products such as snacks and flour. Beyond nutrition, chickpeas enhance soil fertility through nitrogen fixation, reducing the need for synthetic fertilizers and supporting sustainable farming.

India's chickpea yields average 0.8–1.2 tons per hectare (t/ha), compared to 1.5–2.0 t/ha in countries like Australia. With advancements in seed varieties, irrigation, and pest management, farmers can achieve yields of 1.5–2.6 t/ha, strengthening food security and economic returns. However, erratic weather, small landholdings, and market volatility pose challenges, necessitating innovative approaches.

Soil and Climate Requirements

Chickpeas thrive in well-drained loamy or sandy loam soils with a pH of 6.0–7.5. In India, they are grown in black cotton soils (vertisols) in central regions and alluvial soils in the north. The crop prefers moderate temperatures (15–30°C) and low humidity, making the *rabi* season ideal. Under optimal conditions, yields can reach 2.0–2.6 t/ha, but climate change—marked by rising temperatures and unpredictable rainfall—threatens productivity. Drought-tolerant varieties and efficient water management are critical for adaptation.

Land Preparation and Sowing Techniques

Land Preparation

Proper land preparation is essential for chickpea cultivation. Fields should be plowed 2–3 times to create a fine tilth, ensuring good seed-soil contact. Incorporating 5–10 t/ha of organic manure, such as farmyard manure or compost, improves soil fertility and structure. In rainfed areas, conservation tillage practices like zero-tillage or minimum-tillage are gaining traction, particularly in Rajasthan and Madhya Pradesh, to conserve moisture and reduce soil erosion.

Sowing Methods

Sowing from mid-October to early November aligns with favourable temperatures, maximizing yields up to 2.0 t/ha. Delayed sowing, often due to late monsoon withdrawal, can reduce yields by 15–25%. Modern sowing techniques include:

- **Line sowing**: Seed drills place seeds at 5–7 cm depth, with 30 cm row spacing and 10 cm plant spacing, enhancing germination and weed control.

- **Raised bed planting**: Improves drainage in waterlogged areas, increasing yields by 10–15%.
- **Precision planters**: GPS-guided tools, though less common, optimize seed placement, reducing seed rates (60–80 kg/ha for *desi*, 80–100 kg/ha for *kabuli*).

Seed treatment with fungicides like carbendazim (2 g/kg seed) or bioagents like *Trichoderma viride* (5 g/kg seed) protects against soil-borne pathogens.

Seed Selection and Varietal Improvements

High-quality seeds are the foundation of successful chickpea farming, enabling yields of 1.5–2.6 t/ha. Indian research institutions, including the Indian Institute of Pulses Research (IIPR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), have developed high-yielding, resilient varieties tailored to India's diverse agro-climatic zones. These varieties are classified into *desi* (small, dark seeds, 80–85% of production, used for traditional dishes and flour) and *kabuli* (large, cream-colored seeds, preferred for salads and exports). Notable varieties include:

1. **Pusa 362**: Yields 1.8–2.2 t/ha, resistant to Fusarium wilt.
2. **Pusa 372**: Early-maturing, yields 1.7–2.0 t/ha, suited for rainfed areas.
3. **JG 11**: Drought-tolerant, yields 1.6–2.0 t/ha, popular in southern India.
4. **Pusa 547**: Pod borer-resistant, yields 1.9–2.3 t/ha.
5. **Super Annigeri 1**: High-yielding *desi*, yields 1.8–2.1 t/ha, market-preferred.
6. **Pusa 1003**: *Kabuli*, yields 2.0–2.5 t/ha, ideal for exports.
7. **JG 14**: Drought-resistant, yields 1.5–1.9 t/ha, suitable for central India.
8. **DCP 92-3**: Wilt-resistant, yields 1.6–2.0 t/ha, grown in northern India.
9. **Vijay**: Early-maturing, yields 1.7–2.1 t/ha, adaptable to various soils.
10. **Pusa 1108**: *Kabuli*, yields 2.1–2.6 t/ha, resistant to Ascochyta blight.

Biotechnology, including marker-assisted breeding, has enhanced resistance to pests like pod borer (*Helicoverpa armigera*) and diseases like Fusarium wilt. Research into genetically modified chickpeas for drought tolerance is ongoing but not yet commercialized in India.

Nutrient Management

Chickpeas have moderate nutrient requirements, with nitrogen-fixing *Rhizobium* bacteria reducing the need for nitrogen fertilizers. A basal dose of 15–20 kg/ha nitrogen, 40–60 kg/ha phosphorus, and 20–30 kg/ha potassium supports early growth. Micronutrient deficiencies, prevalent in Indian soils, are addressed with:

- Zinc sulfate: 25 kg/ha as basal application or 0.5% foliar spray at flowering.
- Borax: 10 kg/ha as basal or 0.1% foliar spray to improve pod formation.

Integrated nutrient management, combining chemical fertilizers, organic manures, and biofertilizers like *Rhizobium* (10 g/kg seed) and phosphate-solubilizing bacteria, can increase yields by 15–20%.

Water Management and Irrigation

Most Indian chickpea crops are rainfed, relying on residual monsoon moisture. One or two irrigations at critical stages—pre-flowering (30–35 days) and pod-filling (60–70 days)—can boost yields from 0.8–1.2 t/ha to 1.5–2.0 t/ha. Over-irrigation risks root rot, so efficient systems are essential:

- **Drip irrigation**: Saves 30–50% water, ideal for arid regions like Rajasthan.
- **Sprinkler irrigation**: Ensures uniform water distribution, suitable for uneven terrains.
- **Mulching**: Crop residue or plastic mulches conserve moisture, increasing yields by 10–15%.

Pest and Disease Management

Chickpeas are susceptible to pests like pod borer (*Helicoverpa armigera*), aphids, and cutworms, and diseases like Fusarium wilt and Ascochyta blight, which can reduce yields by 20–40%.

Integrated Pest Management (IPM) combines multiple strategies:

- **Cultural Practices**: Crop rotation with cereals like wheat or intercropping with coriander disrupts pest and disease cycles.
- **Biological Control**: Releasing *Trichogramma* wasps (50,000/ha) targets pod borer eggs.
- **Chemical Control**:
  Insecticides:
  - Indoxacarb: 500 ml/ha at early podding for pod borer control.
  - Spinosad: 150 ml/ha for pod borer and aphid management.

  Fungicides:
  - Mancozeb: 2 kg/ha for Ascochyta blight control.
  - Carbendazim: 500 g/ha for Fusarium wilt management.
- **Resistant Varieties**: Varieties like Pusa 547 and Pusa 1108 reduce reliance on chemicals.

Weed Management

Weeds such as *Chenopodium album* (bathua) and *Cyperus rotundus* (nutgrass) can reduce yields by 30–40%. Effective weed control includes:

- **Pre-emergence herbicides**: Pendimethalin (1 kg/ha) applied within 2–3 days of sowing.
- **Mechanical weeding**: Hand weeding or hoeing at 20–30 days after sowing, common in smallholder farms.
- **Mulching**: Organic or plastic mulches suppress weeds and retain moisture, boosting yields by 10%.

Harvesting and Post-Harvest Management

Chickpeas are harvested at 100–120 days when pods dry and leaves turn yellow. Manual harvesting is common, but mechanized combine harvesters, used in larger farms, reduce losses by 5–10%. Yields range from 1.5–2.6 t/ha, depending on variety and management practices.

Post-Harvest Practices:

- **Threshing and Cleaning**: Mechanical threshers separate seeds, followed by winnowing to remove debris.
- **Storage**: Drying to 8–10% moisture content prevents fungal growth. Hermetic bags protect against storage pests like pulse beetle (*Callosobruchus chinensis*).
- **Grading**: Sorting by size and quality ensures better market prices, particularly for *kabuli* chickpeas.

Mechanization and Technology Adoption

Mechanization, including tractors, seed drills, and harvesters, enhances efficiency and reduces labor costs. Precision agriculture tools, such as soil moisture sensors and drone-based pest monitoring, are emerging in progressive states like Punjab and Haryana. Mobile apps like Kisan Suvidha and AgriApp provide real-time weather, market, and advisory services. The e-NAM platform connects farmers to markets, ensuring competitive prices for quality produce.

Challenges in Indian Chickpea Farming

Indian chickpea farmers face several challenges:

- **Climate Variability**: Droughts and heatwaves impact yields, particularly in rainfed areas (70% of production).
- **Small Landholdings**: Most farmers own less than 2 ha, limiting mechanization and economies of scale.
- **Market Fluctuations**: Price volatility affects profitability.
- **Knowledge Gaps**: Limited access to extension services hinders technology adoption.

Government initiatives like the National Food Security Mission (NFSM-Pulses) and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) provide subsidies for seeds, irrigation, and equipment, addressing these challenges.

Future Prospects and Innovations

The future of chickpea production in India lies in sustainable, technology-driven practices:

- **Climate-Resilient Varieties**: Developing chickpeas tolerant to drought, heat, and salinity, targeting yields of 2.5–3.0 t/ha.
- **Digital Agriculture**: Leveraging AI, IoT, and satellite imagery for crop monitoring and yield prediction.

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- **Value Addition**: Promoting processed products like chickpea protein isolates and ready-to-eat snacks.
- **Organic Farming**: Meeting growing demand for organic chickpeas in domestic and export markets.

Collaborations between IIPR, ICRISAT, and agribusinesses drive research and technology dissemination. India's export potential, particularly for *kabuli* chickpeas to markets like the UAE and Europe, offers significant economic opportunities.

Conclusion

Chickpea production in India is advancing through modern technologies and sustainable practices. By adopting high-yielding varieties, precision irrigation, integrated pest management, and mechanization, farmers can achieve yields of 1.5–2.6 t/ha, enhancing food security and livelihoods. With government support and ongoing research, chickpeas will continue to play a pivotal role in India's agricultural landscape, nourishing millions while promoting environmental sustainability.

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Mustard Cultivation Technology: Fueling India's Oilseed Economy

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Mustard, locally known as *sarson*, is a vital oilseed crop in India, supporting edible oil production, nutrition, and rural livelihoods. As one of the world's leading mustard producers, India cultivates this crop across states like Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, and Punjab during the *rabi* season (October–March). Despite its significance, challenges such as climate variability, pest pressures, and low yields persist. Modern production technologies are addressing these issues, enabling farmers to enhance productivity and sustainability. This article explores advanced mustard cultivation practices, focusing on India's unique agricultural context, and provides practical guidance for farmers, researchers, and stakeholders.

Importance of Mustard in India

Mustard (*Brassica juncea* for Indian mustard, *Brassica napus* for rapeseed) is a key oilseed crop, contributing to India's edible oil needs. Its seeds yield 35–45% oil, used in cooking, and the seed cake serves as animal feed. Mustard greens are consumed as *sarson ka saag*, a popular dish in northern India. Rich in healthy fats, protein (20–25%), and micronutrients like calcium and iron, mustard supports nutrition and food security.

India's mustard yields average 1.2–1.5 tons per hectare (t/ha), compared to 2.0–2.5 t/ha in countries like Canada. With advancements in seed varieties, irrigation, and pest management, farmers can achieve yields of 1.8–2.5 t/ha, bolstering the oilseed economy and farmer incomes. However, challenges like erratic weather, water scarcity, and market volatility necessitate innovative solutions.

Soil and Climate Requirements

Mustard thrives in well-drained loamy or sandy loam soils with a pH of 6.0–7.5. In India, it is grown in alluvial soils of the Indo-Gangetic plains (Uttar Pradesh, Haryana and Punjab), black cotton soils in central India (Madhya Pradesh), and sandy loams in Rajasthan. The crop prefers cool temperatures (10–25°C) and low humidity during the *rabi* season. Under optimal conditions, yields can reach 2.0–2.5 t/ha, but climate change—marked by heatwaves and unpredictable rainfall—threatens productivity. Drought-tolerant varieties and efficient water management are essential for adaptation.

Land Preparation and Sowing Techniques

Land Preparation

Proper land preparation is critical for mustard cultivation. Fields should be ploughed 2–3 times to create a fine tilth, ensuring good seed-soil contact. Incorporating 5–10 t/ha of organic manure, such as farmyard manure or compost, improves soil fertility and structure. In irrigated regions like Haryana, laser land levelling enhances water distribution and reduces runoff. In rainfed areas, particularly in Rajasthan, conservation tillage practices like zero-tillage or minimum-tillage conserve moisture and reduce soil erosion.

Sowing Methods

Sowing from mid-October to early November aligns with optimal temperatures, maximizing yields up to 2.0 t/ha. Delayed sowing, often due to late monsoon withdrawal, can reduce yields by 10–20%. Modern sowing techniques include:

- **Line sowing**: Seed drills place seeds at 3–4 cm depth, with 30–45 cm row spacing and 10–15 cm plant spacing, improving germination and weed control.
- **Ridge planting**: Enhances drainage in waterlogged areas, increasing yields by 10–15%.
- **Precision planters**: GPS-guided tools, used in progressive farms, optimize seed placement, reducing seed rates (4–5 kg/ha for most varieties).

Seed treatment with fungicides like metalaxyl (2 g/kg seed) or bio agents like *Trichoderma harzianum* (5 g/kg seed) protects against soil-borne pathogens like white rust.

Seed Selection and Varietal Improvements

High-quality seeds are the foundation of successful mustard farming, enabling yields of 1.8–2.5 t/ha. Indian research institutions, such as the Indian Agricultural Research Institute (IARI) and the Directorate of Rapeseed-Mustard Research (DRMR), have developed high-yielding, resilient varieties tailored to India's diverse agro-climatic zones. These varieties include Indian mustard (used for oil and greens) and rapeseed (used for oil). Notable varieties include:

1. **Pusa Bold**: Yields 2.0–2.4 t/ha, resistant to white rust, widely grown in northern India.
2. **Pusa Mustard 25**: Yields 1.8–2.2 t/ha, early-maturing, suitable for late sowing.
3. **NRCHB 101**: Yields 2.0–2.5 t/ha, resistant to Alternaria blight, popular in Rajasthan.
4. **RH 749**: Yields 2.1–2.5 t/ha, drought-tolerant, suited for rainfed areas.
5. **Pusa Vijay**: Yields 1.9–2.3 t/ha, resistant to aphids, grown in Haryana.
6. **Pusa Agrani**: Yields 1.8–2.2 t/ha, early-maturing, ideal for central India.
7. **Varuna**: Yields 1.8–2.3 t/ha, adaptable to diverse soils, widely grown.
8. **RGN 73**: Yields 2.0–2.4 t/ha, resistant to white rust, suited for irrigated areas.
9. **Giriraj**: Yields 2.1–2.5 t/ha, high oil content, popular in Uttar Pradesh.
10. **Pusa Mustard 30**: Yields 1.9–2.3 t/ha, resistant to Alternaria blight and aphids.

Biotechnology, including marker-assisted breeding, has enhanced resistance to diseases like white rust and pests like aphids. Research into genetically modified mustard, such as the Dhara Mustard Hybrid (DMH-11), is ongoing but not yet widely commercialized in India.

Nutrient Management

Mustard has moderate nutrient requirements. A basal dose of 60–80 kg/ha nitrogen, 40–60 kg/ha phosphorus, and 20–40 kg/ha potassium supports optimal growth. Nitrogen is applied in split doses: 50% at sowing and 50% at flowering (30–40 days). Sulphur, critical for oil content, is applied at 20–40 kg/ha. Micronutrient deficiencies, common in Indian soils, are addressed with:

- Boron: 1 kg/ha as basal application or 0.2% foliar spray at flowering.
- Zinc sulphate: 15 kg/ha as basal or 0.5% foliar spray to enhance seed formation.

Integrated nutrient management, combining chemical fertilizers, organic manures, and biofertilizers like *Azotobacter* (10 g/kg seed) and phosphate-solubilizing bacteria, can increase yields by 10–15%.

Water Management and Irrigation

Mustard is primarily rainfed in India, relying on residual monsoon moisture, but irrigated cultivation is common in Punjab and Haryana. One or two irrigations at critical stages—branching (30–40 days) and pod formation (60–70 days)—can boost yields from 1.2–1.5 t/ha to 1.8–2.2 t/ha. Over-irrigation risks fungal diseases, so efficient systems are vital:

- **Drip irrigation**: Saves 20–30% water, ideal for water-scarce regions like Rajasthan.
- **Sprinkler irrigation**: Ensures uniform water distribution, suitable for uneven terrains.
- **Mulching**: Crop residue or plastic mulches conserve moisture, increasing yields by 10–15%.

Pest and Disease Management

Mustard is susceptible to pests like aphids (*Lipaphis erysimi*), painted bugs, and mustard sawflies, and diseases like white rust (*Albugo candida*), Alternaria blight, and downy mildew, which can reduce yields by 15–30%. Integrated Pest Management (IPM) combines multiple strategies:

- **Cultural Practices**: Crop rotation with cereals like wheat or intercropping with chickpeas disrupts pest and disease cycles.
- **Biological Control**: Releasing ladybird beetles (5000/ha) targets aphids.
- **Chemical Control**:
  Insecticides:
  - Imidacloprid: 500 ml/ha at flowering for aphid control.
  - Malathion: 1 L/ha for painted bug and sawfly management.

  Fungicides:
  - Mancozeb: 2 kg/ha for Alternaria blight and downy mildew control.
  - Metalaxyl: 500 g/ha for white rust management.
- **Resistant Varieties**: Varieties like Pusa Bold and NRCHB 101 reduce chemical dependency.

Weed Management

Weeds like *Chenopodium album* (bathua) and *Anagallis arvensis* (blue pimpernel) can reduce yields by 20–40%. Effective weed control includes:

- **Pre-emergence herbicides**: Pendimethalin (1 kg/ha) applied within 2–3 days of sowing.
- **Post-emergence herbicides**: Quizalofop-ethyl (50 g/ha) at 20–25 days for grassy weeds.
- **Mechanical weeding**: Hand weeding or hoeing at 20–30 days, common in smallholder farms.

Harvesting and Post-Harvest Management

Mustard is harvested at 90–120 days when pods turn brown and seeds harden. Manual harvesting is common, but combine harvesters, used in larger farms in Punjab and Haryana, reduce losses by 5–10%. Yields range from 1.8–2.5 t/ha, depending on variety and management.

Post-Harvest Practices:

- **Threshing and Cleaning**: Mechanical threshers separate seeds, followed by winnowing to remove debris.
- **Storage**: Drying to 8–10% moisture content prevents fungal growth. Hermetic bags or silos protect against storage pests like *Rhyzopertha dominica* (lesser grain borer).
- **Grading**: Sorting by seed size and quality ensures better market prices, especially for high-oil-content seeds.

Mechanization and Technology Adoption

Mechanization, including tractors, seed drills, and combine harvesters, enhances efficiency and reduces labour costs. Precision agriculture tools, such as soil moisture sensors and drone-based pest monitoring, are emerging in states like Punjab and Haryana. Mobile apps like Kisan Suvidha and AgriApp provide real-time weather, market, and advisory services. The e-NAM platform connects farmers to markets, ensuring competitive prices for quality produce.

Challenges in Indian Mustard Farming

Indian mustard farmers face several challenges:

- **Climate Variability**: Heatwaves and erratic rainfall impact yields, particularly in rainfed areas (60% of production).
- **Water Scarcity**: Declining groundwater levels in Haryana and Punjab threaten irrigated farming.
- **Market Fluctuations**: Price volatility affects profitability.
- **Knowledge Gaps**: Limited access to extension services hinders technology adoption.

Government initiatives like the National Mission on Oilseeds and Oil Palm (NMOOP) and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) provide subsidies for seeds, irrigation, and equipment, addressing these challenges.

Future Prospects and Innovations

The future of mustard production in India lies in sustainable, technology-driven practices:

- **Climate-Resilient Varieties**: Developing mustard tolerant to heat, drought, and salinity, targeting yields of 2.5–3.0 t/ha.
- **Digital Agriculture**: Leveraging AI, IoT, and satellite imagery for crop monitoring and yield prediction.
- **Value Addition**: Promoting processed products like mustard oil, sauces, and seed meal for animal feed.
- **Organic Farming**: Meeting growing demand for organic mustard oil in domestic and export markets.

Collaborations between DRMR, IARI, and agribusinesses drive research and technology dissemination. India's export potential for mustard oil and seeds to markets like Southeast Asia and the Middle East offers significant economic opportunities.

Conclusion

Mustard production in India is advancing through modern technologies and sustainable practices. By adopting high-yielding varieties, precision irrigation, integrated pest management, and mechanization, farmers can achieve yields of 1.8–2.5 t/ha, enhancing the oilseed economy and livelihoods. With government support and ongoing research, mustard will continue to play a pivotal role in India's agricultural landscape, meeting nutritional and economic needs while promoting environmental sustainability.

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Wheat Cultivation Technology: Strengthening India's Food Security

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Wheat, known as *gehu* in India, is a cornerstone of the nation's agriculture, underpinning food security, nutrition, and rural livelihoods. As the world's second-largest wheat producer, contributing about 13% of global output, India cultivates this staple crop across states like Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, and Rajasthan during the *rabi* season (October–April). Despite its significance, challenges such as climate variability, pest pressures, and stagnating yields persist. Modern production technologies offer solutions to enhance productivity and sustainability. This article explores advanced wheat cultivation practices, focusing on India's unique agricultural context, and provides practical guidance for farmers, researchers, and stakeholders.

Importance of Wheat in India

Wheat (*Triticum aestivum* for bread wheat, *Triticum durum* for durum wheat) is a dietary mainstay, rich in carbohydrates (70–75%), protein (10–14%), and micronutrients like iron and zinc. It is used in staples like *roti*, *naan*, bread, and pasta, meeting the nutritional needs of millions. India's wheat yields average 3.0–3.5 tons per hectare (t/ha), compared to 7.0–8.0 t/ha in countries like China. With advancements in seed varieties, irrigation, and pest management, farmers can achieve yields of 4.0–5.5 t/ha, bolstering food security and farmer incomes. However, rising temperatures, water scarcity, and market fluctuations necessitate innovative approaches.

Soil and Climate Requirements

Wheat thrives in well-drained loamy soils with a pH of 6.0–7.5. In India, it is grown in alluvial soils of the Indo-Gangetic plains (Punjab, Haryana, Uttar Pradesh), black cotton soils in central India (Madhya Pradesh), and sandy loams in Rajasthan. The crop prefers cool temperatures (10–25°C) and low humidity during the *rabi* season. Under optimal conditions, yields can reach 4.5–5.5 t/ha, but climate change—marked by heatwaves and erratic rainfall—threatens productivity. Heat-tolerant varieties and efficient water management are critical for adaptation.

Land Preparation and Sowing Techniques

Land Preparation

Effective land preparation is essential for wheat cultivation. Fields should be plowed 2–3 times to achieve a fine tilth, ensuring good seed-soil contact. Incorporating 5–10 t/ha of organic manure, such as farmyard manure or compost, enhances soil fertility and structure. In irrigated regions like Punjab, laser land leveling improves water distribution and reduces runoff. In rainfed areas, conservation tillage practices like zero-tillage or minimum-tillage, popular in Haryana and Uttar Pradesh, conserve moisture and reduce soil erosion.

Sowing Methods

Sowing from late October to mid-November aligns with optimal temperatures, maximizing yields up to 4.5 t/ha. Delayed sowing, often due to late monsoon withdrawal, can reduce yields by 10–20%. Modern sowing techniques include:

- **Line sowing**: Seed drills place seeds at 4–6 cm depth, with 20–22 cm row spacing and 5–

7 cm plant spacing, improving germination and weed control.

- **Bed planting**: Enhances water use efficiency in irrigated areas, increasing yields by 10–15%.
- **Precision planters**: GPS-guided tools, used in progressive farms, optimize seed placement, reducing seed rates (100–120 kg/ha for most varieties).

Seed treatment with fungicides like carbendazim (2 g/kg seed) or bioagents like *Trichoderma harzianum* (5 g/kg seed) protects against soil-borne pathogens like root rot.

Seed Selection and Varietal Improvements

High-quality seeds are the foundation of successful wheat farming, enabling yields of 4.0–5.5 t/ha. Indian research institutions, such as the Indian Agricultural Research Institute (IARI) and the Directorate of Wheat Research (DWR), have developed high-yielding, resilient varieties tailored to India's diverse agro-climatic zones. These varieties include bread wheat (used for *chapati* and bread) and durum wheat (used for pasta and noodles). Notable varieties include:

1. **HD 2967**: Yields 4.5–5.0 t/ha, resistant to stripe rust, widely grown in northern India.
2. **HD 3086**: Yields 4.8–5.2 t/ha, heat-tolerant, suitable for late sowing.
3. **PBW 725**: Yields 4.7–5.3 t/ha, resistant to yellow rust, popular in Punjab.
4. **DBW 187**: Yields 4.9–5.5 t/ha, high-yielding, adaptable to irrigated areas.
5. **WH 1105**: Yields 4.5–5.0 t/ha, resistant to leaf rust, suited for central India.
6. **HI 1544**: Durum wheat, yields 4.0–4.8 t/ha, ideal for pasta production.
7. **PBW 660**: Yields 4.3–4.9 t/ha, drought-tolerant, suitable for rainfed areas.
8. **HD 3226**: Yields 4.8–5.3 t/ha, resistant to stripe and leaf rust.
9. **DBW 222**: Yields 5.0–5.5 t/ha, high-yielding, suited for irrigated plains.
10. **RAJ 3765**: Yields 4.0–4.7 t/ha, adaptable to rainfed conditions in Rajasthan.

Biotechnology, including marker-assisted breeding, has enhanced resistance to diseases like rust and pests like aphids. Research into genetically modified wheat for heat and drought tolerance is ongoing but not yet commercialized in India.

Nutrient Management

Wheat has moderate to high nutrient requirements. A basal dose of 120–150 kg/ha nitrogen, 60–80 kg/ha phosphorus, and 40–60 kg/ha potassium supports optimal growth. Nitrogen is applied in split doses: 50% at sowing, 25% at tillering (25–30 days), and 25% at flowering (50–60 days). Micronutrient deficiencies, common in Indian soils, are addressed with:

- Zinc sulfate: 25 kg/ha as basal application or 0.5% foliar spray at tillering.
- Manganese sulfate: 10 kg/ha as basal or 0.2% foliar spray to enhance grain filling.

Integrated nutrient management, combining chemical fertilizers, organic manures, and biofertilizers like *Azotobacter* (10 g/kg seed) and phosphate-solubilizing bacteria, can increase yields by 10–15%.

Water Management and Irrigation

Wheat in India is primarily irrigated, though rainfed cultivation occurs in parts of Rajasthan and Madhya Pradesh. Four to six irrigations at critical stages—crown root initiation (20–25 days), tillering (40–45 days), jointing (60–70 days), flowering (80–90 days), and grain filling (100–110 days)—can boost yields from 3.0–3.5 t/ha to 4.5–5.0 t/ha. Over-irrigation risks waterlogging, so efficient systems are vital:

- **Drip irrigation**: Saves 20–30% water, ideal for water-scarce regions like Rajasthan.
- **Sprinkler irrigation**: Ensures uniform water distribution, suitable for uneven terrains.
- **Check-basin irrigation**: Common in Punjab, optimizes water use in flat fields.

Pest and Disease Management

Wheat is susceptible to pests like aphids, termites, and shoot flies, and diseases like stripe rust, leaf rust, and powdery mildew, which can reduce yields by 15–30%. Integrated Pest

Management (IPM) combines multiple strategies:

- **Cultural Practices**: Crop rotation with pulses like chickpeas or mustard breaks pest and disease cycles.
- **Biological Control**: Releasing ladybird beetles (5000/ha) targets aphids.
- **Chemical Control**:

  Insecticides:
  - Imidacloprid: 500 ml/ha at tillering for aphid control.
  - Chlorpyrifos: 1 L/ha for termite management.

  Fungicides:
  - Propiconazole: 500 ml/ha for stripe and leaf rust control.
  - Tebuconazole: 500 ml/ha for powdery mildew management.
- **Resistant Varieties**: Varieties like HD 3086 and DBW 187 reduce chemical dependency.

Weed Management

Weeds like *Phalaris minor* (gullidanda) and *Chenopodium album* (bathua) can reduce yields by 20–40%. Effective weed control includes:

- **Pre-emergence herbicides**: Pendimethalin (1 kg/ha) applied within 2–3 days of sowing.
- **Post-emergence herbicides**: Sulfosulfuron (25 g/ha) at 30–35 days for grassy weeds.
- **Mechanical weeding**: Hand weeding or hoeing at 20–30 days, common in smallholder farms.

Harvesting and Post-Harvest Management

Wheat is harvested at 110–130 days when grains harden and straw turns golden. Manual harvesting is common, but combine harvesters, used in larger farms in Punjab and Haryana, reduce losses by 5–10%. Yields range from 4.0–5.5 t/ha, depending on variety and management.

Post-Harvest Practices:

- **Threshing and Cleaning**: Mechanical threshers separate grains, followed by winnowing to remove debris.
- **Storage**: Drying to 10–12% moisture content prevents fungal growth. Hermetic bags or silos protect against storage pests like weevils (*Sitophilus granarius*).
- **Grading**: Sorting by grain size and quality ensures better market prices, especially for durum wheat.

Mechanization and Technology Adoption

Mechanization, including tractors, seed drills, and combine harvesters, enhances efficiency and reduces labor costs. Precision agriculture tools, such as soil moisture sensors and drone-based pest monitoring, are emerging in states like Punjab and Haryana. Mobile apps like Kisan Suvidha and AgriApp provide real-time weather, market, and advisory services. The e-NAM platform connects farmers to markets, ensuring competitive prices for quality produce.

Challenges in Indian Wheat Farming

Indian wheat farmers face several challenges:

- **Climate Variability**: Heatwaves and erratic rainfall impact yields, particularly in rainfed areas (20% of production).
- **Water Scarcity**: Declining groundwater levels in Punjab and Haryana threaten irrigated farming.
- **Market Fluctuations**: Price volatility affects profitability.
- **Knowledge Gaps**: Limited access to extension services hinders technology adoption.

Government initiatives like the National Food Security Mission (NFSM-Wheat) and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) provide subsidies for seeds, irrigation, and equipment, addressing these challenges.

Future Prospects and Innovations

The future of wheat production in India lies in sustainable, technology-driven practices:

- **Climate-Resilient Varieties**: Developing wheat tolerant to heat, drought, and salinity, targeting yields of 5.5–6.0 t/ha.
- **Digital Agriculture**: Leveraging AI, IoT, and satellite imagery for crop monitoring and yield prediction.
- **Value Addition**: Promoting processed products like whole-wheat flour, pasta, and bakery items.

- **Organic Farming**: Meeting growing demand for organic wheat in domestic and export markets.

Collaborations between IARI, DWR, and agribusinesses drive research and technology dissemination. India's export potential, particularly for durum wheat to markets like Europe and the Middle East, offers economic opportunities.

Conclusion

Wheat production in India is advancing through modern technologies and sustainable practices. By adopting high-yielding varieties, precision irrigation, integrated pest management, and mechanization, farmers can achieve yields of 4.0–5.5 t/ha, enhancing food security and livelihoods. With government support and ongoing research, wheat will continue to play a pivotal role in India's agricultural landscape, nourishing millions while promoting environmental sustainability.

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Biostimulants - The agricultural technology of the future and its alchemy

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Biostimulants are a ground-breaking development in agricultural technology that will be essential to future sustainable farming methods. By using natural biological processes, biostimulants, as opposed to conventional fertilizers or insecticides, improve plant growth and resistance. They enhance nutrient uptake, stress tolerance, and general plant health and are made composed of ingredients such as seaweed extracts, humic acids, amino acids, and beneficial microorganisms. By lowering reliance on chemical inputs, this green technique promotes soil fertility and lessens environmental degradation. Biostimulants' "alchemy" is their capacity to unleash the latent potential of plants, turning common agricultural products into high-quality, high-yield produce. Biostimulants present a workable way to boost output without jeopardizing ecological balance as the world's food demand rises and climate issues worsen. The future of food production is changing as a result of its integration with organic farming and precision agriculture, which places an emphasis on resilience, sustainability, and efficiency. The science underlying biostimulants, their constituents, modes of action, and possible advantages are examined in this abstract, which positions them as the foundation of next-generation agriculture. Biostimulants are at the vanguard of an agricultural renaissance where nature and technology coexist peacefully to sustainably feed the globe as research and innovation continue to progress.

Keywords: Biostimulants, Sustainable Agriculture and Microorganisms.

Biostimulants

"A substance or microorganism that, when applied to seeds, plants, or on the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, crop quality and yield" is what the 2018 Farm Bill calls "biostimulants." To increase crop yields by stimulating plant activity, biostimulants—chemicals or microorganisms that naturally affect plant metabolism are added to Biosolutions. Providing a viable substitute for plant protection agents and assisting in the transition of the agriculture industry towards more environmentally friendly farming practices. Crops are now more resilient to extreme weather events like drought and temperature swings because of biostimulants. Crop yields are maintained while productivity in agriculture rises.. In contemporary agriculture, biostimulants are a crucial tool that can boost crop sustainability and productivity. Even if you've never heard the word "biostimulant," you've probably seen ads for goods that fit this description. They have labels like "Probiotic for Plants," "Biological Plant Activator," and "Plant Health Stimulator." They might offer better nutrition and water uptake, greater resistance to abiotic stress, and improved plant vigour, quality, and output **Riya Johnson *et al.*, 2023.**

Applying chemicals or microbes to plants, soil, or seeds with the intention of improving crop yield, quality attributes, plant tolerance to a variety of biotic and abiotic challenges, and/or nutrient usage efficiency is known as plant biostimulant. The term "biostimulant" is not well understood, and many definitions have been put out in the past. In an effort to encourage the adoption of biostimulants by future legislation, the majority of these definitions made an effort to distinguish between biostimulants and fertilizers as well as between pesticides and bio-control agents **(Du. Jardin, 2015)**. The fact that some biostimulants can serve as both a biostimulant and a bi-control agent, or that they can be purchased in various combinations that may include fertilisers, complicates matters. The classification of biostimulants is multifaceted. The most well-liked ones are seaweed extracts, humic acids, composting liquid manure, and helpful fungus and bacteria.

1. Acids fulvic and humic
2. Extracts from seaweed
3. Composting liquid manure
4. Helpful fungi and bacteria

The Alchemical Transformation of Biostimulants

Using a combination of modern science and traditional methods, biostimulants have become a potent instrument in the alchemical transformation of agriculture, improving crop health, production, and sustainability. The transforming potential of biostimulants in agriculture is aptly described by the term "alchemy". Several crucial processes help to explain this transformation: **Ayush Bahuguna *et al.*, 2022.**

1. Stress Adjustment

Biostimulants improve plant survival rates by strengthening the plants' resistance to environmental challenges including salinity and drought. Additionally, they can strengthen a plant's defense mechanisms, increasing its resistance to illnesses and pests.

2. Enhancement of Soil Health

Biostimulants increase the number of helpful microorganisms in the soil, creating a thriving ecosystem that improves microbial diversity and nutrient cycling, which in turn improves soil structure and nutrient cycling. They improve soil structure by encouraging aggregation and aeration, which makes it easier for roots to absorb and retain water.

3. Increased Uptake of Nutrients

Plants can access trapped nutrients more readily when they are released by biostimulants. This is especially important in soils low in nutrients since they promote root development and growth, which improves the plant's capacity to take up water and nutrients.

4. Ecological Farming

Biostimulants can lessen the need for synthetic fertilisers and pesticides by improving plant health and productivity, encouraging more environmentally friendly farming methods and Biostimulants supported healthy soils can enhance carbon sequestration, reducing the impact of climate change.

Biostimulants in Modern and Future Agriculture Technology

"Products containing substances and/or microorganisms whose function, when applied to plants or the rhizosphere, is to stimulate natural processes to improve/benefit nutrient uptake, nutrient efficiency, abiotic stress tolerance, and crop quality" is how the European Biostimulant Industry Council (EBIC) defines biostimulants. Every year, the biostimulant market expands. By 2025, the market for biostimulants with active ingredients is predicted to grow to a value of around $5 billion. Technology based on biostimulants is an effective, efficient, or sustainable substitute for their synthetic equivalents. The size of the Indian biostimulants market is projected to be USD 188.19 million in 2024 and USD 310.14 million by 2029, with a compound annual growth rate (CAGR) of 10.51% from 2024 to

2029 **Youssef Rouphael & Giuseppe Colla (2020).**

Growers can adopt a novel approach to crop management by utilising biostimulants, which enhance the plant's inherent activities. Enhancing crop resilience, quality, and productivity in a sustainable way can be achieved by combining biostimulants with conventional fertilisers. Biostimulants hold great potential to contribute significantly to the development of a more sustainable and productive future as the agriculture sector undergoes further evolution. Here is a summary of their function in both the present and the future.

1. Present-day Use in Agriculture.
2. The Integration of Technology.
3. Trends for the Future.
4. Issues and Things to Think About.
5. Biostimulant Definition.

Role of Biostimulants in Agriculture

Through the stimulation of soil microbial and enzyme activity or the production of more plant hormones, biostimulants improve crop growth and yield. Similar to this, biostimulants help and enhance a plant's metabolic processes, lessen the impacts of stress, lessen the need for fertiliser, and promote plant growth and resilience to abiotic challenges like drought and heat. The following points illustrate the role of biostimulants.

1) Increasing Nutrient Uptake by Root Development and Nutrient Mobilization.
2) Improving Plant Resilience by Stress Tolerance and Disease Resistance.
3) Improving the Quality and Yields of Crops.
4) Encouraging Sustainable Practices by Reducing Chemical Inputs and Carbon Sequestration.
5) Helping to Promote Regenerative Agriculture.

Benefits of Biostimulants in Agriculture

t has been demonstrated that biostimulants improve a wide range of parameters that impact plant growth, such as root diameter and growth, soil water-holding capacity, increased microbial activity resulting in higher nutrient availability, and many more. However, most of the time, the results are quite varied, lower pesticide requirements, lower production costs, improve food quality and nutrient content, raise food security, boost disease and insect resistance, and provide medical benefits.

Summary

In contemporary agriculture, biostimulants have become a viable option for improving crop production by promoting resilient growth and general plant health. Biostimulants are an important tool for sustainable farming techniques since they function by enhancing the physiological processes of the plant, as opposed to traditional fertilisers which supply nutrients directly. Biostimulants could be crucial in tackling the problems of contemporary agriculture and promoting a more robust and sustainable food system as research advances and adoption rates rise. By integrating them into farming methods, they promote environmental stewardship and crop health by bringing agricultural practices into line with ecological balance.

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Trade Wars and Tariffs: Dynamics of Global Agricultural Markets

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Introduction

Trade wars and tariffs have become crucial issues in the global economy, significantly affecting agricultural exports. Most countries are limited by their natural resources and ability to produce certain goods and services. They trade with other countries to get what their population needs and demands. However, trade isn't always conducted in a smooth manner between trading partners. Policies, geopolitics, competition, and many other factors can create conflicts and make trading partners unhappy.

The imposition of tariffs and the resulting trade wars can disrupt the flow of agricultural goods, leading to higher prices, reduced market access, and economic hardships for farmers. For example, recent trade tensions between major economies have resulted in tariffs on key agricultural products such as soybeans, dairy, and meat. These tariffs have caused significant shifts in global trade patterns, forcing countries to seek new markets and altering established supply chains.

Moreover, the uncertainty created by trade wars can have long-term effects on agricultural investments and productivity. Agribusinesses may delay or cancel plans to develop new products or enter new markets due to fears of market instability and unpredictable trade policies. This can hinder the overall growth and development of the agricultural sector. Additionally, the disruption in trade relationships can lead to increased costs for consumers and reduced availability of certain agricultural products, impacting food security and prices globally.

This report aims to explore the impact of trade wars and tariffs on agricultural exports in detail. By examining case studies, economic data, and expert analyses, we will gain a deeper understanding of how these economic conflicts influence agricultural trade dynamics.

Trade Wars

A trade war is an economic confrontation between two or more countries. As a result, trade barriers and other trade protectionist measures are imposed by both nations against one another. Tariffs, import quotas, domestic subsidies, currency devaluation, and embargoes are some of the methods by which these barriers can be implemented. Every time one nation implements a trade barrier, the other will respond with a different measure. This gives rise to the idea of "war".

Industries can be protected in the short term by trade restrictions. But in the long run, they typically have a detrimental effect on the economy as a whole. When the government of one nation feels that another is using unfair trade practices that are

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harming its markets, trade wars can break out. Countries could implement a trade barrier, such as tariff on a vital product imported from the other nation, in an effort to safeguard their own domestic industry or generate employment. This tit-for-tat conflict will turn into a trade war if the other nation retaliates.

Tariffs

One of the ways governments deal with trading partners they disagree with is through tariffs. A tariff is a tax imposed by one country on the goods and services imported from another country to influence it, raise revenues, or protect competitive advantages.

Tariffs are used to limit imports; in other words, they raise the cost of goods and services bought from other countries, making them less appealing to domestic consumers. It's important to remember that a tariff impacts the exporting country because there's a chance that consumers in the country that imposed the tariff will avoid imports because of the price increase, but if they still choose the imported product, then the tariff has effectively increased the cost to the consumer in another country.

Advantages and Disadvantages of Tariffs

The advantages of tariffs are-

- **Produce revenues:** Governments can increase revenue by imposing tariffs. This can assist the government in lowering deficits and lessen the tax burden that a county's residents bear. For example, in order to balance the trade deficit, President Donald Trump and his administration imposed tariffs on a number of goods in 2018 and 2019. $41.6 billion was collected in customs duties during the 2018 fiscal year. Duties received in fiscal year 2019 totalled $71.9 billion.
- **Support a nation's goals:** In order to promote businesses and the economy, one of the most common use of tariffs is to ensure that domestic products are given preference inside a nation. For example, when Russia invaded Ukraine, much of the world protested by boycotting Russian goods or imposing sanctions. In April 2022, President Joe Biden suspended normal trade with Russia. In June, he raised the tariff on Russian imports not prohibited by the April suspension to 35%.
- **Protect domestic industries:** A common tactic used by governments to protect their home industries from foreign competition is tariffs. Tariffs on imports raise their price and reduce their competitiveness when compared to domestically made goods. This can sustain market share and support the growth of indigenous industries.

The disadvantages of tariffs are-

- **Create issues between governments**: Tariffs are a common tool used by many countries to impose punishment or prevent behaviour they find objectionable. Unfortunately, doing so may exacerbate tensions between two nations and cause further issues.
- **Initiate trade wars**: When tariffs are placed on a nation, that nation usually responds in kind, starting a trade war in which neither nation gains from the other.

Side-effects of Trade Wars and Tariffs

Tariffs can have unintended side effects:

- Trade wars and tariffs can hinder innovation and efficiency in home industries by lowering competition. A study by the OECD (Organisation for Economic Co-operation and Development) found that a 10% increase

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in trade openness is associated with a 4% increase in productivity. Conversely, increasing tariffs or reducing trade openness can negatively impact productivity growth.

- They may harm domestic customers because prices tend to rise when there is less compet ition. Research by the National Bureau of Economic Research (NBER) shows that the tariffs imposed by the U.S. on Chinese imports resulted in price increases of 10-30% for affected goods, contributing to an estimated additional cost of $3 billion per month for U.S. consumers and firms. This increase in prices effectively reduced real incomes by about $1.4 billion per month.
- By giving preference to some industries or geographical areas over others, they may cause conflict. For instance, rural consumers, who are not benefited from the policy and are likely to pay more for manufactured items, may be harmed by tariffs that are intended to assist manufacturers in urban areas.
- Finally, an attempt to pressure a rival country by using tariffs can devolve into an unproductive cycle of retaliation, commonly known as a trade war.

Overall impacts of Trade Wars on Agricultural Markets

- **Impact on Farmers:** Trade wars can have detrimental effects on farmers, who may face reduced access to export markets, lower commodity prices, and increased input costs. The loss of export opportunities can lead to excess supply in domestic markets, resulting in downward pressure on prices and income instability for farmers.
- **Effects on Consumers:** Trade wars can also affect consumers by increasing the prices of imported agricultural products, reducing choices, and potentially leading to lower food quality due to reduced competition. Vulnerable populations may be particularly impacted by rising food prices, exacerbating issues of food affordability and access.
- **Disruptions in Supply Chains**: Trade wars can disrupt complex agricultural supply chains, impacting both upstream and downstream industries. Integrated supply chains, relying on inputs from multiple countries, can face logistical challenges, delays, and increased costs, affecting the overall efficiency and competitiveness of agricultural sectors.
- **Disruptions in Global Food Supply Chains:** The global food system is intricately interconnected, with agricultural trade playing a crucial role in ensuring food security. Trade wars disrupt this system, affecting the availability and affordability of food, particularly in countries heavily reliant on imports.
- **Threats to Food Security:** International trade allows countries to access a diverse range of food products and bridge the gap between production deficits and surpluses. Trade wars can undermine food security by reducing trade flows, increasing food prices, and disrupting supply chains, particularly in regions highly dependent on imported food.
- **Long-term Impacts on Agricultural Development:** Trade wars can have long term consequences for agricultural development, potentially hampering investments, technological advancements, and knowledge transfer in the agricultural sector.

Mitigation of effects of Trade Wars

There are various strategies to mitigate the effects of trade wars. Few of them are:

- **Improving market access and reducing barriers:** Efforts to improve market access and reduce trade barriers through negotiations, bilateral agreements, and international institutions can help alleviate the negative effects of trade wars on agricultural markets. Streamlining customs procedures, harmonizing regulations, and promoting fair trade practices contribute to a more stable trading environment.

- **Strengthening international institutions and dispute settlement mechanisms:** Strengthening international institutions, such as the World Trade Organization (WTO), and ensuring effective dispute settlement mechanisms is essential for resolving trade conflicts and enforcing trade rules. Upholding rules based international trading system enhances stability and predictability for agricultural markets.
- **Enhancing risk management and resilience in agriculture:** Agricultural sectors need to enhance risk management strategies and build resilience to mitigate the impacts of trade wars. Diversification of markets, adoption of advanced risk management tools, and investment in sustainable agricultural practices contribute to the sector's ability to withstand trade disruptions.

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Fruit Reimagined: How CRISPR-CAS9 is Revolutionizing Horticulture

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Imagine biting into a strawberry that doesn't rot in two days, or a banana that shrugs off the deadliest of plant diseases. Once the stuff of science fiction, these possibilities are now sprouting in labs and fields thanks to a game-changing tool: CRISPR-Cas9.

CRISPR—short for Clustered Regularly Interspaced Short Palindromic Repeats—might sound like a tongue-twister, but in simple terms, it's nature's very own genetic toolkit. Originally discovered in bacteria as a defence system against viruses, scientists quickly realized they could adapt it to edit genes in any living organism—including our favourite fruit crops. At the heart of this technology is Cas9, a protein that acts like a pair of molecular scissors. Guided by a strand of RNA, Cas9 can precisely snip DNA at chosen spots, allowing scientists to add, remove, or tweak specific genes. It's like using "find and replace" in a Word document, but with the code of life.

THE CASE FOR EDITING OUR FRUITS:

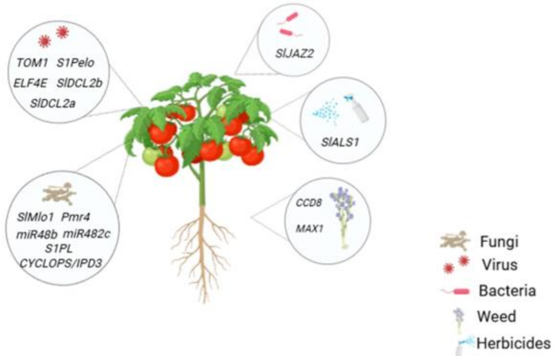
Horticultural fruit crops have always been vulnerable—to pests, diseases, climate shocks, and even our own food habits. Traditional breeding techniques are slow, unpredictable, and often come with trade-offs. But CRISPR changes that. This technology allows scientists to accelerate the development of fruit varieties with better taste, longer shelf life, greater disease resistance, and even higher nutritional value. And unlike older genetic modification methods, CRISPR doesn't necessarily involve adding foreign DNA, making it a cleaner, more acceptable alternative for many.

TOMATOES: MORE THAN JUST JUICY:

Tomatoes were among the first fruit crops to enter the CRISPR spotlight. These versatile fruits (yes, they're technically fruits!) are vital in cuisines across the globe—from pasta sauces to salsas. But they're also notorious for their short shelf life, uneven ripening, and susceptibility to disease. Scientists have used this tool to:

- Knock out genes responsible for over-ripening, leading to tomatoes that stay fresh longer after harvest.
- Tweak fruit development genes to improve uniformity in size and color—important for commercial packaging and visual appeal.
- Reduce fruit cracking, a common problem caused by irregular watering and environmental stress.

In one breakthrough, researchers even recreated traits lost during traditional breeding—like better flavour and aroma—by precisely editing regulatory genes. This means we could soon have tomatoes that are not only hardier but tastier, reconnecting us with the rich, natural flavours of heirloom varieties.



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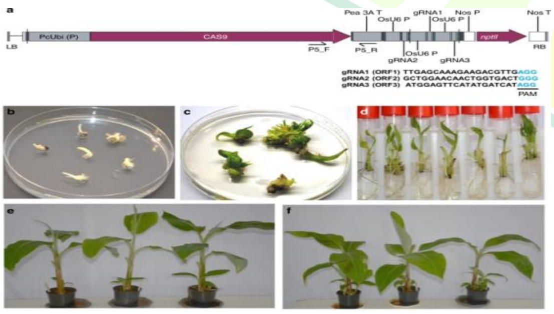
BANANAS: A TOUGHER PEEL ON THE HORIZON:

Bananas are more than just a breakfast staple—they're a lifeline for millions of farmers and a key export crop for several tropical nations. But their genetic uniformity, especially the widely grown Cavendish variety, makes them vulnerable to disease. One of the biggest threats is Panama disease Tropical Race 4, a lethal fungal infection that spreads through the soil and has no cure once established.CRISPR-Cas9 is now being used to edit the banana plant's own genes to increase resistance to this disease. Unlike traditional GMOs that introduce foreign genes, this method simply boosts the banana's natural defences.Early trials show promise: bananas that can resist infection without altering their taste, texture, or nutritional value. With CRISPR, we're not just saving a fruit—we're protecting an entire agricultural economy.

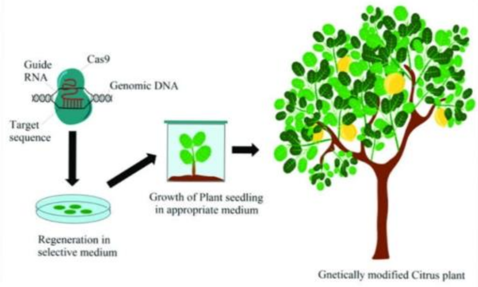


CITRUS: FIGHTING A BITTER BATTLE:

Citrus fruits like oranges, lemons, and limes are facing a slow-moving catastrophe. Citrus Greening Disease (HLB), caused by a bacterium spread by tiny insects, is decimating citrus groves around the world. Affected trees produce bitter, misshapen fruits and eventually die. CRISPR is stepping in as a potential saviour. Researchers are working to:

- Edit susceptibility genes in citrus plants, making them resistant to the bacterium.
- Develop trees that can block or tolerate the infection, even if the insects remain in the environment.

In Florida, where HLB has caused billions in losses, CRISPR trials are offering a glimmer of hope. One day, we may enjoy orange juice without worrying about whether orange trees will still exist in the next decade.



GRAPES AND STRAWBERRIES: FROM VINE TO VICTORY:

Grapevines often fall prey to powdery mildew, leading to heavy fungicide use. With CRISPR, breeders can target the plant's vulnerability genes and enhance its natural resistance, reducing chemical inputs.

Strawberries, meanwhile, are getting CRISPR attention for improving firmness, sweetness, and

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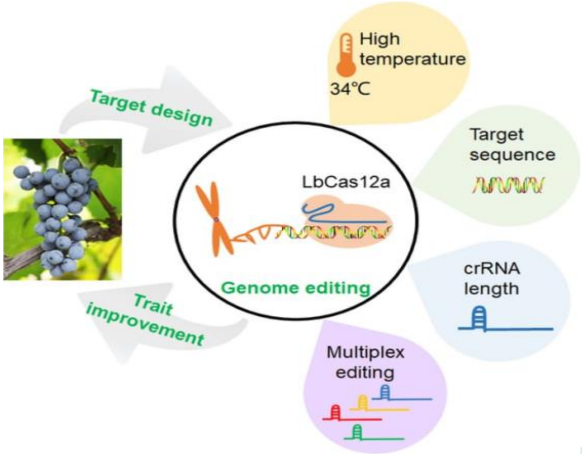
shelf life—a welcome change for farmers and fruit lovers alike



GRAPES

STRAWBERRYS

THE SWEET AND THE SOUR:

Of course, CRISPR is not a magic wand. There are ethical questions about gene editing, fears of unintended effects, and regulatory hurdles in many countries. Public perception also plays a major role—many people still confuse gene editing with older GMOs, even though the two are quite different. Still, CRISPR's precision and potential are hard to ignore. Unlike transgenic modifications, CRISPR often uses the plant's own genes, making it closer to accelerated breeding than foreign gene insertion. As the world faces challenges like climate change, shrinking farmland, and rising food demands, CRISPR-Cas9 offers a powerful way to grow more with less. It could drastically reduce our dependence on chemical pesticides, make fruits last longer on shelves, and open up exciting new frontiers in nutrition.

CONCLUSION:

As we walk through bustling fruit markets or harvest crops from our own gardens, we rarely think about the genetic codes running beneath the skin of each fruit. But in quiet labs and greenhouses, scientists are rewriting those codes—with precision, purpose, and promise. CRISPR-Cas9 is sowing the seeds of a new horticultural revolution. One that could protect biodiversity, boost farmer incomes, and feed a growing world with fewer inputs and more intelligence**.** In this delicate balance between tradition and technology, the question is no longer **"Should we edit fruit?"—but "How can we do it responsibly, equitably, and deliciously?"**

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Farming in the Air: The Rise of Aeroponics

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Introduction

The old-style farming, which used the soil, sunlight, and massive open areas for thousands of years, has undergone fundamental changes. With the world's population increasing coupled with climate change causing disarray with the weather patterns, there is an increasing appetite for innovative, efficient, and sustainable food-growing methods. Newer technologies such as hydroponics, vertical farming, and in particular aeroponics are driving this agricultural revolution – helping farmers to produce more crops than ever with less land, less water, and fewer negative environmental consequences as well.

These global issues of land and water scarcity, and climate change are adding strain to ecosystems, business, and human life. Towns and cities are rising rapidly, forests are diminishing and soils are becoming less fertile, while more people and unsustainable farming use up more freshwater. If we do not hurry to manage land, conserve water, and stop climate change, these hazards will only worsen inequality, create tension, and make it harder to get enough food.

Aeroponics is a cutting-edge, soil-less farming technique that grows plants in an air or mist environment, with roots suspended and periodically sprayed with a nutrient-rich solution. This futuristic method uses up to 95% less water than traditional agriculture while accelerating plant growth and maximizing space efficiency, making it ideal for urban areas and regions with poor soil.

Aeroponics

In aeroponics, plants are grown in the air or mist without any soil or other kind of material. Plants are grown in a way that their roots are suspended free in the air and they are watered and fed regularly by misting a nutrient-rich mixture.

Method of supporting and misting the plants' roots:

Suspension: The plants are kept in a structure (for example, a tray or foam support) with their roots hanging down and touching a closed or semi-closed chamber below. The plant's stem is positioned on top of the chamber so that the roots get access to air.

Misting: Every so often, the system sprays a mist of water containing nutrients onto the roots of the plants. The mist generated by high-pressure pumps contains nutritious water and other important minerals for the plant's growth.

Nutrient Delivery: Both the roots and lower parts of plants are easily supplied with the nutrients that are contained in the mist. Surplus mist is either drained out or recycled to ensure the surroundings are clean and well-oxygenated.

Aeration: Being suspended in air means the roots breathe in plenty of oxygen which encourages faster growth and helps the plant get healthier than those in soil.

Working of Aeroponics

Aeroponics is a soilless farming method where plant roots are suspended in an enclosed chamber or tower and periodically misted with a nutrient-rich solution. Here's how it works, focusing on the components and emphasized elements:

Components:

1. Plant Support Structure:

Holds plants in place, typically using foam collars, net cups, or baskets. Roots dangle freely in the air below, allowing maximum exposure to mist and oxygen.

2. Nutrient Misting System:

High-pressure pumps and nozzles (or ultrasonic foggers) create a fine mist (5–50 microns) of water mixed with dissolved nutrients. This mist is sprayed directly onto the roots at timed intervals, ensuring efficient nutrient absorption.

3. Enclosed Chamber or Tower:

A sealed or semi-sealed environment (e.g., towers, trays, or tubes) houses the roots, maintaining high humidity, protecting roots from light, and preventing evaporation. Towers are common in vertical setups to maximize space. Chambers can vary in design, with minimum heights of 15 cm for leafy crops and up to 80 cm for root or tuber crops. These chambers are often covered by Styrofoam plates, with 16-mm-diameter drip hoses and nebulizers placed every 50 cm for uniform mist distribution.

Emphasized Features:

1. Sensors and Automation:

Sensors monitor environmental factors like humidity, temperature, pH, and nutrient concentration. Automated systems (e.g., timers, controllers) adjust misting frequency, lighting, and nutrient delivery for optimal growth. For example, IoT-enabled setups can remotely fine-tune conditions via apps, reducing labor and improving precision.

2. Recirculating Water Systems:

Excess nutrient solution is collected in a reservoir below the chamber, filtered, and reused, minimizing water waste (up to 95% less water than traditional farming). Pumps recirculate the solution, and periodic replenishment ensures nutrient balance.

Process Overview:

- Plants are secured in the support structure with roots exposed in the chamber.
- The misting system delivers the nutrient solution in short bursts (e.g., every 2–5 minutes), ensuring roots stay moist but not waterlogged.
- Sensors and automation optimize conditions, while the recirculating system conserves water and nutrients.
- Roots absorb oxygen, water, and nutrients directly from the mist, promoting faster growth (up to 30% quicker than soil-based methods) and higher yields.
- This setup enables year-round, scalable farming with minimal resource use, ideal for urban or controlled-environment agriculture.

Advantages of Aeroponics

- Water Efficiency: Uses up to 95% less water than traditional farming through recirculating systems.
- Faster Growth: Plants grow up to 30% faster due to direct nutrient and oxygen delivery to roots.
- Higher Yields: Optimized conditions boost crop production in compact spaces.
- Space Efficiency: Vertical towers maximize land use, ideal for urban or limited spaces.
- Reduced Disease Risk: Soilless setup minimizes soil-borne pests and diseases.
- Year-Round Production: Controlled environments enable consistent, weather-independent harvests.

Challenges of Aeroponics

- High Initial Costs: Expensive setup with advanced components like misting systems and automation.

- Energy Dependence: Relies on electricity for pumps, sensors, and lighting, increasing operational costs.
- Technical Complexity: Requires expertise to manage nutrient solutions, pH, and automated systems.
- System Vulnerability: Power failures or clogged nozzles can quickly damage plants.
- Maintenance Demands: Needs regular cleaning, monitoring, and calibration to prevent system failures.

Prospects

The future of aeroponics lies in its water-saving, space-efficient design and ability to work in different environments. Since it saves more than 90% of water, aeroponics is most helpful for farming in deserts or other dry places, and vertical methods are used in city farming and exploration by NASA. New technologies in AI, IoT, and automation help maximize cultivation with less work involved, while solar misting systems are one way to control how much energy is used. Regardless of the scale, aeroponics systems can make food security better and help farmers grow multiple crops. Nevertheless, resolving the issues of setup, relying on energy resources, and needing technology will be vital for solar energy to benefit everyone worldwide.

Conclusion

Aeroponics is an effective and eco-friendly growing method that provides nutrients to plants suspended in the air using a mist. It provides many valuable features such as increased water use efficiency, more productive growing seasons, and more produce. Aeroponics helps farmers cultivate all year round in enclosed settings, which saves land and copes with environmental dangers like damaged soil and pests. However, the installation costs, difficult technical aspects, and electricity usage make it difficult for many to adopt. With the growth of automation and renewable power, aeroponics may boost the production and supply of food in areas that need it most.

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Feeding the Future: How Artemia Supports the Blue Economy

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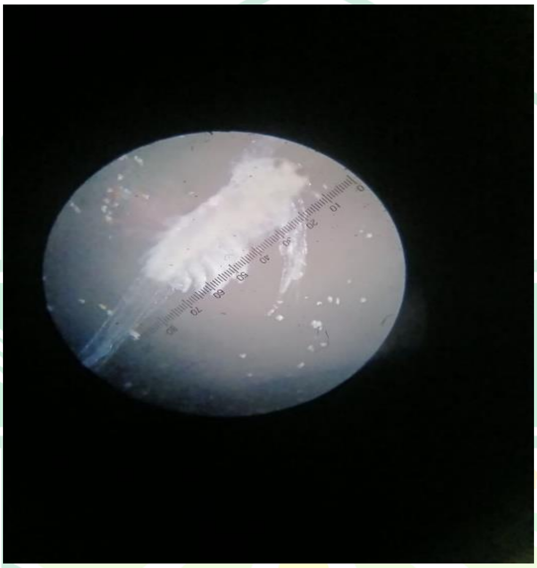
Introduction

As the world's population continues to increase day by day, it is now crucial to ensure food security using creative and sustainable methods. Aquaculture has gained more attention as an essential sector as the result of the blue economy, which promotes the sustainable use of ocean resources for economic growth and better lifestyles. Artemia, sometimes referred to as brine shrimp, has become an important species in aquaculture hatcheries in this regard. Despite its small size, Artemia has a significant influence on aquaculture systems' production and larval survival, which supports the larger objectives of the blue economy.



What is Artemia?

Artemia is a genus of aquatic crustaceans found predominantly in hypersaline environments like salt lakes and evaporation ponds. The species ***Artemia franciscana*** is the most commonly used in aquaculture due to its unique ability to produce dormant cysts (encapsulated embryos) that can withstand harsh conditions and be stored for extended periods. These small organisms have the remarkable ability to produce dormant cysts—encapsulated embryos—that can survive extreme environmental conditions. These crustaceans typically grow to a length of **8 to 12 millimeters** when fully developed. These cysts can be harvested and stored for long periods, ensuring a consistent and reliable supply of live feed for aquaculture hatcheries (Lavens & Sorgeloos, 2000). When rehydrated, these cysts hatch into nauplii (larvae), which are rich in essential fatty acids and other nutrients that promote the growth and survival of fish and crustacean larvae.

The Role of Artemia in Aquaculture

Aquaculture hatcheries, particularly those that culture marine finfish and crustaceans, require high-quality live feed during the early larval stages. Artemia nauplii are one of the most popular live feeds due to their high nutritional value, simplicity of preparation, and capacity to promote larval eating behavior. Artemia is high in proteins, vital amino acids, and fatty acids such as docosahexaenoic acid (DHA), which helps diverse species thrive and survive. For example, *Litopenaeus vannamei* (Pacific white shrimp), *Chanos chanos* (milkfish), and *Lates calcarifer* (seabass) had considerably increased survival and growth rates when given Artemia (Dhont & Van Stappen, 2003).

In addition to its nutritional benefits, Artemia supports healthy digestive function in larvae by stimulating natural eating activity. This relationship is especially crucial for species with high metabolic rates and quick growth requirements in the early stages of development.

Nutrient	Approximate Value (per dry weight)	Remarks
Protein	55–65%	High-quality protein, essential for larval growth
Lipids (Total Fat)	13–25%	Can vary; enriched Artemia have higher lipid content
EPA (Eicosapentaenoic acid)	1.5–2.5%	Omega-3 fatty acid; often low in native Artemia
DHA (Docosahexaenoic acid)	< 0.1% (unenriched)	Supplemented via enrichment techniques
Carbohydrates	5–10%	Energy source
Ash (Minerals)	10–15%	Includes essential minerals like Na, K, Mg
Moisture Content	5–8% (in dry Artemia)	Varies based on processing
Energy Value	~450–500 kcal/100g	Useful for fast-growing larvae
Vitamins	Trace amounts (A, D, E, B-complex)	Often supplemented during enrichment
Carotenoids (Astaxanthin)	50–200 µg/g	Provides pigmentation; antioxidant properties

Artemia Production and the Blue Economy:

Artemia production contributes significantly to the larger blue economy, supporting both the aquaculture sector and coastal individual's lives. Artemia is obtained from natural sources such as the Great Salt Lake in the United States and Lake Urmia in Iran, as well as in salt ponds across Latin America and Asia. In India, for example, saltpan-based Artemia production is common in coastal regions such as Gujarat and Tamil Nadu, creating job opportunities for locals and promoting integrated salt-aquaculture systems (Sivagnanam et al., 2011).

The growing and harvesting of Artemia contributes to the blue economy in numerous ways:

Sustainable Livelihoods: Artemia production provides employment, particularly in coastal and rural communities. The sector generates revenue not only from direct production, but also from the processing and distribution of Artemia cysts for aquaculture feed (FAO, 2019).

Poverty Alleviation: By providing an alternative source of income for communities, Artemia production can help reduce poverty in coastal regions where other forms of agriculture or fishing may be ineffective.

Gender Empowerment: Women, in particular, benefit from job opportunities in small-scale processing and packaging units associated with Artemia production, contributing to economic inclusivity and empowerment (FAO, 2019).

Innovation and Sustainability in Artemia Use:

As demand for Artemia rises, there are rising worries about sustainability, including overharvesting from natural resources. This has resulted in substantial innovation in the Artemia producing business. One alternative is to build closed-loop production methods for Artemia, which reduce reliance on wild populations and provide a more sustainable method of production. These systems recycle water and nutrients, making the process more efficient and eco-friendly.

Furthermore, microalgal enrichment procedures have been developed to increase the nutritional value of Artemia nauplii. These procedures, which enrich the nauplii with important fatty acids, carotenoids, and other nutrients, ensure that Artemia remains an appropriate feed source for aquaculture species. Biotechnology is also playing a role, with studies aimed at strengthening the genetic strains of Artemia to boost productivity, resilience, and stress tolerance.

Environmental Benefits and Climate Resilience:

Artemia production has various environmental advantages, mainly due to its low-impact nature. The crustaceans are grown in hypersaline water bodies that are generally unsuited for traditional agriculture or aquaculture, reducing the demand on freshwater resources. Furthermore, Artemia production requires little inputs, like as fertilizers and pesticides, making it an environmentally beneficial feed source. In terms of climate resilience, Artemia's capacity to survive in harsh environmental circumstances, such as high salinity and temperature variations, makes it an excellent feed organism in response to climate change. As ocean temperatures rise and freshwater availability decreases, Artemia cultivation can provide a sustainable and resilient feed supply for aquaculture operations across the world (FAO, 2019).

Conclusion:

Artemia supports the blue economy by providing a sustainable and extremely nutritious feed source for aquaculture species. Its manufacture not only increases hatchery productivity and efficiency, but it also benefits coastal and rural populations' livelihoods, therefore reducing poverty and empowering women. As worldwide demand for seafood rises, Artemia's role in maintaining long-term food security and economic prosperity will become increasingly vital. The Artemia sector could expand while limiting environmental effect by implementing innovative manufacturing methods like as closed-loop systems and microalgal enrichment. Artemia, as a low-cost, environmentally friendly resource, provides a paradigm for sustainable aquaculture that can assist overcome the difficulties posed by a growing global population and climate change. Thus, Artemia symbolizes a little creature with a significant function to play in feeding the future.

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Innovations and Challenges in Agricultural Extension: Bridging the Gap between Research and Farmers

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Introduction:

Agricultural extension services have long played a key role in disseminating information and innovations to farmers. Their goal is to improve agricultural productivity, enhance rural livelihoods, and ensure food security. This section introduces the concept of agricultural extension, its historical development, and its significance in agricultural growth. A brief overview of the shift from traditional to modern extension models (e.g., participatory extension) will also be highlighted.

This review explores the evolving role of agricultural extension in bridging the gap between research advancements and practical adoption by farmers. By examining the various models of extension, technological innovations, and the impact of extension services on productivity and sustainability, this article discusses how extension services can improve farm livelihoods. The article also delves into the challenges faced by extension agents and farmers in implementing these technologies and offers recommendations for enhancing their effectiveness in the future.

Evolution of Agricultural Extension Models:

Agricultural extension has evolved significantly over the decades, transitioning from a top-down approach to more inclusive and dynamic models. Initially, extension strategies relied heavily on one-way communication, where experts and authorities disseminated information to farmers without considering local knowledge or feedback. However, this method often led to limited adoption and poor contextual relevance. In contrast, the bottom-up approach emerged as a more effective model, placing farmers at the center of the learning process. This participatory communication model encourages farmers to actively engage in discussions, share indigenous knowledge, and make informed decisions in collaboration with extension personnel.

In recent years, the rise of ICT-based extension has further transformed the landscape. The use of mobile phones, online platforms, social media, and various digital tools has enabled faster, broader, and more personalized information delivery to farmers, even in remote regions. Key distinctions also exist between public and private extension systems, each facing its own set of challenges and strengths — public extension often struggles with resource constraints, while private services may be limited in outreach or equity. One of the most successful participatory models, the Farmer Field School (FFS), empowers farmers through experiential learning and has shown impactful results across multiple countries by enhancing both knowledge and practice. These developments reflect a broader shift toward more inclusive, technology-driven, and farmer-centric agricultural extension systems aimed at sustainable development.

Innovations in Agricultural Extension:

The integration of ICT tools and mobile applications has revolutionized the agricultural extension landscape by delivering real-time, location-specific information directly to farmers' fingertips. Mobile apps, SMS services, and social media platforms now play a crucial role in disseminating timely updates on weather, crop management, pest control, and market prices. This digital shift is further strengthened by e-Extension platforms, which offer virtual access to expert knowledge, training modules, and advisory services—greatly expanding both the reach and effectiveness of extension efforts. Additionally, ICT initiatives targeted at farmer groups have been instrumental in building digital literacy, enabling collective access to essential agricultural inputs, government schemes, and marketing networks. These efforts empower rural communities to make data-driven decisions, negotiate better prices, and adopt innovative practices.

Furthermore, the adoption of drone and remote sensing technologies has brought a new dimension to precision agriculture. These tools enhance crop monitoring, support efficient resource management, and facilitate early detection of pest infestations or nutrient deficiencies—enabling quicker and more accurate interventions. Altogether, the use of ICT in agriculture marks a significant stride toward making extension services more inclusive, efficient, and responsive to farmers' evolving needs.

Impact of Agricultural Extension on Farm Productivity and Sustainability:

Effective agricultural extension programs have played a pivotal role in enhancing farm productivity, improving crop management practices, and encouraging the sustainable use of resources. By bridging the gap between scientific research and field-level implementation, these programs have empowered farmers with timely, relevant, and practical knowledge. As a result, many regions have witnessed substantial increases in crop yields, better pest and nutrient management, and more efficient use of water and soil resources.

Globally, several case studies highlight the success of such programs. In India, initiatives like the Agricultural Technology Management Agency (ATMA) have brought multi-stakeholder collaboration to the grassroots. In Africa, farmer-led innovation platforms have improved adoption of climate-smart technologies, while Southeast Asia has benefited from integrated pest management and Farmer Field Schools that emphasize participatory learning. Importantly, extension services are now at the forefront of promoting climate-resilient agriculture, helping farmers adapt to unpredictable weather patterns through practices such as crop diversification, conservation agriculture, and the use of stress-tolerant varieties. These efforts not only support food security but also promote environmental sustainability and resilience in the face of climate change.

Challenges in Agricultural Extension:

Despite the growing importance of agricultural extension, several challenges continue to hinder its effectiveness and outreach. One of the primary constraints is limited resources, including inadequate financial support, shortage of skilled extension personnel, and lack of technological infrastructure, especially in rural and remote areas. Additionally, farmer resistance to adopting new practices remains a barrier, often rooted in cultural norms, risk aversion, or a strong reliance on traditional methods. Communication barriers further complicate outreach—differences in language, low literacy levels, and restricted access to digital tools can all limit the effectiveness of knowledge transfer.

Another critical issue is gender inequality, as many extension programs fail to adequately reach or consider the specific needs of women farmers, who play a vital role in agriculture but often face systemic exclusion from training, resources, and decision-making platforms. Addressing these challenges requires inclusive policies, targeted interventions, and a focus on participatory and context-specific strategies to ensure that extension services benefit all segments of the farming community.

Role of Agricultural Extension in Addressing Global Challenges:

Agricultural extension services play a crucial role in guiding farmers toward climate change adaptation by promoting climate-smart agricultural practices. These include adopting resilient crop varieties, efficient water use methods, and weather-based advisory services that help mitigate climate risks. Extension programs are also instrumental in encouraging sustainable agricultural practices such as organic farming, agroforestry, integrated pest management, and soil conservation.

By providing training, demonstrations, and technical support, they empower farmers to transition toward environmentally friendly and resource-efficient farming systems. Furthermore, with the evolving nature of rural economies, extension services are increasingly supporting agri-entrepreneurship by nurturing innovation, enhancing market linkages, and building farmers' business skills. Through capacity building, mentorship, and access to financial and digital tools, extension programs help transform traditional farmers into entrepreneurs capable of leading agri-based startups and value-added ventures. In essence, agricultural extension is not just a channel for knowledge transfer, but a transformative force for sustainable, resilient, and economically vibrant farming communities.

Recommendations for Enhancing Agricultural Extension:

To enhance the effectiveness and long-term impact of agricultural extension services, several forward-looking strategies are essential. Improved training and capacity building of extension personnel is crucial to equip them with the knowledge and skills needed to navigate emerging technologies, climate challenges, and evolving farmer needs. Strengthening public-private partnerships can bring together the resources, innovation, and outreach capabilities of government agencies, NGOs, and private companies, resulting in more efficient and wide-reaching extension delivery. Equally important is community engagement, where participatory approaches ensure that extension initiatives are tailored to local realities and enjoy greater acceptance, ownership, and sustainability. Lastly, the development of robust monitoring and evaluation systems is vital for measuring the real impact of extension programs on farmers' productivity, income, and well-being. Regular assessment helps in refining strategies, ensuring accountability, and fostering continuous improvement in agricultural extension services.

Conclusion:

Summarize the importance of agricultural extension in modern farming systems, emphasizing the need for continuous innovation, farmer engagement, and the role of ICT in enhancing outreach. Highlight the ongoing challenges and the potential for agricultural extension to address global food security, sustainability, and climate adaptation.

In conclusion, agricultural extension remains a cornerstone for transforming rural livelihoods and achieving sustainable agricultural development. As farming faces growing challenges from climate change, resource limitations, and technological shifts, it is imperative that extension systems evolve to become more inclusive, participatory, and tech-enabled. Strengthening the capacities of extension workers, fostering collaborative partnerships, engaging communities actively, and implementing robust monitoring mechanisms are all key to ensuring that extension services are not only effective but also resilient and future-ready. With a renewed focus on innovation, equity, and sustainability, agricultural extension can truly empower farmers to thrive in a rapidly changing world.

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NANO REVOLUTION IN AGRICULTURE: TINY PARTICLES, BIG IMPACT!

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Nanotechnology has emerged as a transformative force in agriculture, offering novel tools to address critical challenges such as declining soil fertility, pest resistance, environmental degradation, and the demand for higher productivity under climate stress. This review explores the growing body of research and real-world applications of nanotechnology in agricultural systems, with a focus on nano-fertilizers, nano-pesticides, and nano-encapsulation technologies. These nanoscale innovations enable targeted delivery, controlled release, and enhanced bioavailability of agro-inputs, leading to improved nutrient uptake, reduced chemical use, and minimized environmental impact. Case studies such as nano-urea in India and chitosan nanoparticle-based fungicides for rice blast illustrate the tangible benefits of nano-interventions in crop yield and disease resistance. The integration of nanotechnology with precision agriculture, biosensors, and data-driven systems further paves the way for smart, sustainable farming. While the potential is vast, this review also discusses the pressing need for robust regulatory frameworks, long-term toxicity studies, farmer education, and equitable access to ensure responsible and inclusive deployment. Ultimately, nanotechnology holds the promise to drive the next green revolution, ushering in an era of sustainable agriculture where tiny particles yield enormous impact.

1. Introduction: The Dawn of a New Era

Nanotechnology, the science of materials at the 1–100 nanometer scale about 1/100,000th the width of a human hair, has revolutionized multiple fields by exploiting unique physical, chemical, and biological properties at this scale (Bhushan, 2017; Roco & Bainbridge, 2005). A nanometer is one-billionth of a meter, enabling precise manipulation of atoms and molecules to create materials with tailored functions. This technology is transforming industries like medicine, electronics, and cosmetics, enabling targeted drug delivery, smaller faster devices, and effective UV protection without residue (Kah et al., 2018; Nel et al., 2006; Liu et al., 2008). Nanomaterials such as nano-silver and nanofibers enhance antimicrobial dressings and filtration systems, highlighting vast potential beyond current applications.

Agriculture now stands to benefit significantly from nanotechnology amid challenges like population growth, shrinking arable land, climate change, pest resistance, and environmental concerns (Godfray et al., 2010; Parisi et al., 2015). Conventional methods reliant on chemicals are insufficient and ecologically harmful. Nano-sized fertilizers, pesticides, and sensors offer precise nutrient delivery, early disease detection, and reduced chemical runoff. These innovations improve crop efficiency and reduce environmental footprints, addressing the urgent need for sustainable intensification. What once seemed futuristic is now realized in experimental fields globally, marking a “nano revolution” in agriculture (Fraceto et al., 2016; Khot et al., 2012). As research progresses, integrating nanotechnology with precision agriculture and digital tools promises smarter, data-driven farming systems. However, careful assessment of long-term environmental and health impacts is crucial to ensure safe deployment. Nanotechnology thus emerges not only as a scientific breakthrough but as a vital tool for building a sustainable, resilient agricultural future capable of feeding the growing global population.

2. Nanotechnology Meets Agriculture

Nanotechnology has revolutionized modern agriculture by offering innovative solutions to enhance productivity, reduce environmental impacts, and ensure sustainable farming practices. Among the most promising applications are nano-fertilizers, nano-pesticides, and nano-encapsulation systems.

a. Nano-Fertilizers: Efficient Nutrient Delivery

Nano-fertilizers are designed to enhance nutrient uptake efficiency while minimizing losses from leaching or volatilization. Their nanoscale size allows for controlled, targeted nutrient release aligned with plant needs. For example, zinc oxide nanoparticles significantly improved wheat growth and yield (Raliya et al., 2016), while nano-formulations of zinc, copper, and iron oxides enhanced overall nutrient absorption and plant development (Rameshaiah et al., 2015). IFFCO's nano-urea exemplifies real-world application—500 mL per acre can replace a 45 kg bag of conventional urea, reducing nitrogen loss and environmental impact (IFFCO, 2021). Additionally, nano-hydroxyapatite and nano-zeolite serve as carriers for slow-release nitrogen and phosphorus, ensuring efficient nutrient delivery in sync with plant demand (Liu & Lal, 2015).

b. Nano-Pesticides: Targeted Pest Control

Nano-pesticides offer precise pest control with reduced environmental impact and improved efficacy. They enhance the stability of active ingredients, lower required doses, and extend residual activity (Kah et al., 2013). For instance, silver nanoparticles effectively controlled fungal pathogens like Alternaria and Fusarium in tomatoes by disrupting pathogen cell membranes (Choudhury et al., 2017). Silica and titanium dioxide nanoparticles also act as protective barriers, deterring insect pests and reducing disease incidence. In field trials, nano-pesticides reduced pesticide usage by 70–80% in crops like brinjal and rice without compromising protection (Prasad et al., 2014), highlighting their potential as a sustainable alternative to conventional pesticides.

c. Nano-Encapsulation: Controlled Release of Agrochemicals

Nano-encapsulation enables the controlled, sustained release of agrochemicals, reducing application frequency and minimizing environmental runoff. Nanoscale carriers like chitosan, silica, or biodegradable polymers protect active ingredients and allow gradual release (Ghormade et al., 2011). For example, chitosan-encapsulated curcumin exhibited antifungal activity with sustained release (Bayer, 2023). Similarly, tricyclazole encapsulated in chitosan nanoparticles improved efficacy against Magnaporthe oryzae while enhancing plant immunity. Neem oil encapsulated in polymer nanoparticles prolonged insecticidal action and reduced harm to beneficial organisms (Kumar et al., 2022). Nano-carriers have also been used to deliver plant growth regulators like gibberellic acid for precise crop development (Tiwari et al., 2019). In practical applications, IFFCO's nano-urea reduced conventional urea use by 50% without yield loss, and bio-formulated chitosan nanoparticles boosted rice blast resistance through immune modulation (Hafeez et al., 2024).

3. Tiny Tools with Big Benefits

Nanotechnology is emerging as a transformative force in agriculture, offering solutions that enhance productivity while promoting sustainability. Nano-fertilizers like zinc oxide have significantly improved crop yield and quality by enabling efficient nutrient delivery (Raliya et al., 2016), while iron and copper oxide nanoparticles boost chlorophyll content and biomass in crops such as tomato and spinach (Naderi & Danesh-Shahraki, 2013). Nano-formulations of pesticides and fertilizers also reduce chemical usage by up to 80%, minimizing environmental contamination through targeted delivery (Kah et al., 2013).

Additionally, nanoparticles like chitosan not only act as carriers but also trigger plant immune responses, improving resistance to diseases like rice blast (Hafeez et al., 2024). Soil health and water conservation benefit from nano-clay, zeolites, and hydrogels, which retain moisture and support microbial activity (Ravichandran, 2011), while nano-sensors enable real-time monitoring for precision agriculture. Collectively, these advances make nanotechnology a powerful tool for sustainable and efficient crop management.

4. Case Studies

Numerous field trials worldwide have demonstrated the practical benefits of nanotechnology in agriculture, especially for staple crops like rice and wheat, as well as vegetables. In India, the Indian Farmers Fertiliser Cooperative Limited (IFFCO) developed Nano Urea, a liquid formulation that can replace traditional urea fertilizer. Field tests across multiple states showed that a 500 mL bottle of Nano Urea can substitute a 45 kg bag of conventional urea, resulting in 8–10% higher yields in crops like wheat, paddy, and mustard, while reducing nitrogen runoff and input costs (IFFCO, 2021).

In rice, chitosan nanoparticles have been effective against rice blast disease, enhancing plant defense enzymes such as peroxidase and phenylalanine ammonia-lyase, which improved plant health and yield under both greenhouse and field conditions (Hafeez et al., 2024). For wheat, silica nanoparticles have shown promise in managing fungal diseases like powdery mildew and rust, while also promoting growth and photosynthesis (El-Shetehy et al., 2021). In vegetable crops such as tomato and brinjal, silver and copper nanoparticles effectively controlled bacterial and fungal pathogens, leading to healthier plants and increased fruit yields, offering eco-friendly alternatives to conventional pesticides (Choudhury et al., 2017).

Globally, nano-encapsulated herbicides have been tested in countries like the United States and Brazil. For example, Brazil's field trials with nano-encapsulated atrazine demonstrated controlled release, reduced leaching, and minimized groundwater contamination without compromising weed control efficiency (Grillo et al., 2014). These studies highlight the broad potential of nanotechnology to enhance crop productivity, reduce environmental impact, and support sustainable agriculture worldwide.

5. Advancing Nano-Agriculture: Challenges and Future Directions

Despite its promise, nano-agriculture faces key challenges. Public concerns about nanoparticle toxicity and long-term effects hinder acceptance, especially for materials like silver and zinc oxide. Limited awareness, lack of transparent risk assessments, and insufficient regulatory frameworks further slow adoption. Most current regulations are based on conventional agrochemicals and fail to address nanoscale properties. Additionally, the absence of large-scale field trials and lifecycle studies limits confidence in their real-world applicability. Addressing these issues requires targeted risk evaluation, farmer training, and coordinated efforts between research institutions, startups, and policymakers to develop safe, scalable nano-based solutions.

Looking ahead, nanotechnology integrated with AI, IoT, and precision farming can revolutionize agriculture. Nano-sensors embedded in soil or plants can monitor pH, moisture, nutrients, and disease in real time, enabling site-specific input application. These systems reduce resource use and enhance crop resilience. In the next 10–20 years, biodegradable nanomaterials, smart-release formulations, and portable biosensor kits may become standard tools. Students can lead innovation, startups can scale localized solutions, and governments must support with funding, regulations, and pilot programs. With collaborative action, nano-agriculture can drive climate-smart, high-efficiency, and sustainable food systems.

6. Conclusion: Small Science, Huge Impact

The Nano Revolution in agriculture is transforming farming with tiny engineered particles that boost crop nutrition, protection, and productivity. Nano-fertilizers enhance nutrient uptake and reduce runoff, while nano-pesticides target pests precisely with minimal environmental impact. Innovations like controlled-release formulations and sensor-based diagnostics enable real-time field decisions, reducing chemical use, lowering costs, and improving yields—key for resilience against climate change and resource limits. Moving forward, collaboration among scientists, farmers, and policymakers, alongside public education, is vital to ensure safe, ethical adoption. Responsible scaling must focus on affordability, accessibility, and sustainability so all farmers benefit. With the right approach, nanotechnology can drive a new green revolution, defined by its powerful impact rather than size.

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Digital Tools and AI in Plant Pathology: Smarter Disease Detection and Management

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Indian agriculture is currently grappling with the dual challenges of feeding a growing population and mitigating the adverse environmental impacts of conventional pesticide usage. Nanotechnology, through the development of nano-pesticides, offers a sustainable and efficient alternative. This article explores the role of nano-pesticides in revolutionizing pest management by enhancing the bioavailability, stability, and targeted delivery of active ingredients. It highlights the advantages of nano-pesticides such as reduced chemical runoff, improved crop yield, and minimized harm to non-target organisms. Additionally, the article discusses recent advancements, safety concerns, and the regulatory landscape in India, emphasizing the need for awareness and responsible adoption. Ultimately, it presents nano-pesticides as a promising solution to ensure food security and environmental sustainability in Indian agriculture.

1. Introduction

Traditional methods of plant disease detection and management largely depend on manual field inspections, expert knowledge, and laboratory analyses. These approaches are often time-consuming, subjective, and limited by the availability of skilled personnel, especially in resource-constrained regions (Mahlein, 2016). Delays in accurate disease diagnosis can result in ineffective treatments, leading to severe crop losses and threatening food security worldwide (Strange & Scott, 2005). Moreover, conventional chemical control strategies, when applied without precise diagnosis, can cause environmental harm and promote pathogen resistance (Savary et al., 2019).

The complexity of plant-pathogen interactions and the increasing incidence of emerging diseases due to climate change and global trade demand faster, more reliable diagnostic tools (Garrett et al., 2018). This urgency has driven the integration of digital tools and artificial intelligence (AI) into plant pathology, ushering in a new era of smart agriculture. AI-powered technologies leverage large datasets, including high-resolution images, spectral data, and environmental parameters, to detect subtle disease symptoms often invisible to the naked eye (Kamilaris & Prenafeta-Boldú, 2018). These tools enable early detection, precise monitoring, and predictive modeling of disease outbreaks, facilitating proactive disease management.

The convergence of machine learning algorithms, computer vision, remote sensing, and Internet of Things (IoT) devices has led to the development of smartphone applications, drone-based surveillance, and sensor networks tailored for plant health monitoring (Ferentinos, 2018; Bock et al., 2020). For example, convolutional neural networks (CNNs) have demonstrated remarkable accuracy in classifying plant diseases from leaf images across various crops (Mohanty et al., 2016). Additionally, AI models can integrate weather data and pathogen life cycle information to forecast disease risks, allowing farmers to optimize pesticide use and reduce environmental impact (Mahlein et al., 2019). As digital tools become more accessible and affordable, they empower farmers, agronomists, and researchers to make data-driven decisions, improving disease management efficiency and crop productivity. However, challenges remain in ensuring data quality, interoperability, and farmer training to fully realize the potential of AI in plant pathology. Addressing these issues is critical for sustainable agriculture and global food security in the face of evolving threats.

2. The Role of Digital Tools in Plant Disease Management

Digital technologies are rapidly transforming plant disease management by enabling faster, more precise, and cost-effective monitoring of crop health. Smartphones equipped with high-resolution cameras allow farmers to capture images of symptomatic plants, which can then be analyzed using AI-powered applications for rapid disease diagnosis without requiring expert knowledge on-site (Kamilaris & Prenafeta-Boldú, 2018). This democratization of plant health expertise is particularly valuable in remote or resource-limited areas. Drones and unmanned aerial vehicles (UAVs) extend disease surveillance capabilities by providing aerial views of large fields, capturing multispectral, hyperspectral, and thermal images that reveal early disease symptoms or stress responses invisible to the naked eye (Zhang & Kovacs, 2012). These aerial platforms enable regular, wide-area monitoring and help identify hotspots of infection, supporting targeted interventions that save time and reduce chemical use.

Ground-based sensors and Internet of Things (IoT) devices continuously gather environmental parameters such as humidity, temperature, leaf wetness, and soil moisture—critical factors influencing disease development and spread (Mahlein et al., 2019). Integration of these real-time data with weather forecasts and disease models allows predictive analytics, which can alert farmers about impending outbreaks, facilitating timely and precise management actions. Several smartphone apps and online platforms have been developed to assist in disease diagnosis and management. For example, Plantix uses deep learning algorithms to identify hundreds of plant diseases from images and provides localized treatment recommendations, thereby helping farmers optimize pesticide use and reduce crop losses (Ferentinos, 2018). Similarly, PlantVillage Nuru employs AI to diagnose diseases in important crops like cassava, maize, and beans, supporting farmers in sub-Saharan Africa through simple mobile interfaces (Ramcharan et al., 2019). These tools often incorporate user-friendly interfaces and multilingual support to increase accessibility.

Beyond diagnosis, digital platforms are increasingly integrating disease data with farm management systems, enabling traceability and data-driven decision-making. For instance, digital dashboards allow farmers to monitor crop health trends, track pesticide application, and coordinate with extension services and supply chains. This connected ecosystem enhances overall farm resilience and productivity. Moreover, big data analytics and machine learning models trained on vast datasets collected through these digital tools are continuously improving disease prediction accuracy and enabling the development of new disease-resistant crop varieties through precision breeding programs. By reducing reliance on blanket chemical applications, these innovations also contribute to environmental sustainability.

3. Artificial Intelligence and Machine Learning: Revolutionizing Diagnosis

Artificial Intelligence (AI) and Machine Learning (ML) are transforming plant disease diagnosis by enabling the rapid analysis of vast and complex datasets to identify patterns that human experts might miss. ML algorithms can be trained on thousands of labeled images of healthy and diseased plants, learning to recognize subtle visual cues and differentiate between multiple diseases with high accuracy (Mohanty et al., 2016). Image recognition models, particularly those based on deep learning and convolutional neural networks (CNNs), have shown remarkable success in diagnosing plant diseases from leaf images. These models automatically extract important features such as color changes, lesion shape, and texture without manual intervention, allowing for efficient, real-time disease detection directly from photographs taken in the field (Sladojevic et al., 2016).

For example, a widely cited study by Mohanty et al. (2016) trained a CNN on over 50,000 images covering 14 crop species and 26 diseases, achieving an accuracy of over 99% in controlled conditions. Another example is the PlantVillage project, which developed an AI-powered app capable of identifying common diseases in crops such as tomato, potato, and corn, assisting farmers worldwide in early and accurate diagnosis (Ferentinos, 2018). Additionally, AI models are being tailored for specific diseases in staple crops. For instance, Ramcharan et al. (2019) developed a deep learning model for cassava disease detection in Africa, which significantly outperformed traditional methods and helped mitigate the spread of devastating viral diseases. These AI-driven diagnostic tools not only reduce dependence on scarce plant pathology experts but also facilitate timely interventions, ultimately minimizing yield losses and promoting sustainable crop management.

4. Precision and Early Detection

AI-powered diagnostics enable early and precise detection of plant diseases, which is crucial for effective disease management and minimizing crop losses. Early identification allows farmers to implement targeted interventions before infections spread widely, reducing the need for broad-spectrum pesticide applications and lowering production costs (Li et al., 2020). These advanced systems improve specificity by reducing false positives that often occur in traditional visual inspections. Machine learning models can distinguish between disease symptoms and other abiotic stresses like nutrient deficiencies or physical damage, increasing diagnostic accuracy and enabling more confident decision-making (Barbedo, 2018).

Moreover, integrating AI diagnostics with environmental data, such as weather patterns, humidity, and soil conditions, enhances disease outbreak prediction. Predictive models use this combined data to forecast pathogen development and spread, allowing proactive measures such as timely fungicide application or altering planting schedules (Mahlein et al., 2019; Jones et al., 2020). This precision approach not only optimizes input use but also promotes sustainable agriculture by preventing unnecessary chemical applications and mitigating environmental impact.

5. Decision Support Systems (DSS) for Management

AI-driven Decision Support Systems (DSS) are transforming plant disease management by providing tailored recommendations based on precise disease diagnosis. These platforms analyze diagnostic data along with environmental, crop, and management variables to suggest optimal treatment options, including the type, timing, and dosage of pesticides or biological agents (Wolfert et al., 2017). By optimizing pesticide use, DSS reduce excessive chemical applications, lowering input costs and minimizing negative environmental impacts such as soil and water contamination (Patil et al., 2020). This precision helps maintain ecosystem health while protecting crop productivity.

DSS also play a vital role in integrated disease management (IDM) by combining digital diagnostics, forecasting, and treatment recommendations within a holistic framework. This supports farmers in making informed decisions that balance disease control with sustainability goals (Kamilaris et al., 2018).Overall, AI-driven DSS enable smarter, data-informed disease management that enhances crop resilience and supports sustainable agricultural practices.

6. Challenges, Limitations, and Future Perspectives

Despite their promise, digital and AI tools face barriers such as limited technology access and internet connectivity in many rural farming communities, restricting widespread adoption (Kamilaris et al., 2018). Data privacy and security concerns also arise as large volumes of sensitive farm data are collected and shared (Wolfert et al., 2017). AI systems require local adaptation to account for regional crop varieties, disease strains, and farming practices to ensure accuracy and relevance (Patil et al., 2020). Looking ahead, emerging technologies like AI-powered robotic scouts and autonomous drones promise to enhance real-time monitoring and precision interventions. There is also growing potential for global disease surveillance networks that enable early warning and coordinated response to outbreaks across borders. Achieving this future demands strong interdisciplinary collaboration among technologists, plant pathologists, policymakers, and farmers to overcome challenges and promote responsible, equitable adoption.

7. Conclusion

Digital tools and artificial intelligence are revolutionizing plant disease detection and management by enabling faster, more accurate, and cost-effective diagnostics. These technologies empower farmers to make timely decisions, optimize resource use, and reduce environmental impact, ultimately enhancing crop productivity and sustainability. As global food security faces increasing threats from climate change and emerging pathogens, the integration of AI-driven solutions offers a critical pathway toward resilient agricultural systems. Continued innovation, combined with farmer education and accessible technology deployment, is essential to fully realize the benefits of this digital transformation and ensure that farmers worldwide can harness these advances for healthier crops and improved livelihoods.

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Safflower: The Bioenergy Crop

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Safflower (*Carthamus tinctorius*), traditionally cultivated for oil, dyes, and livestock feed, is emerging as a promising bioenergy crop due to its high oil content (20-40%), drought tolerance, and adaptability to marginal lands. Recent research highlights its potential for biodiesel, renewable diesel, and sustainable aviation fuel (SAF), with yields comparable to conventional biofuel crops like soybean and canola but with significantly lower water requirements. Despite challenges such as yield volatility and limited processing infrastructure, advancements in genetic engineering and sustainable farming practices are enhancing safflower's viability. This article explores safflower's role in the bioenergy sector, its environmental and economic benefits, and the innovations driving its future as a key player in renewable energy. With supportive policies and investment, safflower could contribute significantly to reducing greenhouse gas emissions and diversifying energy sources in a climate-constrained world.

Introduction:

As global temperatures rise and fossil fuel reserves dwindle, the world is urgently seeking sustainable alternatives that don't compete with food security. One surprising candidate is safflower (*Carthamus tinctorius*)—a drought-resistant oilseed crop cultivated since ancient Egypt. Once valued for its dyes and medicinal properties, safflower is now emerging as a promising player in the bioenergy revolution. Recent USDA studies indicate safflower can yield 200–300 gallons of biodiesel per acre—comparable to canola and significantly more water-efficient than corn ethanol. In Australia, where climate change has reduced traditional crop yields by up to 40%, safflower is being recognized as a "climate-smart" biofuel solution. This article explores how this humble thistle could help decarbonize transportation, empower farmers, and redefine renewable energy.

What is Safflower?

Safflower belongs to the Asteraceae family and thrives in arid regions with just 12–18 inches of annual rainfall. There are two major types: high-oleic varieties, rich in monounsaturated fats ideal for biofuels and cooking oils, and high-linoleic types, used in paints and nutritional supplements. First domesticated in Mesopotamia over 4,000 years ago, safflower has served diverse purposes through history—from dyeing Egyptian mummy wrappings to Ayurvedic medicine in India. In the U.S., it found use in industrial paints and varnishes during the 1940s and '50s. Today, leading safflower producers include Kazakhstan (which

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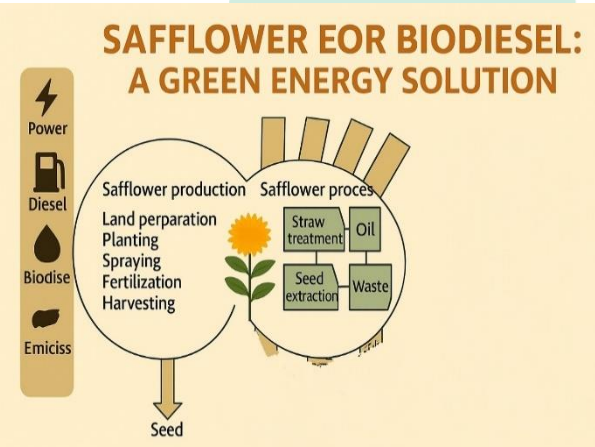
supplies over 50% of the global output), India, Mexico, and the U.S., particularly Montana and North Dakota. The crop's resilience has made it a valuable alternative in Australia's drought-stricken wheat belt, where over 150,000 acres are now dedicated to safflower cultivation.

Safflower as a Bioenergy Source

When compared with other biofuel crops, safflower stands out. It yields 200–300 gallons of oil per acre while requiring relatively little water. In contrast, soybeans produce only 50–100 gallons, canola 120–170, and corn ethanol just 20–30 gallons—with far higher water demands. Beyond biodiesel, safflower oil is being tested for hydrotreated vegetable oil (HVO) applications by companies like Shell and Neste, targeting truck and jet fuel use. A 2023 study from the University of Georgia found that safflower-based sustainable aviation fuel (SAF) could reduce aviation emissions by up to 65% over its lifecycle. The crop also offers zero-waste potential: the protein-rich press cake (30% protein) serves as livestock feed, and stalks can be burned for bioelectricity—one ton of biomass delivers energy equivalent to low-grade coal.



Advantages Over Other Biofuels

Safflower boasts several advantages that make it particularly appealing in the context of climate change. Its deep taproots—reaching 6 to 10 feet—enable it to access subsoil moisture, giving it a major edge in drought conditions. For instance, during Texas' severe 2022 drought, safflower yields dropped just 5%, compared to corn's devastating 40% collapse. In terms of environmental impact, safflower biodiesel emits 85% less CO_2 than fossil diesel, according to USDA lifecycle analyses. Furthermore, the crop thrives on marginal, saline, or eroded lands where food crops can't grow, making it an excellent candidate for sustainable expansion. Economically, safflower offers attractive returns—$200–$400 per acre compared to $150–$300 for wheat—according to Montana State University data. It also fits well in crop rotations, helping to disrupt pest cycles and improve subsequent wheat yields by 10–15%.

Challenges to Overcome

Despite its promise, safflower is not without challenges. Its yield can be sensitive to high temperatures; flowers may abort above 35°C (95°F), a concern as heatwaves become more frequent. Pests like safflower aphids can also cause significant damage—up to 50% yield loss if unmanaged—highlighting the need for integrated pest management (IPM) strategies. Infrastructure remains a bottleneck, with only five dedicated safflower oil mills in the U.S. compared to over 300 for soybeans. Many farmers depend on niche contracts, such as those offered by the Montana Bioenergy Cooperative, limiting broader adoption. Additionally, as high-oleic safflower oil gains popularity for heart-healthy diets, a rise in biofuel demand could push up cooking oil prices, sparking the familiar food vs. fuel debate. One solution may lie in developing dual-purpose varieties that balance nutrition with fuel utility.

Cutting-Edge Innovations

To overcome these barriers, scientists and companies are investing in innovation. Syngenta's "Super Safflower," genetically engineered to produce 50% more oil, is currently undergoing field trials in Argentina. At UC Davis, researchers are using CRISPR to enhance heat tolerance by editing the *Cthsp17* gene. Agroecological approaches are also showing promise—intercropping safflower with chickpeas in India has been shown to increase farmer incomes by 22%, according to a 2023 ICRISAT study. Precision agriculture tools, such as drones that monitor flower maturity, are improving harvest timing and efficiency. Real-world success stories are emerging: in Australia, over 500 farms now supply safflower oil for biodiesel powering Brisbane's public buses, while Boeing is funding safflower R&D in California's Central Valley as part of its SAF initiatives.

The Road Ahead

For safflower to fulfill its bioenergy potential, targeted policy support is essential. This includes extending subsidies—like the U.S.'s $1.00-per-gallon biodiesel tax credit—to safflower-based fuels and increasing USDA REAP grants for safflower-to-jet-fuel projects. Market forecasts are optimistic: the global safflower oil market is projected to reach $3.2 billion by 2030. Additionally, safflower's ability to sequester carbon—estimated at 1.2 tons of CO_2 per acre annually—could offer farmers a new revenue stream through carbon credits. With the right combination of research, innovation, and incentives, safflower could very well become the next big player in the global bioenergy landscape.

Future Aspects

The future of safflower as a bioenergy crop looks increasingly promising, especially in the face of escalating climate challenges and the global push for cleaner fuels. With ongoing advances in genomics and molecular breeding, we can expect new safflower varieties that offer higher oil yields, greater heat tolerance, and resistance to pests—traits essential for adapting to changing agro-climatic zones. The integration of precision farming, AI-based crop monitoring, and carbon-smart practices will further enhance safflower's efficiency and environmental impact. Expansion into marginal and underutilized lands provides a unique opportunity to scale safflower production without affecting food security. Governments and private investors are beginning to recognize this potential, opening the door for increased funding in research, processing infrastructure, and market development. Moreover, the growing interest in sustainable aviation fuel (SAF) and hydrotreated vegetable oil (HVO) positions safflower as a viable contributor to the decarbonization of long-haul transportation sectors like aviation and freight.

Conclusion

Safflower's future as a bioenergy crop is bright, driven by its adaptability, environmental benefits, and alignment with global sustainability goals. While challenges remain, concerted efforts in research, policy, and market development can unlock its full potential. As the world transitions to renewable energy, safflower could emerge as a cornerstone of low-carbon bioenergy systems, offering a sustainable solution for farmers, industries, and the planet.

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ANTHRAX: THE BITTER SPORES

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Anthrax is an acute infectious disease affecting both animals and humans, caused by the bacterium *Bacillus anthracis*. The disease is known by different names depending on the host and mode of infection; in animals, it is often called Wool Sorter's Disease. *Bacillus anthracis*, the causative agent, belongs to the Bacillaceae family. The incubation period for anthrax can range from a few hours to up to 60 days, depending on the form of the disease. The disease is more prevalent in tropical and subtropical regions, especially where livestock vaccination is insufficient, and environmental conditions support the survival of spores. Anthrax is endemic in parts of Africa, Asia, South America and the Middle East, with occasional outbreaks in countries like India and Bangladesh. Herbivores are the natural hosts, and humans typically acquire the disease incidentally through contact with infected animals or animal products. Transmission occurs primarily via contact with *Bacillus anthracis* spores, which can enter the body through the skin, respiratory tract, or gastrointestinal tract. The clinical manifestations of anthrax vary depending on the route of infection viz., cutaneous, inhalational or gastrointestinal. Diagnosis is made based on patient history, clinical symptoms and confirmatory laboratory tests. Effective control of anthrax requires rigorous biosecurity measures, safe handling of infected materials, timely vaccination and proper disposal of carcasse.

Introduction

Anthrax is a zoonotic disease found worldwide, known for its high contagiousness and potentially fatal outcomes. The word anthrax is derived from Greek word “anthrakites” which means 'coal', and referring to the blackened eschar skin lesion. In the year 1850, French scientists Pierre Rayer and Casimir Joseph Davaine were the first to observe the rod-shaped microorganisms in the blood of animals that had died from anthrax. Their discovery marked a significant milestone in Veterinary Microbiology and Public Health, marks the beginning for further research into the bacterial cause of the disease. Anthrax is caused by the bacterium *Bacillus anthracis* (B. anthracis), a spore-forming organism capable of surviving in the environment for long periods. Herbivorous animals, such as cattle, sheep, goats, and buffaloes, serve as the natural hosts of this disease. However, all warm-blooded animals, including humans, are susceptible to infection. Humans typically contract anthrax incidentally through direct contact with infected animals, contaminated animal products, or by handling or consuming meat from infected carcasses. The disease can spread from animal to animal, and from animals to humans, especially in areas where preventive measures are lacking. Due to its zoonotic nature, anthrax remains a public health concern, particularly in regions with poor veterinary infrastructure and uncontrolled livestock movement. Anthrax manifests in three primary forms in humans viz., cutaneous, inhalational and gastrointestinal, depending on the route of entry of the *Bacillus anthracis* spores. Cutaneous anthrax, the most common form, occurs when spores enter through cuts or abrasions on the skin, accounting for approximately 95% of human cases. Inhalational anthrax, though less frequent (about 5%), is the most severe and occurs when spores are inhaled into the lungs. Gastrointestinal anthrax, caused by ingestion of contaminated meat, is extremely rare and represents less than 1% of all cases. A fourth and even rarer manifestation, anthrax meningitis, can arise as a complication of any of the other three forms, often leading to a fatal outcome. Notably, during the Industrial Revolution in Victorian England, inhalational anthrax gained notoriety as 'wool sorters' disease' due to its prevalence among workers handling contaminated wool and animal hides. Diagnosis of anthrax is typically based on clinical signs, history of exposure and laboratory testing. In suspected cases, blood samples, skin lesions or respiratory secretions are collected to detect the presence of *Bacillus anthracis* using methods such as PCR (Polymerase Chain Reaction), blood culture or immunohistochemistry. Early identification is crucial for effective treatment. For inhalational or severe cases, additional supportive care, including intravenous antibiotics and sometimes antitoxin therapy, may be required. Vaccination of animals and at-risk workers is a preventive measure, and a vaccine is also available for high-risk groups to reduce the risk of infection.

Historical and Occupational Terminologies of Anthrax

Anthrax is known by various names depending on the host and the route of infection. In animals, it is commonly referred to as Wool sorter's disease. In humans, different synonyms have been used based on occupational exposure and clinical manifestation. Wool sorter's disease also refers to pneumonic or pulmonary anthrax, particularly among individuals handling wool or animal products. Other occupationally linked names include Rag-picker's disease, Knacker's disease, and Hide-porter's disease, often associated with cutaneous anthrax resulting from direct contact with contaminated animal materials. Clinical terms such as malignant edema, malignant carbuncle, malignant pustule, charbon (French), Milzbrand (German) and splenic fever reflect the severe and often systemic nature of the disease. These synonyms highlight the historical and occupational relevance of anthrax, as well as its varied clinical presentations.

The Organism and Etiology

The causal agent of anthrax is *Bacillus anthracis* which belongs to family Bacillaceae. It is one of the largest among all the bacterial pathogens (3-5 x 1-1.2 µm). The bacilli aerobic, gram positive, non-motile spore forming rods which are arranged in long chains. Bacillus anthracis exists in two distinct forms viz., the vegetative form and the spore form. Inside the host, where the environment is low in oxygen, the bacterium remains exclusively in its vegetative state. However, when conditions become unfavourable for growth and survival such as outside the host, the vegetative cells begin to transform into spores. This process of sporulation requires the presence of free oxygen. Spores can develop in laboratory cultures, contaminated soil and in the tissues or discharges of dead animals. These spores are oval or ellipsoidal in shape, centrally located within the bacterial cell, and are known for their remarkable resistance to extreme environmental conditions, including high and low temperatures, desiccation, chemical disinfectants, pH variations and even irradiation. This resilience enables them to persist in the environment for decades, posing a long-term risk of infection.

Incubation Period

The incubation period for anthrax can vary significantly, ranging from a few hours to as long as 60 days, depending on the form of the disease. In cutaneous anthrax, the incubation period typically lasts between a few hours and 3 weeks, with most cases presenting symptoms within 2 to 6 days after exposure. Gastrointestinal anthrax usually has an incubation period of 3 to 7 days, with symptoms emerging relatively quickly after ingestion of contaminated meat. For inhalational anthrax, the median incubation period is approximately 4 days, though it can extend up to 10 or 11 days, depending on the dose of spores inhaled and the individual's immune response. Early recognition and timely treatment are critical, especially for inhalational anthrax, as the disease can progress rapidly once symptoms appear.

The Global Scenario

Anthrax is more common in tropical and subtropical regions, particularly where livestock vaccination is inadequate and environmental conditions favour spore survival. The disease is endemic in parts of Africa, Asia, South America and the Middle East, and sporadic outbreaks continue to occur in countries like India and Bangladesh. In India, anthrax is reported from several states including Odisha, Andhra Pradesh, Tamil Nadu and Karnataka, where rural communities depend heavily on livestock for livelihood. Outbreaks often coincide with dry seasons or after flooding, when dormant spores resurface from the soil. Human cases are usually occupational, affecting farmers, butchers, wool and hide workers, and veterinarians who come into direct contact with infected animals or animal products. The persistence of spores in the soil for decades without losing infectivity contributes to recurring outbreaks. Poor carcass disposal practices and lack of awareness further increase the risk of disease transmission. Despite being a notifiable disease in many countries, underreporting is common due to inadequate surveillance and diagnostic facilities in rural areas.

Host Range and Reservoirs

Herbivorous animals, both domestic (such as cattle, sheep, goats, and buffaloes) and wild species, are highly susceptible to anthrax. In contrast, animals like swine, horses, dogs, and camels show moderate susceptibility. Birds and carnivores typically exhibit a high level of natural resistance to the disease. Humans are considered moderately resistant; however, anthrax remains a significant occupational hazard, especially for those working in high-risk industries such as wool processing, meat handling, hair and hide preparation, bone meal production, and leather work. Although the number of human cases is relatively low compared to the level of exposure, the risk persists due to the enduring presence of spores in the environment.

Transmission

Anthrax is primarily transmitted through contact with spores of the bacterium *Bacillus anthracis*, which can enter the body through the skin, respiratory tract, or gastrointestinal tract. These spores are highly resilient and can survive in soil for decades, making contaminated environments a long-term source of infection.

The most common route of transmission in animals is through ingestion of spore-contaminated soil, water, or feed. Grazing animals are especially vulnerable when spores surface due to heavy rains, flooding, or soil disturbance. Carnivores may become infected by feeding on infected carcasses.

In humans, anthrax is not typically spread from person to person, but it is transmitted through:

a. Direct contact with infected animals or their products (e.g., hides, wool, meat, bones), leading to cutaneous anthrax.
b. Inhalation of spores, particularly in industrial settings, which may cause inhalational anthrax, also known historically as “wool sorters' disease.”
c. Ingestion of undercooked meat from infected animals, which can result in gastrointestinal anthrax.
d. Rarely, injectional anthrax has been reported among drug users due to contaminated needles or substances.

Improper disposal of infected carcasses can amplify the risk of outbreaks by contaminating the soil and water, contributing to sustained environmental exposure.

Pathogenesis

Humans can acquire anthrax infection through three primary routes: cutaneous, inhalational, and gastrointestinal. Cutaneous anthrax, the most common form, occurs when *Bacillus anthracis* spores enter through minor cuts or abrasions on the skin, leading to localized bacterial multiplication, inflammation and the characteristic black eschar. Inhalation anthrax, the most severe form, results from inhalation of spores that germinate in the lungs and are transported to regional hilar lymph nodes, causing extensive haemorrhagic mediastinitis and necrosis. Gastrointestinal anthrax arises from ingestion of undercooked or contaminated meat, leading to invasion and ulceration of the gastrointestinal mucosa, often presenting with abdominal pain, vomiting and bloody diarrhoea. All three forms of anthrax can progress to systemic involvement, with dissemination of the bacteria into the bloodstream, resulting in severe toxaemia and high mortality if left untreated. Complications such as anthrax meningitis may also develop in systemic cases, particularly with inhalation anthrax. Recovery from anthrax infection typically provides long-lasting immunity, and reinfections are rare. While the widespread availability of effective antibiotics, such as ciprofloxacin and doxycycline, has significantly reduced the case fatality rate (CFR), prompt diagnosis and treatment remain critical. In untreated cases, especially inhalation and gastrointestinal anthrax, the CFR remains high. Moreover, anthrax remains a serious concern in the context of bioterrorism, where deliberate aerosolization of spores could result in large-scale outbreaks with substantial fatality rates. Thus, vigilance and preparedness are essential, particularly for populations at risk of occupational or deliberate exposure.

Clinical Signs

Anthrax presents with variable clinical signs depending on the route of infection viz., cutaneous, inhalational, or gastrointestinal. In cutaneous anthrax, which is the most common form, symptoms begin with itchy papules that develop into painless ulcers with a characteristic black necrotic centre (eschar). Inhalation anthrax starts with flu-like symptoms such as fever, cough, and malaise, rapidly progressing to severe respiratory distress, shock, and often death if untreated. Gastrointestinal anthrax, acquired through consumption of contaminated meat, causes nausea, vomiting, abdominal pain, bloody diarrhoea, and sometimes intestinal perforation. In severe cases, all forms can lead to systemic infection, septicaemia, and meningitis. In animals, sudden death is often the first sign, frequently accompanied by bleeding from natural body openings and rapid bloating of the carcass. Timely diagnosis and treatment are critical, as untreated anthrax is often fatal.

Diagnosis

Anthrax diagnosis is based on patient history, clinical signs and confirmatory laboratory tests. Microscopic examination of vesicular fluid, skin lesions, respiratory exudates, or blood using polychrome methylene blue, Giemsa or Wright's stain reveals the characteristic square-ended, blue-stained bacilli with a pink capsule known as McFadyean's reaction, a key diagnostic hallmark. In animals, blood smears from the ear vein are similarly stained. Culture on nutrient agar under aerobic conditions yields rough colonies with a medusa-head or bamboo-rod appearance. In gelatin stab cultures, *Bacillus anthracis* forms an inverted fir tree pattern due to facultative anaerobic growth. Confirmation can be done through animal inoculation in guinea pigs or mice, Ascoli's thermo-precipitation test for detecting anthrax antigen in tissues, and modern molecular techniques like PCR for rapid and specific detection.

Prevention

A human anthrax vaccine is available and is primarily derived from the protective antigen (PA) of an attenuated, non-encapsulated strain of *Bacillus anthracis*. The antigen is adsorbed onto alum to enhance its immunogenicity. This vaccine is recommended for individuals with a high risk of occupational exposure, such as laboratory personnel and veterinarians in regions where anthrax is endemic. The standard vaccination schedule includes doses at 0, 2, and 4 weeks, followed by additional doses at 6, 12, and 18 months, with annual boosters thereafter. In the event of post-exposure, the vaccine is administered at 0, 2, and 4 weeks. Adverse reactions are uncommon and generally mild. The vaccine should be administered only when the anticipated benefits clearly outweigh the potential risks.

Public Health and Veterinary Measures for Anthrax Control

Effective anthrax control requires strict biosecurity, careful handling of infected materials, timely vaccination, and proper carcass disposal. Human and veterinary health sectors must coordinate to curb the spread of this zoonotic disease. Upon detection of anthrax, through clinical signs, slaughter house inspection, or post-mortem, immediate restrictions are essential. Slaughter operations should stop, and infected animals must be incinerated or buried in a 2-meter-deep pit with quick lime, away from water sources and animal access. Carcasses must not be opened to avoid spore release; natural orifices should be sealed with disinfectant-soaked cotton, and transport should be done in closed vehicles. Disinfection of all facilities, tools, and clothing is crucial using 5-10% formaldehyde, 4% warm sodium carbonate, 4-5% lye, or 5% phenol. Wool or hair from endemic areas must be treated with 10% formalin, 5% lye, or 3% peracetic acid.

For humans, protective clothing, gloves, masks, and avoidance of contact especially with broken skin are vital when handling carcasses or animal products. In animals, vaccination with spore-based anthrax vaccines is key, though antibiotics should not be used 2–3 days before or after, and pregnant animals should not be vaccinated. These combined efforts are critical for effective anthrax prevention and control.

Conclusion

Anthrax remains a serious zoonotic disease with significant public health implications. Although rare in humans, its high fatality rate and potential for use in bioterrorism demand sustained vigilance. Prevention in humans primarily depends on effective control in cattle through regular vaccination, proper carcass disposal and use of personal protective equipment. Early diagnosis and prompt initiation of appropriate antibiotic therapy are critical for better outcomes. However, the extended duration of treatment poses challenges, emphasizing the urgent need for research into more efficient and shorter therapeutic options. Combating deliberate misuse and strengthening awareness at all levels are key to reducing the threat of anthrax in the future.

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Smart Farming: Integration of IoT and Robotics

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Precision agriculture, sometimes referred to as "smart farming," is a revolutionary development in contemporary agriculture that incorporates robotics and Internet of Things (IoT) technologies into farming operations. The goal of this merger is to improve agricultural output, sustainability, and efficiency. Through the use of technology and data-driven insights, farmers may overcome the difficulties presented by conventional farming practices, maximise resource use, and make well-informed decisions. With the growing global population and increasing food demand, precision farming has become an essential tool in modern agriculture. It not only improves farm profitability but also contributes to environmental sustainability by reducing excessive use of water, chemicals, and energy. As technology continues to advance, the integration of smart sensors, autonomous robots, and AI-driven analytics will further revolutionize precision farming, making agriculture more efficient and resilient to climate change

The Role of IoT in Smart Farming

The foundation of smart farming is the Internet of Things (IoT), which links several gadgets and sensors to gather and examine data in real time from the agricultural environment. Numerous variables, including as crop health, temperature, humidity, and soil moisture, are tracked by these Internet of Things-enabled gadgets. For example, sensors positioned in fields can measure the moisture content of the soil and send the data to a central system, allowing for accurate irrigation control. This method guarantees that crops receive the right amount of hydration, which improves yields while simultaneously conserving water.

Additionally, farming equipment can be remotely monitored and controlled thanks to IoT devices. Using their laptops or smartphones, farmers can control machinery, change settings, and get notifications when an issue occurs. Farmers can run their operations more effectively because to this degree of connectedness, which lessens the requirement for continual human presence in the fields.

Integration of Robotics in Agriculture

By automating labour-intensive jobs, robotics helps to improve farming operations' precision and alleviate labour shortages. Autonomous devices, such drones and ground robots, are being used more and more for a variety of agricultural tasks.

Drones with cutting-edge imaging capabilities can sweep vast areas of land, taking high-resolution pictures that aid in monitoring plant development, identifying pest infestations, and evaluating crop health. These aerial views offer important information that are difficult to obtain from terrestrial observations.

In contrast, ground robots are used for operations such as harvesting, weeding, and planting. For instance, autonomous tractors with GPS navigation systems can prepare the soil and plant precisely with little assistance from humans. In a similar vein, robotic harvesters are made to recognise and choose ripe fruits,

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decreasing the need for manual labour and boosting productivity. The creation of an autonomous agricultural robot that can do semi-autonomous farm duties, such as weeding and fertiliser spraying, for low-height vegetable crops provides as an example.

Case Studies and Applications

Several initiatives worldwide exemplify the successful integration of IoT and robotics in agriculture.

- **Hands Free Hectare (HFH):** The HFH project, which is based at Harper Adams University in the UK, accomplished a significant milestone by finishing the first cropping cycle in history to be entirely independent. The initiative used drones and autonomous tractors to carry out planting, harvesting, and monitoring without the need for human assistance. This project showed how IoT and robotics can be combined to transform conventional farming methods.
- **SwagBot:** SwagBot is an AI-powered autonomous robot created by University of Sydney academics to oversee cattle husbandry. SwagBot, which has sensors and machine learning capabilities, herds cattle to the best grazing locations, evaluates pasture quality, and keeps an eye on livestock health. By avoiding overgrazing and soil degradation, this method not only improves efficiency but also supports environmental sustainability.
- **Bonsai Robotics:** The goal of this AgTech firm is to create self-sufficient machinery for tree crop harvesting. Their robots can effectively harvest nuts including walnuts, pistachios, and almonds by using vision-based technologies. By automating laborious harvesting procedures, this invention attempts to lower food costs and address labour shortages.

Challenges and Considerations

While the integration of IoT and robotics in agriculture offers numerous benefits, it also presents certain challenges.

- **Technical Complexity:** The deployment of advanced technologies requires significant technical expertise. Farmers need to be trained to operate and maintain IoT devices and robotic systems effectively.
- **Economic Factors:** The initial investment for implementing smart farming technologies can be substantial. Small-scale farmers, in particular, may find it challenging to afford these innovations without financial support or subsidies.
- **Data Security and Privacy:** The extensive use of connected devices raises concerns about data security and privacy. Ensuring that sensitive information is protected from cyber threats is paramount.
- **Environmental Impact:** While automation can lead to more efficient resource use, it is essential to assess the environmental footprint of manufacturing and operating these technologies. Sustainable practices should be prioritized to minimize any negative impacts.

Future Prospects

Artificial intelligence (AI) and machine learning, along with the ongoing development and integration of robotics and the Internet of Things (IoT), are key components of smart farming's future. Large volumes of data can be analysed by these technologies to improve decision-making, optimise operations, and yield predictive insights.

AI systems, for example, can forecast weather patterns, which helps farmers better plan when to plant and harvest. In order to suggest the best crop kinds and fertilisation techniques, machine learning algorithms can evaluate soil data. Furthermore, the creation of increasingly complex multitasking autonomous robots will lessen the demand for manual labour and boost agricultural output overall.

Collaborative efforts between technology developers, agricultural experts, and policymakers are crucial to address the challenges and ensure that the benefits of smart farming are accessible to all farmers, regardless of scale. Investments in research, infrastructure, and education will play a vital role in the widespread adoption of these technologies.

Conclusion

The integration of IoT and robotics in agriculture marks a significant evolution in farming practices, offering solutions to enhance efficiency, productivity, and sustainability. By embracing these technologies, the agricultural sector can meet the growing global food demand while conserving resources and protecting the environment. As innovations continue to emerge, the collaboration among stakeholders will be essential in shaping the future of agriculture in the digital age.

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Introduction to Automation in Aquaculture System

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Definition of Automation

- Automation in aquaculture refers to the application of technology and machinery to perform tasks and processes in fish and seafood farming without direct human intervention.
- It encompasses a wide range of activities, from feeding and water quality management to data monitoring and harvesting.

Importance in Aquaculture

- Automation is crucial in modern aquaculture due to its ability to enhance efficiency, precision, and sustainability.
- It helps address challenges such as labor shortages, environmental concerns, and the need for increased production.

Scope for Automation and Need for Automation in Aquaculture

Scope for Automation in Aquaculture:

The scope for automation in aquaculture is extensive and encompasses various aspects of operations, management, and sustainability. As technology advances, the potential for automation in aquaculture is continually expanding. Here are some key areas where automation holds significant scope:

1. Water Quality Management: Automation can monitor and control parameters such as temperature, pH, oxygen levels, and ammonia concentrations in real-time, ensuring optimal conditions for aquatic species.

2. Feeding Precision: Automated feeding systems dispense feed accurately based on species' nutritional requirements and growth stages, minimizing waste and optimizing growth rates.

3. Health Monitoring and Disease Prevention: Automation can detect early signs of stress or disease through behavioural patterns and physiological indicators, enabling timely intervention.

4. Environmental Control: Automation regulates water circulation, aeration, and lighting conditions to replicate natural environments, improving growth rates and overall health.

5. Data Analytics and Decision-Making: Automation generates vast amounts of data that can be analyzed to identify trends, make informed decisions, and optimize processes.

6. Harvesting and Sorting: Automation can facilitate efficient and stress-free harvesting processes, minimizing handling and ensuring consistent product quality.

7. Sustainability and Eco-Friendly Practices: Automation can contribute to sustainable aquaculture practices by minimizing environmental impact and adhering to regulatory requirements.

8. Integrated Aquaculture Systems: Automation can facilitate the integration of aquaculture with other sectors, such as hydroponics or algae cultivation, creating more efficient and resourceful ecosystems.

Need for Automation in Aquaculture

The need for automation in aquaculture arises from several factors that impact the industry's productivity, efficiency, and sustainability:

1. Rising Demand for Seafood: As global demand for seafood increases, aquaculture operations need to enhance productivity to meet consumer needs.

2. Labor Scarcity: Labor availability and costs can be challenging in remote or expansive aquaculture facilities. Automation helps address these issues.

3. Precision and Efficiency: Automation ensures precise control over critical parameters, reducing resource wastage and optimizing growth rates.

4. Environmental Concerns: Automation helps manage environmental impact by reducing the release of pollutants and managing waste more efficiently.

5. Health Management: Early disease detection and stress prevention are critical in aquaculture. Automation can provide continuous monitoring to maintain aquatic health.

6. Data-Driven Decision-Making: The wealth of data generated by automation systems enables more informed decision-making for optimal outcomes.

7. Consistency and Quality: Automation ensures consistent processes, resulting in uniform growth rates and high product quality.

8. Innovation and Industry Growth: Automation encourages the development of new technologies, fostering innovation and driving the growth of the aquaculture industry.

Advantages of Automation in Aquaculture Systems

1. Increased Efficiency: Automation streamlines processes, reduces manual labor and ensures tasks are performed consistently, leading to higher operational efficiency.

2. Enhanced Productivity: Automated systems optimize feeding, water quality, and other parameters, resulting in improved growth rates and increased production.

3. Improved Resource Utilization: Automation minimizes the waste of resources like feed and water, leading to cost savings and reduced environmental impact.

4. Precision Feeding: Automated feeders provide precise and timely feeding, reducing overfeeding and improving feed conversion ratios.

5. Real-time Monitoring: Automation allows continuous real-time monitoring of water quality, health parameters, and environmental conditions, enabling prompt intervention.

6. Labor Cost Reduction: Automation reduces the need for manual labour, cutting labour costs and addressing challenges related to labour availability.

7. Remote Monitoring and Control: Many automation systems allow operators to monitor and adjust parameters remotely, offering flexibility and convenience.

8. Minimized Disease Risk: Early detection of health issues through automation helps prevent disease outbreaks, reducing mortality rates.

Disadvantages of Automation in Aquaculture Systems

1. Initial Investment: Implementing automation systems can require significant upfront investment in technology, equipment, and training.

2. Technical Complexity: Operating and maintaining automated systems may require specialized technical skills, training, and ongoing support.

3. Dependency on Technology: Relying heavily on automation makes operations vulnerable to technical failures or malfunctions, which can disrupt production.

4. Environmental Impact: In some cases, automation systems may consume energy or resources, potentially affecting the environment if not managed sustainably.

5. Lack of Flexibility: Some automated systems are designed for specific tasks, limiting their adaptability to changing conditions or new challenges.

6. Integration Challenges: Integrating new automation technology with existing systems or infrastructure can be complex and time-consuming.

7. Data Management: Collecting and analyzing data generated by automation systems requires appropriate tools and resources for effective decision-making.

8. Reduced Human Interaction: Overreliance on automation might lead to reduced human presence on farms, potentially affecting animal welfare and the ability to respond to unexpected events.

9. Security Concerns: Automation systems connected to networks can be vulnerable to cyberattacks or data breaches, requiring robust security measures.

Current Status and Prospects of Automation in India

Current Status of Automation in India

Automation has made significant strides globally, impacting various industries, including agriculture and aquaculture. In aquaculture, advanced automation technologies are increasingly being adopted to improve efficiency, productivity, and sustainability. Some trends and developments include.In India, the aquaculture sector is gradually embracing automation to improve productivity and efficiency:

1. Feeding and Monitoring: Automated feeding systems and water quality monitoring devices are used to manage ponds and tanks efficiently.

2. Remote Monitoring: Remote monitoring systems are gaining traction, enabling farmers to monitor and control their operations remotely.

3. Technological Adoption: The adoption of automation is increasing, but there's still potential for broader integration of advanced technologies.

Prospects of Automation in India

The opportunities for automation in Indian aquaculture are positive:

1. Increasing Awareness: As awareness about the benefits of automation spreads, more aquaculture operators are likely to adopt these technologies.

2. Government Initiatives: Government support and incentives for adopting advanced technologies could encourage wider automation adoption.

3. Small-Scale Aquaculture: Automation could benefit small-scale aquaculture operations by reducing labour demands and increasing efficiency.

4. Sustainable Practices: Automation will contribute to meeting sustainability goals, which are becoming increasingly important in the Indian aquaculture sector.

In both the global and Indian contexts, the future of automation in aquaculture holds promise for driving innovation, improving productivity, and contributing to sustainable food production. However, careful planning, training, and integration are crucial to realizing these potential benefits effectively.

Conclusion

- Automation revolutionizes aquaculture with efficiency, precision, and sustainability.
- It optimizes feeding, monitoring, and harvesting while reducing labor and errors.
- Automation contributes to better resource management, product quality, and data-driven decisions.
- It aligns with sustainability goals, conserving resources and minimizing environmental impacts.
- The adoption of automation ensures competitiveness and resilience in the evolving aquaculture industry.
- In conclusion, the scope for automation in aquaculture is broad, and the need is driven by increased demand, labour challenges, environmental considerations, and the quest for more efficient and sustainable practices. Embracing automation in aquaculture can lead to improved productivity, enhanced product quality, and a more environmentally conscious approach to seafood production.

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The Impact of Plant Genetics on Agriculture Production and Productivity

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Agriculture continues to be the backbone of human society, providing essential resources like food, fibre, and raw materials. With the world population projected to reach over 9 billion by 2050, there is a critical need to increase agricultural productivity in a sustainable manner. This article discusses the revolutionary potential of plant genetics in meeting this challenge by enhancing crop yields, biotic and abiotic stress resistance, and nutritional value. The book explores major genetic approaches such as traditional breeding, hybridization, genetic engineering, marker-assisted selection, and CRISPR-based gene editing and demonstrates their practical contribution using case studies like the Green Revolution, Bt cotton in India, and drought-tolerant maize in Africa. It highlights the many-sided advantages of genetic progress ranging from productivity and climate resilience to lower reliance on agrochemicals and enhanced farmer incomes. In spite of major successes, the article also addresses current challenges such as ethical issues, regulatory issues, and biodiversity loss. The article concludes on the potential that can be generated by combining the use of cutting-edge genetic tools with digital technology and global collaboration to construct a resilient, sustainable agricultural future.

Introduction

Agriculture has been the bedrock of human civilization through providing vital resources such as food, fibre, and raw materials. As the world population is expected to surpass 9 billion by 2050, the need for greater agricultural productivity is mounting, putting enormous pressure on finite arable land. In response to this issue, improvements in plant genetics have emerged as a key part of contemporary agricultural innovation. Plant genetics, the scientific research of heredity and plant variation, allows scientists to know and control genes that affect crop traits like growth rate, yield, resistance to pests and diseases, and environmental tolerance. Using genetic principles, scientists have been able to produce crop varieties with improved agronomic traits, like, drought tolerance, better nutrient use efficiency, and resistance to biotic stresses. These genetically enhanced cultivars enable farmers to gain greater productivity at the cost of decreased dependence on chemical inputs such as fertilizers and pesticides, hence encouraging more sustainable agriculture (Kumar & Sharma, 2015).

One of the most significant applications of plant genetics is for yield enhancement. The creation of high-yielding varieties through traditional breeding, hybridization, and genetic engineering has added immensely to world food supplies. The Green Revolution, for instance, was mainly fuelled by the introduction of genetically improved wheat and rice varieties that significantly raised cereal output in Latin America and Asia. Besides yield, climate variability resilience is an emerging area of interest. As climate change raises the incidence of droughts, floods, and high-temperature events, crops need to be engineered to withstand such occurrences. Genetic technology has enabled farmers to breed crops such as submergence-tolerant rice (e.g., the "Sub1" type) and drought-resistant maize, both of which have exhibited outstanding performance in climate-vulnerable areas.

Another fundamental contribution of plant genetics is to food nutrition and quality. Biofortification the improvement of nutritional content in crops using genetic approaches has resulted in the creation of crops such as golden rice that is rich in vitamin A, and beans and pearl millet with high iron content. These are key in alleviating hidden hunger among poor communities.

In addition, the progress in molecular breeding technologies like CRISPR-Cas9 and marker-assisted selection has hastened the breeding cycle, making it quicker and more accurate. The technologies permit targeted enhancements without adding foreign DNA, which improves addressing concerns of regulatory and public acceptance for genetically modified organisms (Jaganathan *et al*., 2018).

Plant Genetics

Plant genetics is the scientific research of genes, genetic variation, and heredity in plants. It involves studying how certain traits, like height in plants, colour, disease resistance, and drought tolerance, are passed through generations (Nei & Kumar, 2000). Plant genes can be manipulated by scientists to create novel plant varieties bearing desirable traits like increased growth rate, yield potential, and the ability to thrive under environmental stress, which would be critical towards enhancing agricultural productivity and sustainability (Jones, 2004).

The use of plant genetics in agriculture has its beginning in the early domestication of wild crops. Early farming involved culling plants with desirable qualities for breeding, a practice that was refined into contemporary breeding methods. Gregor Mendel's foundational research, whose laws of inheritance described the regular patterns of gene inheritance in pea plants, laid the foundation on which plant breeding was carried out (Mendel, 1866). His seminal work is the foundation of current genetics and plant breeding (Weiss, 2008).

The 20th century saw tremendous progress in plant genetics in the form of hybrid varieties and the Green Revolution crops. Hybrid varieties, products of the crossing of two genetically different parent plants, tend to have better characters like increased yield, improved disease resistance, and stronger Vigor. The Green Revolution that started in the 1940s brought with it high-yielding varieties of staple foods like wheat and rice, resulting in a spectacular increase in world food production and the relief of food shortages in much of the developing world (Evenson & Gollin, 2003).

Importance of Plant Genetics in Agriculture

1. Improved Crop Yields

Genetically enhanced crops can yield more grains, fruits, or vegetables per plant. This contributes to overall food production, particularly in areas with scarce land. For instance, hybrid rice and maize have greatly increased yields in nations such as India and China.

2. Resistance to Pests and Diseases

Numerous traditional crops are ruined by insects, fungi, and viruses. Genetic studies have produced pest-resistant strains that decrease the use of chemical pesticides. For example, Bt cotton carries a gene from a bacterium that keeps the plant safe from bollworms.

3. Environmental Stress Tolerance

Climate change has increased the difficulty of farming because of droughts, floods, and extreme temperatures. Genetic enhancement enables crops to resist these stresses. For instance, drought-resistant maize and flood-resistant rice are being planted in regions where extreme weather conditions are common.

4. Improved Nutritional Quality

Certain genetically enhanced crops have improved nutritional content. Golden rice, for instance, has been genetically modified to include vitamin A, which will help alleviate vitamin deficiency in developing nations.

Methods Employed in Genetic Improvement of Plants

1. Traditional Breeding

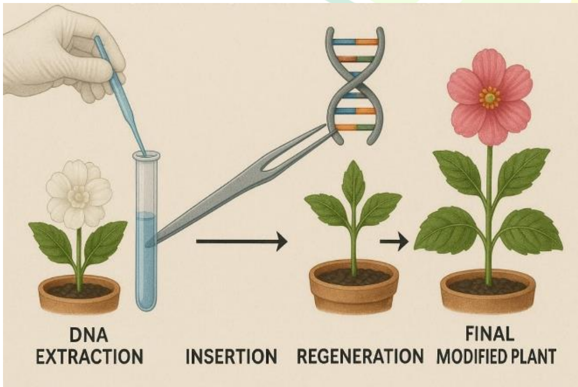
Traditional breeding entails the crossing of two parent crops with preferred characteristics to yield offspring. Traditional breeding has been central to crop variety enhancements like wheat, rice, and maize. In India, traditional breeding has been crucial in creating high-yielding rice varieties like IR8, which was launched during the Green Revolution (Haug, 2015). Though slow, it is an essential mechanism for increasing productivity in Indian agriculture.

2. Hybridization

Hybridization is the process of crossing two genetically dissimilar varieties in an effort to bring together their best characteristics. Hybrid crops such as hybrid rice have been very popular in India due to their improved yield and stronger resistance against diseases such as bacterial blight. Hybrid varieties have played a big role in boosting agricultural productivity in regions such as Punjab and Andhra Pradesh (Kumar *et al*., 2016).

3. Genetic Engineering (GM Crops)

Genetic modification is the direct alteration of a plant's DNA to impart certain characteristics. In India, GM crops such as Bt cotton have transformed cotton cultivation by conferring resistance against pests such as the cotton bollworm, thus lowering the use of chemical pesticides. The large-scale cultivation of GM crops in India has led to higher cotton production and lower input costs for farmers (Kranthi *et al*., 2009).



4. Marker-Assisted Selection (MAS)

Marker-assisted selection (MAS) is a method of utilizing DNA markers to choose plants possessing desired characteristics before maturity. In India, MAS has been used for crops such as rice and wheat to enhance traits like resistance to diseases, tolerance to drought, and quality of grain. The process hastens breeding and enhances the accuracy of choosing plants with better characteristics (Rai *et al*., 2016).

5. CRISPR and Gene Editing

CRISPR technology enables gene editing with accuracy, wherein individual genes are introduced, deleted, or modified without inserting foreign DNA. CRISPR technology has applications in enhancing Indian crops such as rice, wheat, and maize, especially for characteristics like resistance to diseases and drought tolerance. The Indian Council of Agricultural Research (ICAR) is investigating CRISPR for the improvement of crops to meet India's agro-related challenges (Sundararajan & Ramasamy, 2020).

Case Studies: Real-Life Examples

1. Green Revolution

The Green Revolution of the 1960s saw the adoption of high-yielding varieties (HYVs) of major crops like wheat and rice, drastically improving food production in most developing nations, including India. This was facilitated by the application of synthetic fertilizers, pesticides, and high-level irrigation practices. The Green Revolution in India helped shift the nation from its status as a food-deficient nation to a food-self-sufficient one, especially in the case of wheat and rice (Khan, 2014).

2. Bt Cotton in India

Bt cotton, which was launched in India in 2002, has drastically changed the production of cotton by conferring resistance against the cotton bollworm, a serious pest. The use of Bt cotton resulted in decreased pesticide application and increased yields, leading to improved profitability for farmers. In 2020, Bt cotton covers more than 90% of India's cotton-growing territory, representing

3. Drought-Resistant Maize in Africa

The Water Efficient Maize for Africa (WEMA) project came up with drought-resistant maize varieties that improved food security in sub-Saharan Africa, particularly in climate change-affected areas. While geared mainly to African nations, this project is also sharing knowledge and technologies with India, where maize and other crops are being improved to be resistant to drought for mitigating the effects of water scarcity caused by climate change (Joshi *et al.*, 2016).

Advantages of Crop Genetic Improvement

Increased Crop Yield: Genetic improvement allows for increased yields per acre, which means more effective utilization of available land.

Lower Agrochemical Dependence: Increased resistance to pests and diseases results in reduced use of chemical fertilizers and pesticides, ensuring environmental sustainability.

Better Quality and Shelf Life: Genetically improved crops tend to have better nutritional quality, flavour, and longer post-harvest shelf life.

Climate Variability Resilience: Plants improved through genetic breeding are more resistant to drought, floods, and extreme weather conditions, providing consistent yields.

Greater Economic Returns: Improved productivity and lower input costs mean higher profitability and better livelihoods for farmers.

Challenges and Concerns in Plant Genetic Improvement

Ethical and Safety Concerns: Risks of long-term environment and health effects from GM crops, including the possibility of transference of genes to wild relatives, resulting in superweeds or pests.

Consumer Resistance: Consumers resist GM crops because of health hazards and organically produced food preferences, which make large-scale adoption more difficult.

Regulatory Hurdles: Regulations are stringent and slow for GM crop approval, which slows the availability and adoption of GM crops.

Biodiversity Loss: Dominance of only a handful genetically enhanced varieties can lead to diminishing genetic diversity, causing crops to be vulnerable to pests and diseases.

Seed Market Monopolization: Huge corporations owning GM seed patents could render it difficult for smallholder farmers to get affordable seeds.

Unintended Crossbreeding: GM crops could crossbreed with non-GM crops or wild relatives inadvertently, potentially changing genetic traits.

Public Misinformation: Misinformation regarding GM crops generates public fear and distrust, inhibiting their acceptance.

Pesticide Use: Overdependence on GM crops could result in pest resistance and the revival of unsafe pesticide use.

Future Prospects

The developments in plant genetics are revolutionizing agriculture. Resilience to climate change can be ensured by climate-resilient crops and exact gene-editing technology such as CRISPR. The combination of AI and big data will most probably increase productivity and sustainability. Tailor-made crop varieties and international collaboration in research can be game-changers.

Conclusion

Development in plant genetics has transformed contemporary agriculture, providing new solutions for global food security, environmental sustainability, and profitability of the farmer. With the application of traditional breeding practices in tandem with new-fangled techniques such as genetic engineering and CRISPR, researchers have produced crop lines that give more yield, are disease- and pest-resistant, and endure climatic extremes. The face of agriculture in India is especially indicative of the potency of genetic improvement, the tales of success including Bt cotton, improved varieties of rice, and wheat breeding using marker-assisted selection. Though tremendous strides have been achieved, regulatory acceptance, ethical issues, and environmental concerns continue to pose challenges. To overcome these challenges, transparent policies, ongoing public awareness, and sound scientific research are necessary. In the future, the combination of plant genetics with digital agriculture, climate-smart technology, and international collaborations will be instrumental in determining a productive and sustainable agricultural ecosystem that can feed an increasing population.

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"Edible Elegance: Redefining Garden Aesthetics with Edimentals"

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This developing horticultural trend is a component of a wider movement toward eco-friendly living, urban farming, and biodiversity-focused design. Edimentals, including brilliant nasturtiums, brilliant Swiss chard, and eye-catching purple basil, demonstrate multiple uses through integrating culinary value with aesthetic appeal. Their popularity in 2025 is being driven by the demand for space-saving, climate-resilient, and pollinator-friendly planting alternatives. Edimentals, which are rooted in ancient gardening practices but matched with modern environmental goals, help to promote sustainable agriculture while enhancing garden appearance. Edimentals provide a compelling, forward-thinking answer for modern gardens as more people look for practical methods to cultivate nourishment and nature together.

Keywords: Edimentals, edible landscaping, sustainable gardening, ornamental plants, urban agriculture, multifunctional plants, biodiversity, eco-friendly garden design, food security, climate-resilient gardening

Introduction:

In an age where sustainability and aesthetics go hand-in-hand, a new horticultural trend is blossoming in gardens across the world: **edimentals**. This fusion of edible and ornamental plants reflects a growing desire for gardens that are not only visually captivating but also practical and nourishing. As gardeners and designers search for ways to maximize small spaces and promote eco-friendly practices, edimentals have emerged as a perfect solution.

What Are Edimentals?

The term **edimental** is a portmanteau of **edible** and **ornamental**. These are plants that offer culinary value while enhancing the beauty of a garden with their vivid colors, unusual textures, or striking architectural forms. From purple kale and vibrant nasturtiums to fruit-bearing shrubs like blueberries, edimentals bridge the gap between utility and art.

Why Edimentals Matter: The rising popularity of edimentals in 2025 aligns with larger global movements toward **sustainable living**, **urban agriculture**, and **climate-resilient gardening**. With increasing interest in organic food, food security, and biodiversity, edimentals provide:

- **Dual functionality**: Decorative and consumable
- **Space efficiency**: Ideal for balconies, urban gardens, and small yards
- **Pollinator support**: Many edimentals attract bees, butterflies, and beneficial insects
- **Reduced waste**: No need to discard decorative plants at season's end—just harvest and eat!

Examples of Popular Edimental Plants

Plant	Edible Part	Ornamental Feature
Swiss Chard	Leaves & stalks	Bright rainbow-colored stems
Nasturtium	Flowers & leaves	Bold orange and red blooms
Chili Pepper	Fruit	Shiny, colourful peppers
Artichoke	Flower buds	Architectural foliage and blooms
Purple Basil	Leaves	Deep purple foliage and fragrance
Kale	Leaves	Curly leaves in vibrant greens and purples

These plants can be easily incorporated into garden beds, borders, or containers, offering an eye-catching yet practical approach to planting.

Edimentals and Garden Design

Gardeners are increasingly embracing **meadow scaping** and **forest gardening**, which emphasize native biodiversity and edible layering. Edimentals naturally fit into these approaches, where aesthetics, ecology, and food production intersect.

Conclusion

Edimentals are not just a passing trend they're a sustainable response to the needs of modern living. They allow gardeners to cultivate beauty and nutrition side by side, making every square inch of a garden more purposeful. As 2025 unfolds, integrating edimentals into your landscape is not only on trend—it's a smart and responsible choice.

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HEAT STRESS IN POULTRY FARMING: CHALLENGES AND COMPREHENSIVE MANAGEMENT STRATEGIES

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Introduction

Heat stress poses a formidable challenge in poultry farming, particularly in regions like Andhra Pradesh, where summer temperatures frequently soar to 40–45°C from April to July. Poultry are highly sensitive to environmental temperatures, with an optimal range of 18–24°C for their physiological well-being. When ambient temperatures exceed 35°C, especially in humid conditions, poultry experience severe thermal stress, leading to significant declines in productivity and health. Unlike mammals, poultry lack sweat glands, making it difficult for them to regulate body temperature, which exacerbates the effects of heat stress. This results in reduced feed intake, increased water consumption, and a 20–30% drop in egg production. In broilers, weight gain slows, while in layers, egg size and shell quality deteriorate. Furthermore, heat stress compromises immunity, increasing susceptibility to microbial infections such as Mycoplasma, Coccidiosis, Aero sack Syndrome, and Cholera. Timely recognition and proactive management of heat stress are critical to minimizing economic losses and maintaining flock health. Poultry lack sweat glands, making them reliant on panting and behavioural adjustments to dissipate heat. When these mechanisms fail, physiological and behavioural disruptions occur, leading to the following symptoms:

1. Reduced Feed Intake and Increased Water Consumption

Under heat stress, birds instinctively reduce feed consumption to minimize metabolic heat production generated during digestion. This suppression of appetite is linked to altered hormone signaling (e.g., leptin and ghrelin) and reduced blood flow to the gastrointestinal tract. Concurrently, water intake surges as birds attempt to cool themselves through evaporation and prevent dehydration. However, this imbalance disrupts nutrient absorption, leading to weight loss in broilers, reduced egg mass in layers, and metabolic disorders like electrolyte imbalances.

2. Diarrhoea and Wet Litter

Excessive water consumption dilutes intestinal contents, causing loose, watery droppings. Wet litter exacerbates hygiene challenges, fostering bacterial proliferation (e.g., *E. coli* and *Clostridium perfringens*), coccidial growth and ammonia emissions. These conditions predispose birds to **necrotic enteritis** (intestinal tissue necrosis) and **footpad dermatitis**, which compromise welfare and productivity. Additionally, ammonia irritates the respiratory tract, compounding stress and susceptibility to infections.

3. Rapid Breathing (Panting): Panting, a primary cooling mechanism, involves rapid shallow breathing to increase evaporative heat loss from the respiratory tract. However, prolonged panting leads to **respiratory alkalosis**—a rise in blood pH due to excessive CO_2 expulsion. This disrupts acid-base balance, impairing enzyme activity and ion transport (e.g., calcium and bicarbonate), which affects eggshell formation and muscle function. Energy diverted to sustain panting further reduces resources for growth and immunity.

4. Decline in Egg Production and Quality: In laying hens, heat stress suppresses the release of reproductive hormones (e.g., luteinizing hormone), delaying ovulation and reducing egg output. Elevated corticosterone (a stress hormone) also inhibits ovarian follicle development. Egg quality declines due to:

- **Thin shells**: Impaired calcium mobilization from bones and reduced carbonic anhydrase activity (critical for shell formation).
- **Watery albumen**: Altered protein metabolism under heat stress weakens egg white viscosity.
- **Poor hatchability**: Embryonic mortality increases due to hormonal imbalances in breeders and nutrient-deficient eggs.

5. Dehydration and Physical Distress: Dehydration manifests through **hemo concentration** (thickened blood), reduced skin elasticity, and sunken eyes. Birds exhibit lethargy, drooping wings, and pale combs/wattles due to redirected blood flow to the skin for cooling. Core body temperatures exceeding 43°C (109°F) damage cellular proteins and enzymes, triggering **heat stroke** or **sudden death syndrome (SDS)**—a fatal cardiac event in broilers linked to metabolic acidosis and electrolyte depletion.

Secondary Impacts

- **Immune suppression**: Heat stress reduces lymphocyte activity and antibody production, increasing vulnerability to infections.
- **Oxidative stress**: Excess reactive oxygen species (ROS) damage tissues, accelerating muscle degradation (e.g., pale, soft, exudative meat in broilers).
- **Economic losses**: Reduced feed efficiency, higher mortality, and increased medication costs strain profitability.

Mitigation Strategies: While not the focus here, addressing heat stress requires environmental modifications (ventilation, cooling systems), dietary adjustments (electrolyte supplements, antioxidants), and genetic selection for heat-tolerant breeds.

Comprehensive Management Strategies for Heat Stress

Effective management of heat stress requires a multifaceted approach, combining shed management, nutritional interventions, water management, disease prevention, and genetic considerations. Below are detailed strategies to mitigate heat stress in poultry farming:

1. Shed Management

Maintaining a cool and comfortable environment within the poultry shed is paramount. The following measures can significantly reduce heat stress:

- **Wet Burlap Sacks**: Hang wet burlap sacks on shed walls to cool incoming air through evaporative cooling. This is a cost-effective solution for small-scale farmers.
- **Sprinkler Systems**: When temperatures exceed 40°C, use sprinklers to mist water inside the shed, lowering the ambient temperature.
- **Enhanced Ventilation**: Install fans or tunnel ventilation systems to ensure adequate air circulation. Proper airflow prevents heat buildup and maintains oxygen levels.
- **Reduced Stocking Density**: Lower the number of birds per square meter to provide more space per bird, reducing heat generated by crowding.
- **Shed Orientation and Insulation**: Construct sheds with an east-west orientation to minimize direct sunlight exposure. Insulate roofs with materials like polystyrene or reflective coatings to reduce heat penetration.
- **Advanced Cooling Systems**: In commercial setups, evaporative cooling pads and tunnel ventilation systems are highly effective. These systems regulate airflow and maintain optimal temperatures.
- **Green Surroundings**: Plant trees or create green spaces around sheds to provide natural shade and promote a calming environment, which enhances bird welfare and productivity.

2. Nutritional Management

Proper nutrition is critical for supporting poultry during heat stress. Adjustments to feed composition and feeding schedules can mitigate the adverse effects of high temperatures:

- **Optimal Feeding Times**: Provide feed during cooler parts of the day, such as early morning or evening, to encourage consumption and reduce heat production from digestion.
- **Energy-Dense Diets**: Increase the fat content in feed to provide a concentrated energy source, improving palatability and reducing metabolic heat production.
- **Balanced Protein Levels**: Reduce crude protein by 1–2% to minimize heat generated during protein metabolism, while supplementing with essential amino acids like lysine and methionine (5–10% increase) to maintain growth and egg production.
- **Vitamins and Antioxidants**:
  - **Vitamin C (200–500 g/ton of feed)**: Reduces stress hormones (e.g., cortisol) and improves eggshell quality by supporting calcium metabolism.
  - **Vitamin E (100–250 mg/kg of feed)**: Protects cells from oxidative damage caused by reactive oxygen species (ROS), enhancing immunity and supporting egg production and weight gain.
- **Electrolytes**: Add potassium chloride (0.5% in water), sodium bicarbonate (0.5%), and minerals like zinc (25–100 mg/kg) and magnesium to maintain hydration and acid-base balance.
- **Selenium (0.3 mg/kg)**: Supports muscle health and improves meat quality in broilers by reducing oxidative stress.
- **Curcumin (Turmeric, 100–200 mg/kg)**: Acts as a natural antioxidant, strengthening the immune system and reducing inflammation.
- **Probiotics and Prebiotics**: Incorporate Lactobacillus-based probiotics (250–500 ppm) to enhance gut health, improve nutrient absorption, and boost immunity.

The following table summarizes key nutritional interventions for heat stress management:

Nutrient	Benefit	Usage Recommendation
Vitamin E	Protects cells, enhances immunity	100–250 mg/kg of feed
Vitamin C	Reduces stress hormones, improves eggshell quality	200–500 g/ton of feed
Selenium	Supports muscle health, improves meat quality	0.3 mg/kg of feed
Curcumin (Turmeric)	Acts as an antioxidant, strengthens immunity	100–200 mg/kg of feed
Probiotics	Improves gut health, enhances nutrient absorption	250–500 ppm of feed
Electrolytes	Maintains hydration, reduces respiratory distress	0.5% in water or feed

3. Water Management

Access to clean, cool water is essential for preventing dehydration and regulating body temperature:

- **Continuous Water Supply**: Ensure a constant supply of fresh, cool water to encourage drinking and prevent heatstroke.
- **Pipe Maintenance**: Regularly clean water pipes to prevent leaks and contamination, ensuring water quality.

4. Disease Prevention

Heat stress weakens immunity, making poultry vulnerable to infections. The following measures help maintain flock health:

- **Shed Hygiene**: Keep litter dry to prevent diseases like Coccidiosis, which thrive in wet conditions.
- **Vaccination**: Administer vaccines for Mycoplasma, Infectious Bursal Disease (IBD), and other prevalent diseases on schedule.
- **Prompt Diagnosis**: Monitor for signs of respiratory distress or weakness and consult a veterinarian immediately to address potential infections.

5. Genetic Approaches

Selecting heat-tolerant breeds is a long-term strategy for mitigating heat stress:

- **Heat-Tolerant Breeds**: Breeds with the naked neck or frizzle gene (e.g., Pekin, Polish) exhibit superior heat tolerance due to reduced feather coverage, which facilitates heat dissipation.
- **Indigenous Breeds**: Local breeds, adapted to regional climates over generations, are more resilient to high temperatures than modern broiler strains.
- **Modern Broilers**: Commercial broiler breeds have lower heat tolerance and require enhanced management practices to thrive in hot climates.

Economic Impact and Solutions

In Andhra Pradesh, heat stress causes substantial economic losses through reduced egg production, increased mortality, and higher treatment costs. For example, a 20–30% drop in egg yield directly impacts farmers' revenue, while disease outbreaks necessitate costly interventions. To address these challenges, farmers are adopting innovative solutions:

- **Green Nets with Water Sprays**: These provide natural shade and cooling, reducing shed temperatures effectively.
- **Subsidized Technologies**: The Andhra Pradesh Department of Animal Husbandry offers subsidies for advanced systems like fog mist systems, green nets, and solar-powered shading solutions, making them accessible to small-scale farmers.

Conclusion

Heat stress is a significant obstacle in poultry farming, but it can be effectively managed through a combination of shed management, nutritional adjustments, water management, disease prevention, and genetic selection. By implementing cooling systems, providing energy-dense diets with supplements like vitamins and electrolytes, ensuring clean water, maintaining hygiene, and choosing heat-tolerant breeds, farmers can protect flock health and productivity. These strategies not only minimize economic losses but also promote sustainable and profitable poultry farming. For further guidance, farmers should consult local veterinary services or animal husbandry departments.

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Water Management in Agriculture: From Overuse to Efficient Utilization

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Introduction:

Agriculture, a cornerstone of global food security, accounts for approximately 70% of the world's freshwater withdrawals, making it the largest consumer of this precious resource (FAO, 2020). However, the sector faces significant challenges due to widespread inefficient practices, particularly in water-scarce regions, which exacerbate stress on ecosystems and limit agricultural productivity. Traditional methods like flood irrigation, coupled with inadequate water conservation practices, contribute to soil degradation, aquifer depletion, and water pollution. As climate change intensifies and global populations grow, the imperative to implement efficient and sustainable water management practices becomes increasingly critical for ensuring long-term food security and environmental sustainability. This article explores innovative irrigation practices, highlights the vital role of rainwater harvesting, and examines essential policy frameworks that can guide the transition from overuse to efficient and sustainable water utilization in agriculture.

The Importance of Water Management in Agriculture

Water serves as an indispensable resource for agriculture, directly impacting crop yields, livestock productivity, and aquaculture success. Effective water management is critical for optimizing the use of this resource, particularly in regions with limited or unpredictable water availability. Irrigated agriculture is a cornerstone of global food security, providing stability in crop yields, especially in areas with variable rainfall patterns (Molden et al., 2021). The efficient allocation of water enables farmers to supplement natural rainfall, ensuring stable harvests and enhanced agricultural output. Furthermore, sustainable water management practices minimize environmental impacts, safeguard water resources for future generations, and promote resilient agricultural systems that can withstand the challenges posed by climate change. By adopting innovative irrigation technologies, implementing effective conservation measures, and integrating these practices into broader agricultural systems, a balance can be struck between agricultural output and responsible water stewardship.

Technological Innovations Driving Efficiency in Agriculture

The agricultural sector is witnessing a revolution in water management through the adoption of advanced technologies designed to reduce water consumption while simultaneously enhancing crop productivity. Among these innovations, smart irrigation systems and water-retaining soil technologies stand out as particularly promising.

Smart Irrigation Systems: Represent a significant leap forward in agricultural water management. These systems harness real-time data and automation to apply water precisely when and where it is needed, thereby reducing water consumption significantly. AI-powered precision irrigation systems, for instance, can reduce water consumption by 30-50% compared to conventional methods (EOS Data Analytics, 2023). These systems integrate several key components that enable their efficiency:

- **Soil Moisture Sensors:** Providing real-time data on soil moisture levels, these sensors optimize irrigation schedules and prevent overwatering (EOS Data Analytics, 2023).

- **Variable Rate Application (VRA):** Tailoring water delivery to specific field zones based on data from satellites or sensors, VRA improves efficiency in diverse landscapes (EOS Data Analytics, 2023).
- **Drip Irrigation:** Delivering water directly to the plant roots through a network of tubes minimizes evaporation and runoff, using up to 60% less water than traditional flood irrigation (Keller & Khamis, 2019).

The successful implementation of smart irrigation is evident in regions such as Israel, where sensor-driven drip systems have reduced agricultural water use by 40% since 2015.

Water-Retaining Soil Technologies: Another promising area of innovation involves the use of water-retaining soil technologies, such as hydrogels, also known as superabsorbent polymers. These materials can absorb 300-500 times their weight in water, which is then released during dry periods, providing plants with a sustained source of moisture (Kiron, 2023). The benefits of using hydrogels include:

- **Reduced Irrigation Frequency:** By retaining moisture in the soil, hydrogels decrease the need for frequent irrigation, saving water and labor (Kiron, 2023).
- **Increased Yields:** In drought-prone regions, hydrogels can improve crop yields by ensuring that plants have access to water during critical growth stages (Kiron, 2023).
- **Improved Soil Structure:** Hydrogels enhance soil structure by improving aeration and water infiltration, contributing to healthier root systems (Kiron, 2023).

Sustainable Practices for Water Conservation

In addition to technological innovations, sustainable practices play a crucial role in conserving water resources in agriculture. These practices focus on enhancing natural processes and minimizing reliance on external inputs, contributing to more resilient and environmentally friendly farming systems.

Rainwater Harvesting: Rainwater harvesting is a cost-effective and environmentally sound approach to water conservation, particularly in regions facing water scarcity or seasonal rainfall patterns. This technique involves capturing and storing rainwater from various surfaces for later use in irrigation and other agricultural activities (Dhawan & Gupta, 2021). Common methods include:

- **Rooftop Catchments:** Collecting rainwater from building roofs and storing it in tanks or cisterns.
- **Surface Catchments:** Capturing runoff from land surfaces and directing it to ponds or reservoirs.
- **Rainwater Ponds:** Constructing small ponds to store rainwater for irrigation during dry periods.

Rainwater harvesting offers multiple benefits, including reduced groundwater dependence, mitigation of water scarcity, and improved soil health (Dhawan & Gupta, 2021). For example, micro-catchment systems in Rajasthan, India, have successfully replenished aquifers and improved water availability for local communities.

Agroecological Approaches: Agroecological approaches integrate ecological principles into agricultural practices to enhance sustainability and resilience. These methods promote biodiversity, improve soil health, and reduce reliance on external inputs, including water. Key strategies include:

- **Agroforestry:** Integrating trees with crops to increase soil moisture and biodiversity (Kiron, 2023). Trees provide shade, reduce evaporation, and enhance water infiltration into the soil.
- **Alternate Wetting and Drying (AWD):** A water-saving technique used in rice paddies, involving periodic draining and re-flooding of fields to reduce water consumption without compromising yields (Kiron, 2023).
- **Cover Cropping:** Planting cover crops during fallow periods to enhance soil organic matter and water retention (Kiron, 2023). Cover crops improve soil structure, reduce erosion, and increase the soil's ability to hold water, making it more resilient to drought.

Policy Frameworks for Systemic Change

Effective water management in agriculture requires robust policy frameworks that incentivize conservation, promote sustainable practices, and balance the needs of various stakeholders. The OECD (2018) outlines key conditions for effective water policy reforms, which include:

- **Aligning Governance:** Implementing coordinated structures enhances monitoring and management, as demonstrated by Morocco's tiered water pricing.
- **Rebalancing Incentives:** Offering subsidies for efficient technologies, as exemplified by India's National Mission for Sustainable Agriculture (NMSA), encourages adoption.
- **Engaging Stakeholders:** Tailoring policies through inclusive training programs, such as those in Ghana, ensures relevance and effectiveness.
- **Phasing Out Harmful Subsidies:** Reallocating resources, as Egypt did by redirecting irrigation subsidies to solar pumps, promotes efficient water use.

These policies are crucial for achieving systemic change in agricultural water management (Kiron, 2023).

Future Directions

As the challenges of water scarcity and climate change intensify, continued innovation is essential for ensuring sustainable agricultural practices. Several promising avenues are emerging that hold the potential to transform water management in agriculture, including AI-driven predictive models, salt-tolerant crops, and circular water systems. AI-driven predictive models are poised to revolutionize irrigation scheduling by leveraging the power of the Internet of Things (IoT) and satellite data (Zhang et al., 2020). Furthermore, the development and adoption of salt-tolerant crops offer a sustainable approach for maintaining agricultural productivity in saline soils (Kiron, 2023). Circular water systems, which treat and reuse wastewater for irrigation, are also gaining traction as a means of reducing demand on freshwater resources and promoting sustainable water management (EOS Data Analytics, 2023).

Conclusion

With agriculture facing escalating water demands, efficient water management is crucial for ensuring food security and environmental sustainability. Innovative irrigation practices like drip and precision irrigation, along with rainwater harvesting and policy reforms, are shaping the future of water conservation in agriculture. The transition from overuse to sustainable water utilization requires ongoing investment in advanced technologies, research and development, and farmer education. Balancing productivity with the protection of vital water resources is essential for securing the future of agriculture and ensuring the well-being of communities worldwide.

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N-Drip Irrigation System: A New Initiative for Revolutionizing Agriculture in India

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Introduction

India, being predominantly an agricultural country, faces significant challenges regarding water scarcity and the need to increase agricultural productivity. In this context, the N-Drip Irrigation System has emerged as a transformative solution. This system is not only more effective and inexpensive but also more compatible with water conservation compared to traditional irrigation techniques.

The N-Drip Irrigation System is an advanced micro-irrigation method, primarily based on a gravity-driven drip irrigation mechanism. It operates without the need for pumps or electricity, making it an easy-to-install, cost-effective, and sustainable option for farmers. This system is particularly beneficial for those looking to maximize their yield while minimizing resource usage.

N-Drip Characteristics

- Water Saving: The N-Drip system can reduce water consumption by 50-70%, addressing the critical issue of water scarcity in agriculture.
- Low Cost: Unlike conventional drip irrigation systems, the N-Drip system is more affordable, as it eliminates the need for pumps and electricity.
- Simple Installation: The system is user-friendly and easy to set up, requiring minimal technical expertise.
- Increased Crop Production: Farmers can expect a 20-30% increase in crop production due to the targeted and efficient delivery of water directly to the plant's root zone.
- Environmentally Friendly: By reducing both water and energy consumption, the N-Drip system helps mitigate environmental degradation, making it a sustainable agricultural practice.

How Does the N-Drip System Work?

The N-Drip system uses gravity to transport water through pipelines and drippers directly to the plant roots. This controlled flow ensures that only the required amount of water reaches the crops, avoiding waste and optimizing water usage. The lack of reliance on electricity and pumps makes the system an energy-efficient alternative to traditional methods.

Benefits of the N-Drip System

Ideal for Small and Medium Farmers:

The affordability and low maintenance requirements of the N-Drip system make it ideal for small and medium-sized farms, where resources may be limited.

Reduces Waterlogging and Soil Erosion:

By delivering water directly to the root zone, the N-Drip system prevents the occurrence of waterlogging, which can lead to soil erosion.

Effective on Barren and Dry Land:

The system is highly effective in arid and semi-arid regions where traditional irrigation methods may not be as feasible.

Versatility Across Crops:

The N-Drip system is suitable for a wide range of crops, including wheat, rice, vegetables, and fruits, making it adaptable to diverse agricultural needs.

A Revolutionary Solution for Farmers

The N-Drip system can significantly alleviate the challenges faced by Indian farmers dealing with water crises. Its low-cost technology and simplicity make it an accessible and efficient solution, allowing farmers to increase productivity without the burden of excessive resources.

Government Support for the N-Drip System

The Indian government has shown strong support for water conservation initiatives. Subsidies for irrigation systems, including the N-Drip system, can help farmers adopt this technology. Furthermore, government programs such as Kisan Training and Awareness Campaigns have played a crucial role in promoting the adoption of such sustainable farming practices.

By investing in such systems, farmers can improve their crop yield, reduce input costs, and contribute to the larger goal of water conservation and sustainability in agriculture.

Conclusion

The N-Drip Irrigation System is truly a revolutionary step in modernizing Indian agriculture. With its ability to save water, reduce costs, and enhance crop yields, it provides a sustainable solution to the pressing issues of water scarcity and low productivity. Through government support and widespread adoption, this system has the potential to bring about a transformative change in the way farming is done in India, ensuring that agricultural growth remains steady in an era of climate uncertainty and resource constraints.

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Advanced Natural Farming: A Sustainable Path to Regenerative Agriculture

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Introduction

Natural farming, an ecological approach to agriculture, emphasizes working in harmony with nature to produce food without synthetic inputs. Advanced natural farming builds on foundational practices like those pioneered by Masanobu Fukuoka and Subhash Palekar, integrating modern ecological insights, innovative techniques, and localized solutions to enhance sustainability, soil health, and farmer livelihoods. Unlike conventional farming, which relies heavily on chemical fertilizers, pesticides, and monoculture, advanced natural farming prioritizes biodiversity, minimal intervention, and regenerative practices to create resilient agroecosystems. This article explores the principles, techniques, benefits, and challenges of advanced natural farming, with a focus on its global and regional applications, particularly in India, where it is gaining traction through initiatives like the National Mission on Natural Farming (NMNF).

Principles of Advanced Natural Farming

Advanced natural farming is grounded in principles that align agricultural practices with natural processes, ensuring long-term ecological balance and productivity. These principles, inspired by traditional ecological knowledge and modern agroecology, include:

1. **Minimal Soil Disturbance**: Avoiding tillage preserves soil structure, microbiota, and organic matter. Tilling disrupts the delicate balance of soil ecosystems, accelerating decomposition and reducing fertility. Natural farming promotes no-till or reduced-tillage methods to maintain soil integrity.
2. **Biodiversity and Polyculture**: Encouraging diverse plant and animal species enhances ecosystem resilience. Polyculture, intercropping, and agroforestry mimic natural ecosystems, reducing pest outbreaks and improving nutrient cycling.
3. **Use of Indigenous Microorganisms (IMO)**: Leveraging local microbial populations, such as lactobacillus or fungi, boosts soil fertility and plant health. Preparations like Jeevamrit and Beejamrit, made from cow dung, urine, and local ingredients, enrich soil microbiomes.
4. **Natural Inputs and Zero External Dependency**: Advanced natural farming minimizes reliance on purchased inputs by using on-farm resources like compost, vermicompost, and biofertilizers. This reduces costs and fosters self-sufficiency.
5. **Water Conservation and Soil Moisture Retention**: Techniques like mulching, cover cropping, and contour planting conserve water, reduce erosion, and maintain soil moisture, critical in the face of climate variability.
6. **Integration of Livestock and Crops**: Incorporating animals, such as cows for dung and urine or poultry for pest control, creates a closed-loop system where waste becomes a resource.

These principles are not static; advanced natural farming adapts them to local climates, soils, and cultural practices, making it a versatile and scalable approach.

Key Techniques in Advanced Natural Farming

Advanced natural farming combines traditional methods with innovative practices to optimize yields while regenerating the environment. Below are some key techniques, many of which are widely practiced in India and other regions:

1. Zero Budget Natural Farming (ZBNF)

Developed by Subhash Palekar in India, ZBNF is a cornerstone of advanced natural farming. It emphasizes zero external input costs by using locally available materials. Key components include:

- **Jeevamrit**: A fermented microbial culture made from cow dung, cow urine, jaggery, pulse flour, and soil, applied to enrich soil fertility. Studies show Jeevamrit increases microbial biomass and crop yields, with a 74.07% yield increase in sweet corn when combined with other organic inputs.
- **Beejamrit**: A seed treatment using cow dung, urine, and lime to protect seeds from pathogens and enhance germination.
- **Mulching**: Using crop residues or straw to cover soil, reducing evaporation, moderating temperature, and suppressing weeds.
- **Whapasa (Soil Moisture)**: Maintaining optimal soil moisture through minimal irrigation and organic matter addition, reducing water dependency.

ZBNF has been adopted across states like Andhra Pradesh, where 6.5 lakh hectares are under natural farming as of 2023.

2. Indigenous Microorganism (IMO) Applications

IMO technology, popularized in Korean Natural Farming (KNF), involves collecting and culturing beneficial microbes from local ecosystems. These microbes are used to ferment organic matter, creating biofertilizers and biopesticides. For example, fermented plant juices from comfrey or nettle provide nutrient-rich foliar sprays, replacing synthetic fertilizers.

3. Agroforestry and Intercropping

Integrating trees, crops, and livestock creates diverse, resilient systems. Agroforestry enhances carbon sequestration, improves soil fertility through leaf litter, and provides additional income from timber or fruit. Intercropping, such as growing legumes with cereals, fixes nitrogen and reduces pest pressure.

4. Biofertilizers and Vermicomposting

Biofertilizers like Azospirillum, Rhizobium, and phosphate-solubilizing bacteria (PSB) enhance nutrient availability. Vermicomposting, using earthworms to convert organic waste into nutrient-rich compost, is a cost-effective way to recycle farm waste. A study in Assam showed that vermicompost and biofertilizers increased soil nitrogen by 272.53 kg/ha in rice cultivation.

5. Natural Pest Management

Advanced natural farming uses ecological pest control, integrating:

- **Biological Controls**: Releasing predatory insects like ladybugs or parasitoid wasps to manage pests.
- **Cultural Controls**: Crop rotation and trap crops disrupt pest cycles.
- **Botanical Pesticides**: Neem-based sprays or fermented plant extracts like Dasparni repel pests without harming beneficial organisms.

6. Water Harvesting and Conservation

Techniques like contour bunding, rainwater harvesting, and drip irrigation optimize water use. Mulching and cover crops further reduce evaporation, critical in water-scarce regions.

Benefits of Advanced Natural Farming

Advanced natural farming offers multifaceted benefits, addressing environmental, economic, and social challenges. These include:

1. Environmental Sustainability

- **Soil Health**: Practices like mulching and biofertilizer application increase organic matter and microbial activity, improving soil structure and fertility. A Rajasthan study found that FYM and Jeevamrit increased cowpea yield by 1,070.5 kg/ha and soil microbial biomass carbon by 133.92 mg/g.
- **Reduced Chemical Pollution**: Eliminating synthetic inputs prevents groundwater contamination and reduces greenhouse gas emissions.
- **Biodiversity Conservation**: Polyculture and habitat preservation support pollinators,

birds, and soil organisms, enhancing ecosystem resilience.

2. Economic Viability

- **Lower Input Costs**: By using on-farm resources, farmers reduce dependency on expensive fertilizers and pesticides. ZBNF, for instance, cuts cultivation costs significantly, breaking the debt cycle for Indian farmers.
- **Higher Net Returns**: Studies show natural farming increases net returns by 21–75% in crops like wheat and sweet corn due to lower costs and premium prices for chemical-free produce.
- **Market Opportunities**: Growing demand for organic and natural produce, supported by initiatives like India's Jaivik Kheti portal, provides access to premium markets.

3. Social and Health Benefits

- **Farmer Empowerment**: Natural farming reduces reliance on loans, addressing the crisis of farmer suicides in India, where a quarter-million farmers took their lives over two decades due to debt.
- **Healthier Food**: Chemical-free crops have higher nutritional value and medicinal properties, as seen in India's Rishi Kheti practices.
- **Climate Resilience**: Diverse systems and water conservation practices make farms more resilient to droughts, floods, and temperature fluctuations.

4. Policy Support and Scalability

The Indian government's NMNF, launched in 2024, aims to bring 10 million hectares under natural farming by 2025, targeting 1 crore farmers and establishing 10,000 Bio-input Resource Centres (BRCs). This mission promotes certification, branding, and scientific validation, enhancing scalability.

Challenges and Limitations

Despite its promise, advanced natural farming faces challenges that require strategic solutions:

1. **Lower Initial Yields**: Transitioning from conventional to natural farming can reduce yields in the first 2–3 years as soils recover from chemical dependency. Farmer training and financial support during this period are critical.
2. **Knowledge and Skill Gaps**: Advanced techniques like IMO preparation or biofertilizer application require training, which may not be accessible to all farmers.
3. **Market Access**: While demand for natural produce is growing, certification and supply chain infrastructure are limited, particularly in rural areas.
4. **Labor Intensity**: Practices like mulching or compost preparation can be labor-intensive, posing challenges for smallholder farmers with limited resources.
5. **Skepticism and Adoption Barriers**: Farmers accustomed to conventional methods may resist change due to perceived risks or lack of awareness.

Addressing these challenges requires investment in extension services, farmer cooperatives, and research to validate and refine natural farming practices.

Global and Regional Applications

Advanced natural farming is practiced worldwide, with variations tailored to local contexts:

- **Japan**: Masanobu Fukuoka's "do-nothing" farming, outlined in *The One-Straw Revolution*, emphasizes seed balls, no-till, and natural succession. His methods achieved yields comparable to conventional farms without environmental degradation.
- **India**: ZBNF and Rishi Kheti are prominent, with states like Andhra Pradesh and Himachal Pradesh leading adoption. The NMNF aims to scale these practices nationwide.
- **Philippines**: Organizations like Aloha House integrate natural farming with community development, using IMO and biochar to enhance soil fertility.
- **Korea**: Korean Natural Farming (KNF) focuses on IMO and fermented inputs, widely adopted in small-scale farms.

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In India, natural farming is particularly relevant given the high chemical fertilizer use in 228 districts (above 200 kg/ha) and the environmental toll of conventional agriculture. The NMNF targets these regions to reduce input dependency and rejuvenate soils.

Case Studies

1. **Andhra Pradesh, India**: The Community Managed Natural Farming (CMNF) program has transitioned 7 lakh farmers to ZBNF, covering 6.5 lakh hectares. Farmers report 20–30% cost reductions and improved soil health, with women-led self-help groups driving adoption.
2. **Assam, India**: A 2022 experiment at Assam Agricultural University showed that azolla and biofertilizers increased rice soil nitrogen by 272.53 kg/ha, demonstrating the efficacy of natural inputs.
3. **Philippines**: Aloha House's organic farm uses IMO and vermicomposting to produce food for an orphanage, reducing costs and improving nutrition for children.

Future Directions

The future of advanced natural farming lies in integrating technology and science without compromising its ecological ethos. Potential advancements include:

- **Precision Agriculture**: Using drones or sensors to monitor soil health and water needs, optimizing natural inputs.
- **Genetic Diversity**: Breeding climate-resilient, pest-resistant crop varieties through traditional methods, as advocated by Fukuoka.
- **Digital Platforms**: Expanding portals like Jaivik Kheti to connect farmers with buyers and provide real-time advice.
- **Research and Validation**: Establishing scientific standards for natural farming, as planned by the NMNF, to build trust and facilitate certification.

Global collaboration, such as through organizations like ECHO or FAO, can share best practices and adapt natural farming to diverse agroecological zones.

Conclusion

Advanced natural farming represents a paradigm shift in agriculture, offering a sustainable, equitable, and resilient alternative to conventional methods. By leveraging biodiversity, local resources, and ecological principles, it addresses pressing challenges like soil degradation, climate change, and farmer debt. While challenges like yield transitions and market access persist, policy support, research, and community-driven adoption are paving the way for scalability. In India, initiatives like the NMNF signal a commitment to mainstreaming natural farming, with potential to transform global agriculture. As Masanobu Fukuoka noted, "The ultimate goal of farming is not the growing of crops, but the cultivation and perfection of human beings." Advanced natural farming embodies this vision, nurturing both the land and its stewards for a regenerative future.

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Milk Fever in Bovines: Biochemical Interventions and Clinical Importance

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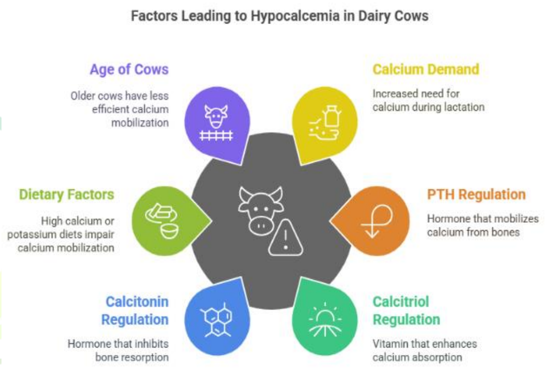
Introduction

Milk fever, also known as hypocalcemia or parturient paresis, is a metabolic disorder primarily affecting high-producing dairy cows during the periparturient period, typically within 24-72 hours post-calving. This condition results from a sudden drop in blood calcium levels due to the high calcium demand for colostrum and milk production. Milk fever can lead to severe clinical manifestations, including muscle weakness, recumbency, and, if untreated, death. It poses significant economic challenges due to reduced milk yield, increased veterinary costs, and higher culling rates. Subclinical hypocalcemia, which is more prevalent, often goes undetected and can predispose cows to other metabolic disorders. Prevalence varies but is estimated to affect 5-10% of dairy cows clinically, with subclinical cases impacting up to 50% of high-producing herds. Risk factors include high milk yield, advanced age, and improper dietary management during the transition period. Early detection and effective interventions are critical to minimizing economic losses and ensuring herd health.

Milk fever is categorized into two forms:

1. **Clinical Milk Fever**: Characterized by overt symptoms such as inability to stand and muscle tremors.
2. **Subclinical Milk Fever**: Marked by low blood calcium without visible signs, increasing susceptibility to secondary diseases.



Biochemical Aspects of Milk Fever

During early lactation, dairy cows face a dramatic increase in calcium demand to support colostrum and milk production. Calcium is essential for muscle contraction, nerve function, and metabolic processes. Blood calcium is maintained through dietary absorption, bone resorption, and renal reabsorption, regulated by parathyroid hormone (PTH), calcitriol (1,25-dihydroxyvitamin D), and calcitonin. At calving, the sudden onset of lactation can outpace these mechanisms, leading to hypocalcemia.

The biochemical cascade begins with increased mammary gland uptake of calcium, depleting plasma calcium levels. In response, PTH is secreted to mobilize calcium from bones and enhance intestinal absorption via calcitriol. However, in high-producing or older cows, these compensatory mechanisms may be insufficient, particularly if prepartum diets are high in calcium or potassium, which impair calcium mobilization. Low blood calcium disrupts neuromuscular function, leading to clinical signs such as muscle weakness and

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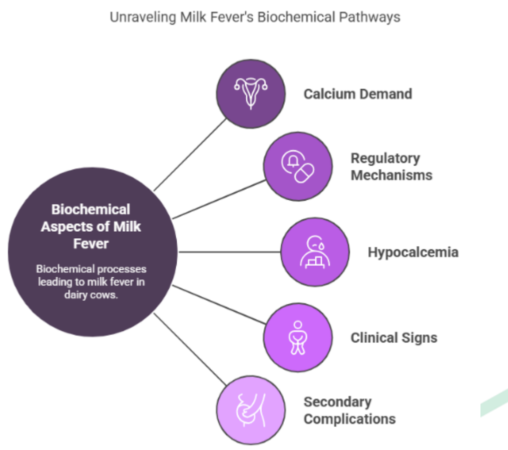
reduced rumen motility. Prolonged hypocalcemia can also cause secondary complications like dystocia, retained placenta, and mastitis.



Calcium Homeostasis in Cattle

- **Calcium demand**: Peaks at calving due to colostrum production (2-3 g/L calcium).
- **Sources**: Dietary absorption (small intestine), bone resorption (mediated by PTH).
- **Regulation**: PTH increases bone resorption; calcitriol enhances intestinal absorption.
- **Disruption**: High dietary cation-anion difference (DCAD) prepartum reduces calcium mobilization efficiency.

Table 1: Biochemical Pathways Involved in Calcium Regulation

Step	Pathway	Key regulators	Outcome
1	Bone Resorption	PTH, Osteoclasts	Release of calcium and phosphorus
2	Intestinal Absorption	Calcitriol	Increased calcium uptake
3	Renal Reabsorption	PTH	Reduced calcium excretion
4	Mammary Secretion	Lactation	Calcium loss in milk

Clinical Manifestations of Milk Fever

1. **Subclinical hypocalcemia**:
   - Blood calcium < 2.0 mmol/L without visible signs.
   - Predisposes cows to secondary disorders (e.g., mastitis, metritis).
2. **Clinical milk fever**:
   - Muscle tremors, weakness, and recumbency.
   - Reduced rumen motility and constipation.
   - Cold extremities and weak pulse in severe cases

Table 2: Clinical signs and their implications

Clinical Sign	Biochemical Basis	Diagnostic Value
Muscle tremors	Low calcium impairs neuromuscular function	Blood calcium < 2.0 mmol/L
Recumbency	Severe hypocalcemia affects muscle contraction	Blood calcium < 1.5 mmol/L
Reduced rumen motility	Calcium-dependent smooth muscle dysfunction	Clinical observation
Cold extremities	Poor peripheral circulation	Severe cases

Diagnosis of Milk Fever

Blood tests

- **Total calcium**: Normal: 2.1–2.5 mmol/L; Hypocalcemia: < 2.0 mmol/L.
- **Ionized calcium**: More accurate; Normal: 1.1–1.3 mmol/L; Hypocalcemia: < 1.0 mmol/L.

Clinical assessment

- Observation of muscle tremors, recumbency, and response to calcium therapy.

Other biomarkers

- **Magnesium and phosphorus**: Often low in milk fever cases.
- **Parathyroid hormone**: Elevated in response to hypocalcemia.

Table 3: Diagnostic Biomarkers for Milk Fever

Biomarker	Normal Range	Hypocalcemia Indicator
Total Calcium	2.1–2.5 mmol/L	< 2.0 mmol/L
Ionized Calcium	1.1–1.3 mmol/L	< 1.0 mmol/L
Magnesium	0.8–1.2 mmol/L	< 0.8 mmol/L
Phosphorus	1.3–2.6 mmol/L	< 1.3 mmol/L

Prevention and Management Strategies

Effects of Poor Management

Suboptimal feed quality, inadequate transition diets, or high DCAD diets (rich in potassium or sodium) can exacerbate milk fever. Poor housing and hygiene increase stress, further impairing calcium metabolism. These factors lead to:

- ▼ Milk yield
- ▼ Reproductive performance
- ▼ Immune function

Nutritional Management

- **Low DCAD Diets**: Prepartum diets with a negative DCAD (e.g., -100 to -150 mEq/kg) enhance calcium mobilization by inducing mild metabolic acidosis.
- **Calcium restriction**: Limit dietary calcium prepartum (< 50 g/day) to stimulate PTH and calcitriol activity.
- **Magnesium supplementation**: Ensures optimal PTH function (0.3–0.4% of dry matter).

Monitoring and Early Detection

- Regular blood calcium testing in early lactation.
- Monitoring high-risk cows (older, high-yielding, or Jersey breeds).

Treatment Approaches

- **IV Calcium Borogluconate**: 400–800 mL of 23% solution for rapid correction.
- **Oral Calcium Gels**: 50–100 g calcium for subclinical cases or maintenance.
- **Vitamin D Injections**: Enhances calcium absorption (e.g., 10,000 IU/kg prepartum)

Table 4: Treatment approaches

Treatment	Mechanism	Dosage
IV Calcium Borogluconate	Restores blood calcium	400–800 mL (23%)
Oral Calcium Gels	Sustained calcium supply	50–100 g
Vitamin D	Enhances absorption	10,000 IU/kg
Magnesium Sulfate	Supports calcium metabolism	50–100 mL (50%)

Recent Findings

- **Anionic Salts in DCAD Diets**: Studies confirm that anionic salts (e.g., ammonium chloride) in prepartum diets reduce milk fever incidence by 30–40% by improving calcium mobilization (Goff, 2020).
- **Biomarker Panels**: Advanced metabolomic profiling identifies early hypocalcemia markers, enabling proactive interventions (Martinez et al., 2023).
- **Calcium Homeostasis Genetics**: Research on calcium-regulating gene expression suggests breed-specific predispositions, guiding selective breeding for resilience (Roche et al., 2022).

Conclusion

Milk fever is a critical metabolic disorder with significant economic and health implications for dairy herds. Understanding its biochemical basis, implementing preventive nutritional strategies, and leveraging early diagnostic tools are essential for effective management. By addressing risk factors and adopting evidence-based interventions, dairy farmers can enhance cow welfare, optimize milk production, and improve herd profitability.

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"Reimagining Rice-Rice Cropping System: Exploring Sustainable Crop Alternatives for Balodabazar District of Chhattisgarh"

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Introduction

The Rice-Rice cropping system has been a dominant agricultural practice in Balodabazar district of Chhattisgarh for decades. With assured irrigation from canals and borewells, favourable government procurement policies, and deep-rooted food preferences, farmers have been encouraged to grow paddy in both Kharif and Rabi seasons. While this system initially provided food security and income stability, it is now increasingly showing signs of unsustainability.

Continuous rice cultivation has led to multiple agronomic and ecological issues. The most critical among them are the rapid depletion of groundwater, degradation of soil health, stagnating yields, and the buildup of weeds, diseases, and pests. Moreover, with rising input costs—especially for fertilizers, water, and labour—the profitability of the Rice-Rice system is gradually declining. Additionally, climate change and irregular rainfall patterns are further challenging the reliability of this traditional system.

Another pressing concern is the environmental impact of rice cultivation, particularly in the Rabi season, which is more water-intensive due to high evapotranspiration. Methane emissions from continuously flooded rice fields also contribute to greenhouse gas accumulation, making the system environmentally burdensome.

To ensure long-term sustainability, there is an urgent need to transition towards more diversified and resilient cropping systems in Balodabazar. Crops like pulses (chickpea, lentil), oilseeds (mustard, linseed), and even cereal alternatives (maize, wheat) can serve as better options, especially in the Rabi season. These crops not only require less water but also enhance soil health and offer better returns when linked with proper markets.

This article aims to explore practical alternatives to the Rice-Rice system, evaluate their agronomic and economic feasibility, and propose actionable recommendations for promoting sustainable cropping systems in Balodabazar. It is time to rethink traditional practices and adopt a more climate-smart and farmer-friendly approach to agriculture.

Background

The rice–rice cropping system is one of the most prominent and practiced cropping patterns in Balodabazar district of Chhattisgarh. With fertile soils, adequate irrigation facilities, and a favorable agro-climatic environment, farmers in this region have long adopted the practice of cultivating rice during both the kharif (monsoon) and summer seasons. One of the major driving forces behind the popularity of this system is the high market demand for summer rice, particularly due to the large number of Poha (flattened rice) mills established in the district. These mills require a steady supply of bold rice grains, and varieties such as **Mahamaya** and **Rajeshwari** are especially preferred for their bold grain size and superior processing quality, making them highly suitable for Poha production. As a result, farmers cultivating these varieties find a reliable market and receive competitive prices. In addition, Balodabazar hosts one of the most active mandis (Bhatapara Mandi) in the region, providing farmers with efficient avenues for selling their rice at remunerative rates.

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However, this intensive system also presents several challenges. Continuous rice cultivation often leads to soil nutrient depletion, especially of nitrogen, phosphorus, and micronutrients like zinc. It can also cause a decline in soil organic carbon, increased water consumption, pest and disease pressure, and reduced input use efficiency. In certain areas, over-extraction of groundwater during the summer season is becoming a concern.

Table 1: Cropping Area and Yield of Rice in Balodabazar (Approximate Values)

Season	Area under Rice (ha)	Average Yield (q/ha)
Kharif	239000	34.10
Rabi	7,000	38.5

While rice yields have remained relatively stable, the long-term sustainability of the system is under threat. Soil fatigue has become common due to nutrient mining and lack of crop rotation. Deficiencies of zinc and boron are now frequently reported. Continuous puddling also leads to deterioration of soil structure. Moreover, Rabi rice requires 3 to 4 times more water than Kharif rice, putting immense pressure on groundwater and canal systems during dry months. Rising input costs especially for irrigation, fertilizers, and labour are reducing profit margins. With climate variability and shifting rainfall patterns, this mono-cropping system is becoming riskier. These challenges underline the urgent need to diversify the cropping system and reduce the overdependence on rice cultivation in both seasons.

Why Change is Needed

The Rice-Rice cropping system in Balodabazar, while historically beneficial, is now showing signs of strain on multiple fronts—environmental, agronomic, and economic. The need for change is driven by both the long-term sustainability of natural resources and the need to ensure stable livelihoods for farmers.

1. Environmental Impacts

Rabi rice in Balodabazar demands 3–4 times more water than Kharif rice, straining groundwater and canal systems. Groundwater levels have declined by 1–2 meters in many blocks. Additionally, flooded rice fields emit significant methane (30–60 kg CH_4/ha/season), contributing to climate change. These environmental concerns raise questions about the sustainability of the Rice-Rice system. Replacing Rabi rice with water-efficient, low-emission crops like pulses and oilseeds can reduce environmental stress, conserve water, and align with climate-resilient agriculture goals.


दैनिक भास्कर
आंचलिक 06-04-2025

40 गांवों में पानी की दिक्कत, जिले में भूजल स्तर 350 फीट तक पहुंच चुका

जिले में हर साल 69–70 सेमी अंडर ग्राउंड वाटर लेबल घट रहा

इन गांवों में स्थिति होती है ज्यादा खराब

गर्मी में प्रति व्यक्ति औसतन 130 लीटर पानी की खपत

रबी सीजन में धान की फसल लेने से हो रही परेशानी

52 करोड़ की धान फसल में 62 करोड़ का बिजली खर्च

2. Soil Health Concerns

Continuous rice cultivation depletes essential micronutrients, especially zinc and boron—over 60% of samples in the district show deficiencies. Puddling weakens soil structure, causing compaction and poor infiltration. Salinity buildup is also emerging in over-irrigated zones. Lack of crop rotation and organic matter reduces microbial activity and leads to soil fatigue. Diversifying crops with legumes and deep-rooted varieties can restore soil health, enhance nutrient cycling, and reduce dependency on chemical fertilizers.

3. Rising Labour and Input Costs

The Rice-Rice system requires heavy labour for transplanting and harvesting, with labour costs ranging from ₹300–400/day. Irrigation, fertilizers, and plant protection inputs have become more expensive, reducing net profits. Rabi rice also faces higher risks from pests and water stress. Marginal farmers are particularly vulnerable. Shifting to low-input crops like chickpea or mustard can reduce production costs, lessen labour dependency, and offer better profitability and risk resilience.

4. Nutritional and Dietary Limitations of Monocropping

With 70–80% of irrigated land under rice, the availability of pulses, oilseeds, and vegetables is reduced, limiting household food diversity. This monoculture contributes to hidden hunger and poor nutrition in rural areas. NFHS-5 data shows high anemia and stunting rates in Chhattisgarh, partly due to dietary gaps. Integrating pulses and vegetables into cropping systems can improve nutrition, food security, and align with national goals like promotion of nutri-cereals and biofortified crops.

Suitable Crop Alternatives

1. Rabi Season Options After Kharif Rice

Several less water-intensive and high-value crops can replace Rabi rice in Balodabazar. Chickpea is well-suited to residual moisture conditions and fixes atmospheric nitrogen, enhancing soil fertility. Yields average 12–18 q/ha under proper management. Lentil is another low-input pulse crop that matures in 90–100 days and improves dietary diversity. Mustard and linseed require limited irrigation (1–2 times) and are ideal for canal tail-end and well-drained fields, providing 10–15 q/ha. Wheat can be grown in better-irrigated patches but should be restricted due to its high-water requirement. These crops reduce groundwater use by 60–70% compared to Rabi rice. Moreover, pulses and oilseeds improve soil organic carbon and contribute to crop rotation benefits, reducing pest and disease buildup.

2. Diversified Kharif Options

Balodabazar's upland and medium land areas are suitable for diversified Kharif crops like maize, arhar (pigeon pea), and soybean, which perform well under rainfed or limited irrigation conditions. Maize, with yields of 30–40 q/ha, is more water-efficient than rice and has strong market demand. Arhar, a deep-rooted legume, enhances soil fertility and is resilient to dry spells. It fetches high prices (₹6000–7000/q) and is suitable for intercropping. Soybean matures within 90–100 days, suits uplands, and improves nitrogen availability in soil. Unlike puddled rice, these crops preserve soil structure and require 40–50% less water. Their inclusion diversifies income sources, reduces pest pressure, and supports ecological sustainability. Promotion through crop demonstrations and seed kits under NFSM pulses/oilseeds can help farmers transition effectively. These crops also provide a basis for developing value chains and farmer producer organizations (FPOs) in the district.

3. Short-Duration Crops or Intercropping Possibilities

Short-duration and intercrops offer flexibility and resource-use efficiency in both Kharif and Rabi. Short-duration varieties of rice (110–120 days) free up the field earlier, allowing timely sowing of Rabi pulses. For instance, varieties like Indira Barani Dhan-1 or MTU-1010 are drought-tolerant and early maturing. In Rabi, short-duration crops like green gram and black gram (60–70 days) can be grown on residual moisture. Intercropping systems like arhar + soybean or maize + cowpea optimize land use and reduce pest incidence through crop diversification. Scientific studies show intercropping can improve land equivalent ratio (LER) by 1.2–1.5, meaning better productivity per unit area. These systems also offer staggered income, helping manage risks. Including vegetables like okra or tomato as intercrops can boost profitability, especially for farmers with market access. Promotion through integrated farming models can increase adoption among smallholders and enhance resource efficiency in Balodabazar.

Agro-Economic Benefits of Replacing Rabi Rice

1. Water Saving and Reduced Input Cost

Replacing Rabi rice with pulses or oilseeds results in significant water and cost savings. Pulses like chickpea and lentil need only 15–25% of the water required for rice, often thriving on residual moisture. Mustard and linseed require just 1–2 irrigations, compared to 15–20 for Rabi rice. Input costs are lower, as these crops need less fertilizer and minimal plant protection. Average cultivation cost is ₹20,000–25,000/ha, nearly half of what is spent on Rabi rice (₹40,000–50,000/ha). Dry sowing and harvesting also allow easier mechanization, saving labor and fuel.

Table 2: Comparative Water Use and Input Cost

Crop	Water Requirement (Irrigations)	Fertilizer Cost (₹/ha)	Total Input Cost (₹/ha)
Rabi Rice	15–20	High	₹40,000–50,000
Chickpea	1–2	Low	₹20,000–25,000
Mustard	2	Low	₹22,000–26,000

2. Increased Income from Pulses and Oilseeds

Chickpea yields of 12–18 q/ha can earn ₹65,000–95,000/ha at MSP rates, with net returns often above ₹40,000/ha. Mustard and linseed offer net profits of ₹30,000–35,000/ha. These crops are less prone to market saturation and see rising demand from nutrition and health-focused markets. Their compatibility with rainfed and low-input conditions makes them ideal for smallholders. Value-added opportunities like dal milling and oil extraction further enhance profitability.

Table 3: Yield and Income Comparison

Crop	Average Yield (q/ha)	Sell Price (₹/q)	Gross Return (₹/ha)	Net Return (₹/ha)
Rabi Rice	35–45	₹2,183	₹76,405–98,235	₹26,000–48,000
Chickpea	12–18	₹5,440	₹65,280–97,920	₹40,000–72,000
Mustard	10–14	₹5,650	₹56,500–79,100	₹30,000–35,000

3. Improved Soil Fertility through Legumes

Legumes fix 20-25 kg N/ha biologically, reducing fertilizer needs and enriching the soil for succeeding crops. They improve soil structure, organic carbon, and microbial health. Their biomass boosts organic matter and water retention, while breaking pest cycles. Pulses can enhance subsequent rice yields by 10–15%, making them both ecologically and economically beneficial.

Table 4: Soil Nutrient Status and Organic Carbon under Different Cropping Systems

Cropping System	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)	Soil Organic Carbon (%)
Rice–Rice	220	14	240	0.38
Rice–Chickpea	265	18	290	0.52
Rice–Mustard	250	17	285	0.48
Rice–Lentil	270	20	310	0.55
Rice–Linseed	255	19	275	0.50

Case Studies or Pilot Successes in Balodabazar

Case Study 1: Chickpea and Mustard in village Rajadhar (Bhatapara Block)

Background:

Rajadhar village in Bhatapara block was traditionally under a Rice-Rice cropping system. With rising input costs, water scarcity, and declining soil health, CFLD was initiated to replace Rabi rice with low-water-demand crops.

Intervention:

- Crops Introduced: Chickpea and Mustard
- Area Covered: 10 hectares
- Support: KVK Bhatapara through CFLD (Oilseed & Pulses) – seed kits, training, and field demonstrations

Outcomes:

- Water usage reduced by ~60%
- Chickpea yields: 14–16 q/ha; Mustard: 10–12 q/ha
- Net returns: Chickpea – Rs. 42,000/ha; Mustard – Rs. 38,500/ha
- Soil organic carbon improved from 0.38% to 0.44% in two years

Farmer Testimonial:

"Earlier, we used to struggle with water and high input costs for Rabi rice. After shifting to chickpea, income improved and fields are ready earlier for Kharif."

— *Shri Mahadev Sahu, Progressive Farmer*

Case Study 2: Pigeon pea and Soybean in village Mohbhatta (Simga Block)

Background:

Medium upland soils in Mohbhatta village faced erratic monsoons and declining productivity under monocropped rice.

Intervention:

- Cropping Introduced: Pigeon pea and Soybean
- Area: 10 hectares
- Support: KVK Bhatapara through CFLD Oilseed and Pulses

Outcomes:

- Gross returns improved from Rs. 55,000 to Rs. 78,000/ha
- Natural pest control observed – reduced pesticide use by 30%

Farmer Testimonial:

Soybean gives early money, and Arhar gives stability. Together they improved my income and reduced my pesticide expenses."

— *Shri Prakash Mahto, Progressive Farmer*

"

Case Study 3: Lentil and Linseed in Muswadih (Kashdol Block)

Background:

Farmers in Mushwadih struggled with poor returns from water-intensive Rabi rice. Soil fatigue and delayed Kharif land prep were common.

Intervention:

- Crops Introduced: Short-duration Lentil and Linseed
- Irrigation: One light irrigation used

Outcomes:

- Harvested by February, allowing early Kharif preparation
- Net profit: Rs. 36,000–40,000/ha
- Household consumption of pulses increased
- Soil structure improved and compaction reduced

Farmer Testimonial:

"We never used to grow pulses. Now we eat what we grow, sell the rest, and save water too."

— *Shri Ramswaroop Nishad, Small Farmer*

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Case Study 4: Kharif Maize in Arjuni (Balodabazar Block)

Background:

Arjuni village lies in a rainfed upland zone near the Balodabazar district. Previously under mono-cropped upland paddy, productivity was poor due to erratic rainfall and poor water retention.

Intervention:

- Crop Introduced: Kharif Maize (Hybrid)
- Area: 5 hectares

Outcomes:

- Yield achieved: 42–48 q/ha (compared to 16–20 q/ha upland rice)
- Gross income: Rs. 62,000–68,000/ha
- Reduced pest incidence; better drought resilience observed
- Residual moisture conserved for short-duration pulse in Rabi

Farmer Testimonial:

"Earlier, I used to cultivate rice in both Kharif and Rabi seasons. But continuous rice farming had started affecting my soil, and water usage was becoming unsustainable. In 2022, with guidance from the Krishi Vigyan Kendra (KVK) Bhatapara, I decided to shift to **maize in the Rabi season** under limited irrigation." *Shri Santosh Verma, Marginal Farmer*

Recommendations and Way Forward

1. Need for Awareness and Training

To transition farmers away from the traditional


दैनिक भास्कर आंचलिक 26-03-2025

बदलाव • अब पलारी ब्लॉक के किसान रबी सीजन में धान की फसल लेना छोड़कर मक्के की खेती में खेती में रुचि ले रहे

मक्के में प्रति एकड़ 40 हजार का शुद्ध लाभ, पानी भी कम लगता है

Rice-Rice system, **capacity building** is essential. Many smallholders are unaware of the economic and environmental benefits of diversified crops.

- Regular field demonstrations, farmer field schools (FFS), and exposure visits should be conducted in collaboration with Agriculture Department and Farmer Producer Organizations (FPOs).
- Training should focus on:
  - Selection of crops based on soil and water availability
  - Improved agronomic practices and pest management
  - Post-harvest processing and value addition

2. Crop Calendar Planning and Input Access

Strategic **crop calendar planning** can ensure optimal land use throughout the year, with minimal overlap between Kharif and Rabi seasons.

- Promote **short-duration Kharif rice** or drought-tolerant alternatives to enable timely Rabi sowing of pulses/oilseeds.
- Ensure **timely availability of quality seeds, bio-fertilizers, and other critical inputs** for alternative crops like chickpea, lentil, mustard, linseed, maize, etc.
- Integrate **real-time agromet advisory services** to align sowing and irrigation decisions with weather conditions.

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Machine Learning - Modernized Plant Breeding Programs to Improve Crop Pliability

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Introduction

In the face of a growing global population, plant breeding is being used as a sustainable tool for increasing food security. A wide range of high-throughput omics technologies have been developed and used in plant breeding to accelerate crop improvement and develop new varieties with higher yield performance and greater resilience to climate changes, pests, and diseases. With the use of these new advanced technologies, large amounts of data have been generated on the genetic architecture of plants, which can be exploited for manipulating the key characteristics of plants that are important for crop improvement. Therefore, plant breeders have relied on high-performance computing, bioinformatics tools, and artificial intelligence (AI), such as machine-learning (ML) methods, to efficiently analyze this vast amount of complex data. The use of bigdata coupled with ML in plant breeding has the potential to revolutionize the field and increase food security. In this review, some of the challenges of this method along with some of the opportunities it can create will be discussed. In particular, we provide information about the basis of bigdata, AI, ML, and their related sub-groups. In addition, the bases and functions of some learning algorithms that are commonly used in plant breeding, three common data integration strategies for the better integration of different breeding datasets using appropriate learning algorithms, and future prospects for the application of novel algorithms in plant breeding will be discussed. The use of ML algorithms in plant breeding will equip breeders with efficient and effective tools to accelerate the development of new plant varieties and improve the efficiency of the breeding process, which are important for tackling some of the challenges facing agriculture in the era of climate change.

Bigdata

Bigdata is a term used to describe massive volumes of structured and unstructured data that are difficult to process using traditional statistical approaches (Katal *et al.*, 2013). Bigdata is commonly defined by three main Vs: volume, velocity, and variety (Dautov and Distefano 2017).

Volume refers to the sheer amount of data that should be processed in a research project or program, usually expressed in terms of bytes, kilobytes, megabytes, gigabytes, terabytes, etc. (Monino and Sedkaoui 2016). In the context of bigdata, velocity refers to the speed at which the data is generated and should be processed to provide useful insights (Elgendy and Elragal 2014). Velocity is a key factor in determining the effectiveness of data analyses and the efficiency of data processing. As a rule of thumb, the faster data are processed, the faster insights can be obtained from the data. Data processing at a high velocity also allows for a more timely analysis of the data, which can be used for decision making. Variety refers to the diversity of data that needs to be processed, which can come in a wide range of formats, including structured (e.g., numerical data) and unstructured (e.g., texts and images) data.

Bigdata in plant breeding is the use of high-throughput technologies, such as omics, to collect and analyze large volumes of data on plant characteristics and their interactions with the environment (Najafabadi and Rajcan 2022). This data is used to identify and improve desirable traits, such as plant yield. Volume in plant breeding can include genetic analysis results, growth observations, and environmental data (Araus and Cairns 2014). By tracking the volume of data produced, breeders can identify the experiments that are the most productive and the areas of a breeding process that require additional data (Kim *et al.*, 2020).

Velocity in breeding datasets can help researchers identify how quickly new data are being produced with different environmental conditions, germplasms, and breeding materials, and if the rate of data generation is fast enough to keep up with the pace of the breeding process (Niazian and Niedbala 2020). By monitoring the velocity of data generation, breeders can adjust their experiments or increase their data collection efforts as needed (Xu *et al.*, 2022).

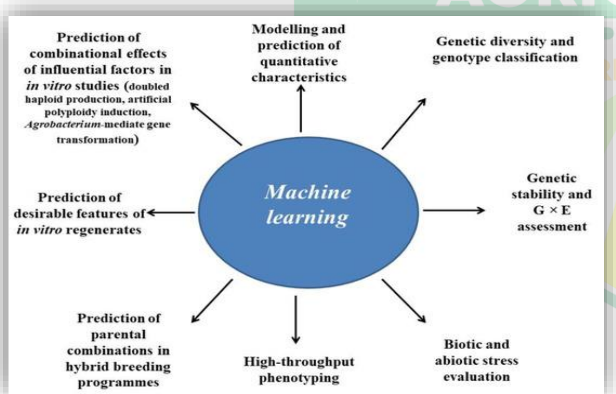

Fig 1. Potential applications of machine learning techniques in classical and modern plant breeding (Mohsen Niazian and Gniewko Niedbała 2023)

Breeders often deal with a variety of datasets, ranging from structured to unstructured datasets. Genomics datasets can be considered structured datasets as the data are organized in columns and rows, and the information is stored in a tabular format. On the other hand, unstructured datasets in plant breeding may include field notes, images, photographs, and videos. These datasets are not necessarily organized in columns and rows and are more difficult to analyze. However, they can reveal valuable insights into a plant's behavior and characteristics, which can help breeders select promising genotypes. For example, a researcher may take notes and pictures to better understand how a plant variety performs in different environmental conditions. Similarly, photographs and videos can be used to observe a plant's physical characteristics and their responses to environmental stimuli.

Machine Learning: Basis and Function

Machine learning, as an important subfield of AI, has been widely used in different aspects of our lives, such as communication and agriculture, among many others (Falk *et al.*, 2020). In agriculture, ML algorithms can be used for crop-yield prediction, crop-growth monitoring, precision agriculture, and automated irrigation (Yoosefzadeh *et al.*, 2022). ML algorithms are typically divided into three subgroups: (Hesami *et al.*, 2022)

- Supervised learning
- Unsupervised learning and
- Reinforcement learning

In supervised learning, the algorithm is trained on a labeled dataset to make predictions based on the data (Hesami and Jones 2020). The model learns by being given a set of inputs and associated outputs and then adjusting its internal parameters to produce the desired output. Supervised learning is the most common subgroup of ML algorithms that are frequently used in plant breeding to predict complex traits in an early growth stage (Yoosefzadeh 2021), detect genomic regions associated with a specific trait (Yoosefzadeh 2022), and select superior genotypes via genomic selection (Yoosefzadeh *et al.* 2022).

Unsupervised learning is used when data is not labeled, and the algorithm uses the data to find patterns and similarities in the dataset on its own. The model learns by identifying patterns in the data, such as clusters or groups. In plant breeding, unsupervised learning is usually implemented to find possible associations among genotypes within a breeding population, design kinship matrices, and categorize unstructured datasets (Mahesh 2020).

Reinforcement learning is another ML algorithm, in which the model is exposed to an environment and receives feedback in the form of rewards or penalties based on its actions (Lee *et al.*, 2012). The model learns by taking actions and adjusting its parameters to maximize the total rewards received. Reinforcement learning is quite a new area in plant breeding, and its applications need to be explored more.

In plant breeding, data collection is an essential step involving the collection of data for target traits from a wide range of environments, trials, and plant populations. Plant breeders often work in different environmental settings in order to gain an accurate understanding of the genotype-by-environment interaction in different trials within each environment. Additionally, they measure different traits in order to establish accurate multi-trait breeding strategies, such as tandem selection, independent culling levels, and selection index. As such, any collected data must be precise, accurate, and pre-processed using various packages and software in order to be suitable for plant breeding programs.

Recently, the *AllInOne* R-shiny package was introduced as an open-source, breeder-friendly, analytical R package for pre-processing phenotypic data (Yoosefzadeh *et al.* 2022). The basis of *AllInOne* is to utilize various R packages and develop a pipeline for pre-processing the phenotypic datasets in an accurate, easy, and timely manner without any coding skills required. A brief introduction to *AllInOne* is available at https://github.com/MohsenYN/AllInOne/wiki. Machine learning (ML) is increasingly used in plant breeding to accelerate the development of improved crop varieties, particularly those resilient to climate change. It helps analyze large datasets, identify beneficial traits, and predict the performance of plant genotypes, ultimately leading to more efficient and effective breeding programs.

Applications in Plant Breeding:

1. **Genotype-to-Phenotype Prediction:**

- ML algorithms can predict plant phenotypes (observable traits) based on genotype data (DNA sequence information).
- This allows breeders to select plants with desired traits even before they are fully grown, saving time and resources.
- Techniques like genomic selection use ML to identify the most promising plants based on their genetic makeup.

2. Marker-Assisted Selection (MAS):

- ML helps identify genetic markers (DNA variations) associated with specific traits.
- Breeders can then use these markers to select plants with favorable traits, accelerating the breeding process.
- MAS allows for precise selection of desirable genes, leading to more efficient crop improvement.

3. Data Analysis and Dimensionality Reduction:

- ML algorithms can handle the large and complex datasets generated by modern plant breeding techniques.
- They can reduce the dimensionality of the data, making it easier to analyze and extract meaningful information.
- This helps in identifying patterns and relationships within the data that might be missed by traditional methods.

4. Phenotyping and Image Analysis:

- ML can be used to analyze high-throughput phenotyping data, such as images of plant growth and development.
- This includes identifying plant diseases, assessing morphological traits, and measuring other important characteristics.
- Deep learning algorithms can be particularly useful for image analysis, allowing for automated and accurate phenotyping.

5. Improving Resistance to Climate Change:

- ML can help identify plant varieties that are more resilient to climate change effects, such as drought, heat, and salinity.
- By analyzing data on plant performance under different environmental conditions, ML can help breeders select plants that are better adapted to changing climates.
- This is crucial for ensuring food security in a changing world.

Table 1. The important attributes of different ML methods in plant breeding based on ranking (low, medium, high, and very high). (Yoosefzadeh *et al.*, 2023)

ML Method	Hyperparameter Tuning	Overfitting Risk	Explainability	Comparative Accuracy	Complexity	Samples Needed	Computation Cost	Implementation Time
Deep Neural Network	Very high	Low	Low	Very high	Very high	Very high	Very high	Very high
Artificial Neural Network	High	High	Low	High	High	Medium	High	High
Random Forest	High	Medium	High	High	Medium	Low	Medium	Low
Non-linear (Kernel) SVM	High	High	Low	High	High	High	High	High
Linear SVM	High	High	Low	High	Medium	High	Medium	Medium
Decision Tree	Medium	High	High	Medium	Medium	Medium	Medium	Low
Self-Organizing Maps	High	High	Medium	Medium	High	Medium	Low	Low
K nearest neighbor	Medium	High	Medium	Medium	High	Medium	Low	Low
Gradient Boosting	Very high	High	Low	High	Very high	Medium	High	Medium
Naive Bayes	Medium	Medium	Medium	Medium	High	Medium	High	Medium
Bayesian Network	High	Medium	Medium	Medium	High	Medium	High	Medium
Partial Linear Regression	Medium	Low	High	Medium	Medium	High	Medium	Low
Logistic Regression	Low	High	High	Low	Medium	Medium	Medium	Low

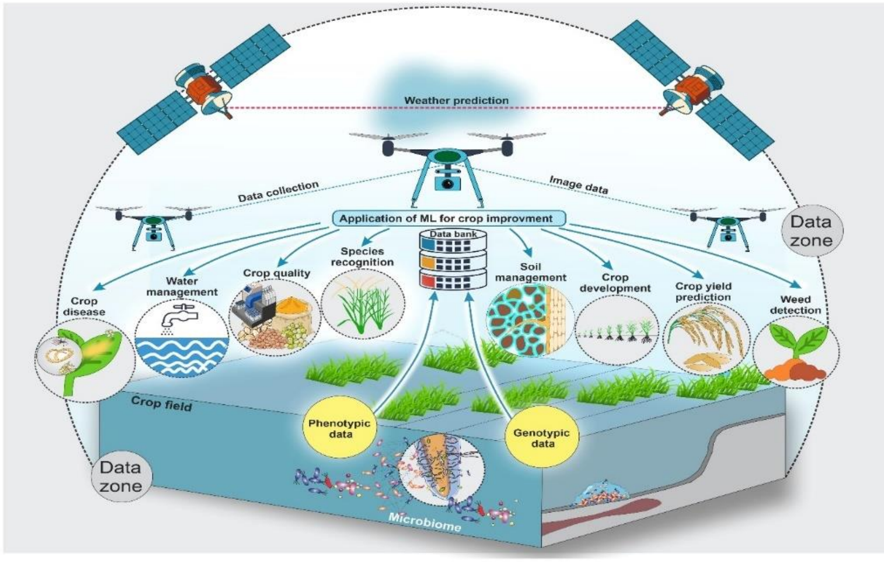

Fig 2. Applications of machine learning for Crop improvement.

6. Other Applications:

- ML can also be used for:
  - **Identifying trait-related genes:** By analyzing multi-omics data, ML can help pinpoint genes that are responsible for specific traits.
  - **Inference of gene regulatory networks:** ML can be used to map the complex relationships between genes and their interactions.
  - **Data-driven genomic design breeding:** ML can help develop breeding strategies based on data analysis and prediction, rather than relying solely on intuition.

Conclusion

ML provides a great opportunity to make plant breeding more efficient and predictable. In this review, we tried to discuss and highlight the main concepts of ML in terms that are relatable to plant breeding and discuss illustrative examples from conventional practices in plant breeding. ML can be employed in almost every step of plant breeding, from selecting appropriate parental lines for crosses to evaluating the performance of advanced breeding lines across several environments. Although this review paper was limited to a discussion on the applications of machine learning in conventional-based plant breeding, high-throughput phenotyping, and genotyping, other breeding-based methods (e.g., in vitro breeding, *Agrobacterium*-mediated genetic transformation, and genome editing) can also benefit from using ML methods. In general, the generation of large, high-quality datasets is a key factor in the continuation of the successful implementation of ML in plant breeding programs. To plan and generate large datasets that can be used for meta-analysis, it is important for the scientific plant breeding community to agree on some fundamental principles, such as data type, content, and data format, to ensure that data generated by different breeders and institutions are compatible and made available, ideally in an ML-readable format. The availability of such datasets can provide a forward-thinking aid to ML-mediated plant breeding and can hopefully overcome many of the challenges faced by plant breeding programs.

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Applications of GPS, GIS, and Remote Sensing in Modern Agriculture

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Global Position System: A position information system enables the user to determine absolute or relative location of a feature on or above the earth's surface.

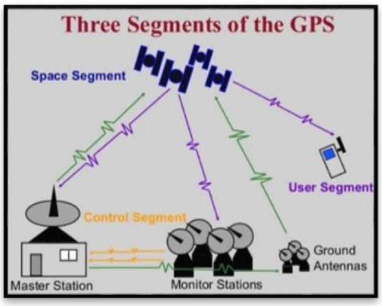
History

- This system so referred as NAVSTAR Or Navigation by Satellite Timing and Ranging by DOD. GPS allows farmers to accurately navigate to specific locations in the field, year after year, to collect soil samples or monitor farm conditions.
- The first Satellite was launched in 1978.
- Each orbit is at an altitude of 20,200 km (12,500 miles).

GPS Segments

1. **Space segment**: Space segment is the part of the GPS that consists of satellites
2. **Ground station**: Ground station is the second part of the GPS system, comprising a receiver and antenna, as well as communication tools that transmit data to the data centre.

- **User segment:** GPS receivers and user community
- **Control segment:** Handful of monitoring stations located around the world.



Types of GPS:

1. Hand Held 2) Backpack 3) Vehicle Mounted 4) Commercially available GPS: Garmin

Area of Applications

Farm planning: GPS plays an important role in the planning of a farmland ready for planting. GPS will give the overall size of the area and help in determining what crop will be planted on what part of the farmland using various factors such as soil characteristics and crop characteristics.

Field mapping: GPS gives an exact estimate of the field that is being prepared for farming and other non-farming related activities.

Soil sampling: GPS provides the necessary data to accurately determine soil variability and to establish whether a given type of soil is ideal for the growth of a particular crop.

Sampling Methods:

1. **Grid sampling:** Intensive sampling of entire fields
2. **Direct sampling:** Intensive sampling of particular targeted areas

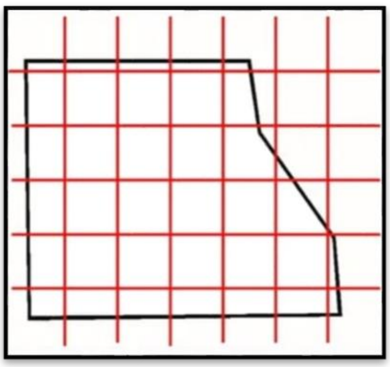


Figure 2. Grid sampling

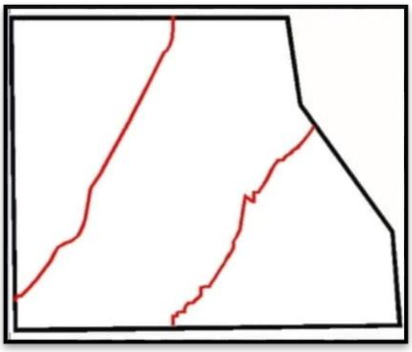


Figure 3. Direct sampling

Yield mapping: After a crop has been planted and is ready for harvesting, GPS can be used to make an estimation of the yield of a given farmland. This can be achieved through aerial mapping where experts can tell the quantity of a yield based on the area covered by the crop.

Advantages:

- GPS costs very low as compared other navigation systems.
- This is the simplest navigating system in water even in in larger water bodies.
- Reduces the fertilizer costs.

Disadvantages:

- If GPS is battery operated device, sometimes leads to battery failure and it need a external power supply which is not always possible.
- Sometimes GPS signals are not accurate due to some obstacles to signals like buildings, trees and sometimes by extreme atmospheric conditions like geomagnetic storms.

Remote Sensing

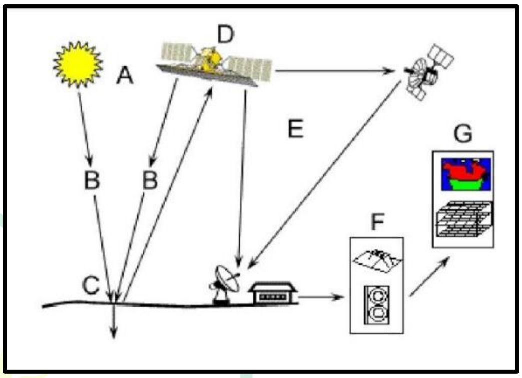
Remote sensing is the study of acquiring data about an item or region from a distance and without connecting physically with an object.

Basic principle:

- The source of remote sensing data is the electromagnetic radiations which are emitted or reflected by the object, which then helps in their identification and classification.
- The sensors measure the amount of energy Reflected from that object.

Components of Remote sensing

(A) Energy source or Illumination
(B) Radiation and the Atmosphere
(C) Interaction with the Target
(D) Recording of energy by the sector
(E) Transmission, Reception and processing
(F) Interpretation and Analysis
(G) Application



Sensors and Platforms

Sensors: It is a device that receives electromagnetic radiations and converts it into a signal that can be recorded and displayed as either numerical data or an image.

Platforms: These are structures or vehicles on which remote sensing instruments are mounted.

1. **Ground-level platform:** To study the properties of a single plant or patch of grass. It would make sense of ground based instrument.
   Example: Towers and Cranes
2. **Airborne platforms:** At present, airplanes are most common airborne platforms.The whole spectrum of civilian and military aircraft are used for RS applications.
   Example: Helicopters, low altitude aircraft, high altitude aircraft

3. Space borne platforms: Most Stable type platforms, where Satellites are used.
Example: space shuttles, polar-orbiting satellites, and geostationary

Types of Remote sensing:

Based on source of energy

1. Active Remote sensing: The RS system have own source of energy for illumination. This type of RS not Works not only during day even during night. Microwave RS with SAR as sensor is an example for this type. (1mm to 1m).

2. Passive Remote sensing: The Remote sensing system uses natural available solar radiation to record the observations. The sunlight illuminates the earth surface and gets reflected in visible range (0.4-0.7μm) and reemitted in IR and thermal IR range (0.7-0.30μm).

Advantages:

- Large area coverage can be done.
- Data collected through remote sensing is analysed at the laboratory which minimizes the work that needs to be done on the field.
- Remote sensing is a relatively cheap and constructive method reconstructing a base map in the absence of detailed land survey methods.

Disadvantages:

- Remote sensing is a fairly expensive method of analysis especially when measuring or analysing smaller areas and Remote sensing requires a special kind of training to analyse the images.
- Powerful active remote sensing systems such as radars that emit their own electromagnetic radiation can be intrusive and affect the phenomenon being investigated.

Geographical Information System (GIS): Is a computer-based tool for mapping and analysing feature events on earth.

- GIS technology integrates common database operations, such as query and statistical analysis, with maps.
- GIS manages location-based information and provides tools for display and analysis of various statistics, including population characteristics, economic development opportunities, and vegetation types.

Basic Functions of GIS:

1) Data Acquisition and prepossessing
2) Data base management and Retrieval Spatial
3) Measurement and Analysis
4) Graphic output and Visualization

Spatial Data models:

Raster Model: Raster data models present information through a grid of cells (points, pixel). Raster grids are usually made up of square or rectangular cells.

- Raster can be used to show the rainfall trends over an area, or to depicts the fire risk on a landscape.

Vector Model: A representation of the world or information using points, lines, and areas or polygons.

- Vector models are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets.

Advantages:

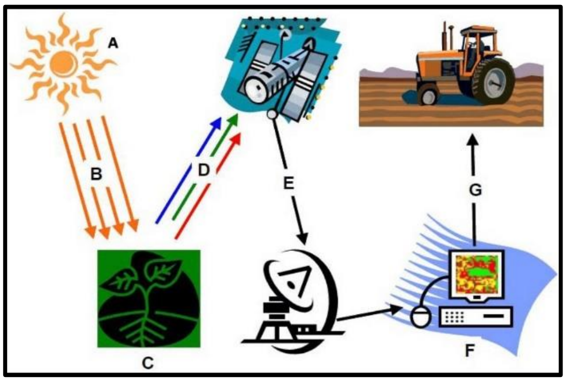
- It allows handling and exploration of large volumes of data.
- It allows integration of data from widely disparate sources.
- It allows wide variety of forms of visualization such as maps, globes, reports, charts etc.

Disadvantages:

- GIS tools are expensive.
- Learning curve on GIS software can be long.
- It shows spatial relationships but does not provide absolute solutions.

This is how both Remote sensing and GIS works in agriculture:

(A) Source **(B)** Light coming to plants **(C)** Plant **(D)** Reflected energy sensed by a sensor in satellite **(E)** It send information to the ground station **(F)** Using computer and software's to analyse the data **(G)** Finally reliable information is given to the farmers that make their farming easy.



Areas of Applications:

1. Crop production: RS plays important role in forecasting the expected crop production and yield over a given area and determining how much of the crop will be harvested under specific conditions.

2. Cropping systems Analysis: RS technology has also been instrumental in the analysis of various crop planting systems.

3. Crop identification: It also played an important role in crop identification especially in cases where the crop under observation is difficult.

4. Crop condition assessment and stress detection: Remote sensing technology plays an important role in the assessment of the health condition of each crop and the extent to which the crop has withstand stress.

Satellite imagery and normalized difference vegetation index (NDVI) technologies are used in order to monitor global food supplies.

- NDVI = NIR - RED/NIR + RED

NDVI values ranges from -1 to 1.

5. Irrigation monitoring and management: Remote sensing gives information on the moisture quantity of soils. This information is used to determine whether a particular soil is moisture deficient or not and helps in planning the irrigation needs of the soil.

6. Identification of problematic soils: Remote sensing has also played a very important role in the identification of problematic soils that have a problem in sustaining optimum crop yield throughout a planting season.

7. Precision farming: Remote sensing has played a very vital role in precision agriculture. Precision agriculture has resulted in the cultivation of healthy crops that guarantees farmers optimum harvests over a given period of time.

8. Identification of planting and harvesting dates: Because of the predictive nature of the remote sensing technology, farmers can now use remote sensing to observe a variety of factors including the weather patterns and the soil types to predict the planting and harvesting seasons of each crop.

9. Crop yield modelling and estimation: It also allows farmers and experts to predict the expected crop yield from a given farmland by using various crop information such as the crop quality, the moisture level in the soil and in the crop and the crop cover of the land.

10. Collection of past and current weather data: Remote sensing technology is ideal for collection and storing of past and current weather data which can be used for future decision making and prediction.

Conclusion:

Land suitability and capability maps provide a spatial representation of soils suitable for agriculture. Green seeker fertilizer management helps conserve nitrogen and enhances grain yield. The developed Vegetation Health Index can be used for site-specific crop management, enabling better utilization of available resources and maximizing crop yield. Together, these technologies offer valuable guidance for both present and future farming practices, supporting informed management decisions.

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The New Agricultural Technologies & Advanced Traditions of Farming

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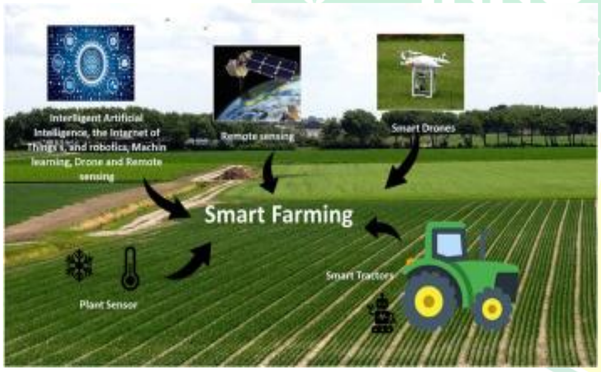
The modern agricultural business is evolving in a variety of directions at the same time. However, its primary focus is utilizing agricultural technologies to boost crop yields through better planning and smarter management. By promoting more efficient and sustainable farming methods, advanced technology in agriculture helps farmers prosper in today's agribusiness. Time-tested practices like crop rotation and new agricultural technologies, such as monitoring field productivity with machinery and satellite images or special farming software, all contribute to the viability of agriculture.



Agriculture Technology

Agricultural technology, also known as "agritech," encompasses a broad range of disciplines and devices that improve agricultural output. That includes vehicles, robotics, computers, satellites, drones, mobile devices, and software. The use of big data analytics and artificial intelligence (AI) technology in agriculture is also an example of how the farming sector is embracing technological advancement.

Changes in farming and field management during the past few decades have been revolutionary. The employment of modern, state-of-the-art technology in agriculture can be credited with much of the recent success in crop management and increased harvests.

Importance of Technology in Agriculture

Agricultural technology aims to make work in the field more efficient and convenient. Each year, there are various new agricultural innovations and, occasionally, ground-breaking technologies. As agribusiness continues to modernize and grow, it is becoming increasingly crucial for agricultural consultants, food producers, and technology managers to be knowledgeable and up-to-date with the latest technological standards.

Water, fertilizer, pesticides, and other inputs are no longer applied "by eye" or uniformly across the field by large agricultural producers. The use of advanced agriculture technologies allows for the precise application

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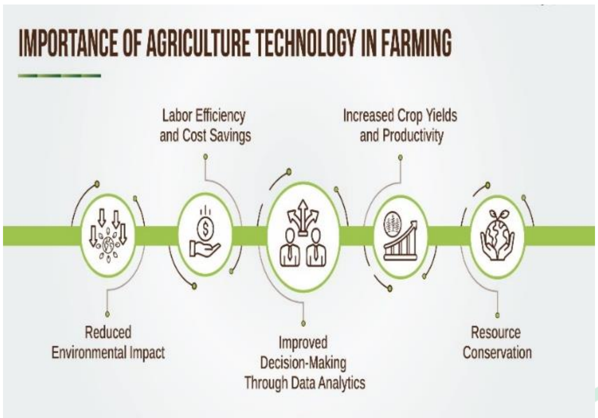
of only what is required in each location, as well as the careful tailoring of treatment for each plant.



Benefits of Technology in Agriculture

The implementation of smart agricultural technology is advantageous for all players in the agri-food chain. With its use in optimizing and automating agricultural operations and field activities, growers and landowners can now save significant amounts of time and effort.

These are just a few examples of how farming has benefited from advances in agriculture technology:

- ❖ Using less water, fertilizer, pesticides, and other inputs allows agricultural producers to cut costs and keep more of their profits.
- ❖ By preventing or drastically reducing the amount of chemical runoff into waterways, businesses lessen agriculture's impact on the environment and take steps toward greater sustainability.
- ❖ Increasing crop yields while decreasing labor inputs.
- ❖ Making it easier for farmers, agronomists, or other agricultural workers to communicate and coordinate activities using mobile devices, apps, or web-based resources.
- ❖ Lowering barriers to accessing agricultural insurance and financial services as well as market and technological data.
- ❖ Mitigation of the damage that could be caused by pests, natural calamities, and bad weather in agriculture with the help of affordable, always-on agricultural monitoring systems.
- ❖ Increase in farm income through improved product quality and increased quality controls.
- ❖ Timely recognizing nutrient deficiency in plants and notifying agricultural producers of the type and amount of fertilizer and other amendments needed.
- ❖ Ability to foresee potential problems on the farm through the visualization of production patterns and trends gleaned from an analysis of current and historical agricultural data. By estimating their overall crop yield, agricultural producers can precisely budget for the next growing season and better prepare for emergencies.

Evolution of Agriculture Technology

Technological progress in agriculture is intrinsically linked to the rise of urban centers and commercial exchange. New technological developments have always been prevalent in this field.

Nonetheless, the technological model of agricultural production remained largely

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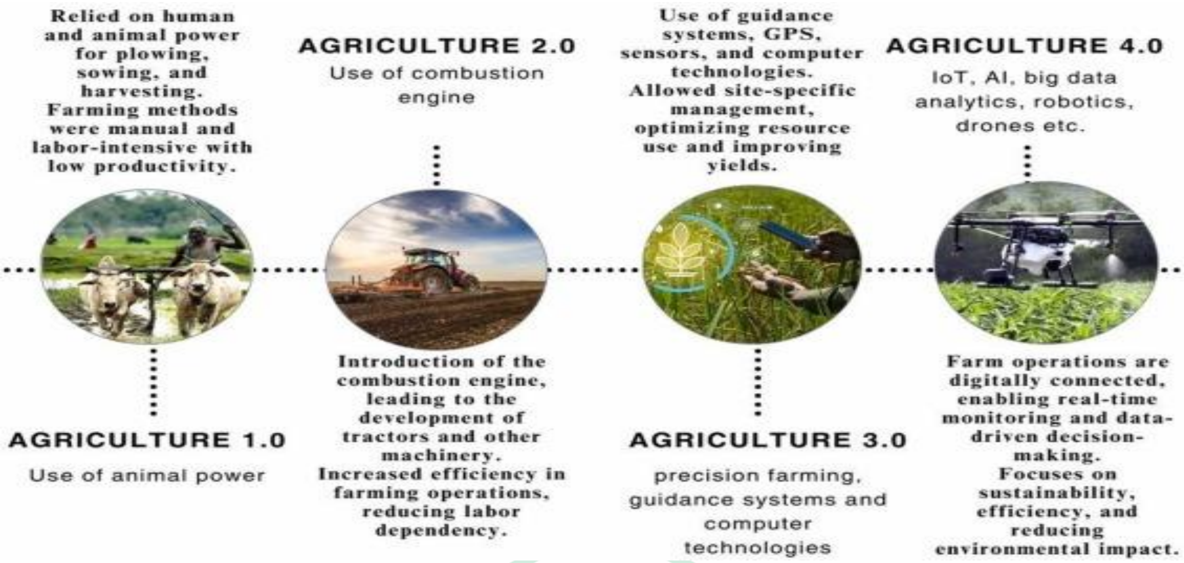


subsistence-based and characterized by poor productivity until the early 20th century. This era, known as "**Agriculture 1.0,**" is marked by the invention of the plow and the widespread use of animal drafts.

Agriculture 2.0 started towards the tail end of the 19th century with the introduction of mechanical machinery such as tractors. And later on, agricultural technology underwent a number of active development cycles as the pace of technological progress increased tremendously.

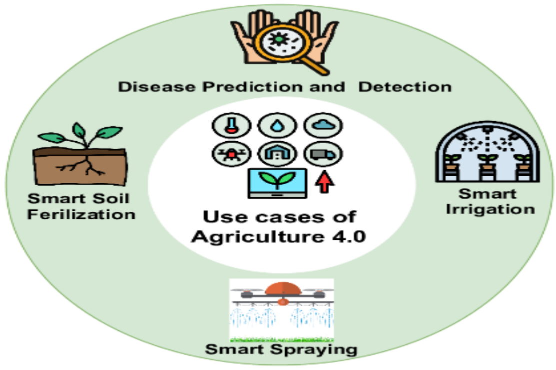
Agriculture 3.0, or Precision Farming

Precision or smart farming, also called Agriculture 3.0, evolved out of the need to track and more efficiently manage all inputs into crop production. The pursuit of precision agriculture and its associated agricultural technology has led to the development of new farming methods and tools.

The Global Positioning Satellite System (GPS) was the breakthrough technology that made this age of farming possible. GPS helps find deviations within a given agricultural production space, allowing for more effective use of available resources. This was the main reason why the idea of sustainable agriculture and a number of automation options came about.

Agriculture 4.0, or Connected Farming

The leap from smart farming to connected farming is a good example of how fast production technology used in agriculture moved forward at the turn of the century. Technology like autonomous machines, sensor-



equipped robots, augmented reality, the Internet of Things (IoT), drones, and satellites is all part of the new agricultural environment, named Agriculture 4.0.

Decision-making in the agricultural sector is now based on data that is stored in the cloud and accessible via digital tools. With the help of this analyzed data, farmers and other major players in the agricultural industry can make better decisions.

Agriculture 4.0 is being born in an era of ubiquitous automation and digital connectivity. All developments in agricultural technology are becoming more integrated and networked, with the goal of optimizing all stages of the production process and enhancing monitoring, management, and control of the business.

Agriculture 5.0, or Digital Farming

Agriculture technology 5.0, or simply put, "digital agriculture," refers to the next generation of farming methods and tools for maximizing crop yields and other agricultural outcomes. One such technology is 5G, which is currently undergoing rapid development and will improve the reach and accessibility of the latest agritech achievements around the world.

Compared to prior farming methods, digital agriculture technology excels in the following aspects:

- ❖ Data collection efficiency: how much data can be collected in a given amount of time or space.
- ❖ Data accuracy: how close a measurement is to the truth.
- ❖ Timeliness: how quickly the data can be processed into practical information and reported to end users.

When it comes to weather, pests, and diseases, agricultural producers have little to no control. Yet, with the advent of digital technologies in agriculture, they may lessen the negative influence of these elements. Meanwhile, digital agricultural technologies give farmers the opportunity to greatly increase the efficiency of decision-making and the return on factors that they directly control. Some examples are:

- ✓ what types of crops to grow.
- ✓ how to rotate crops for the best results.
- ✓ when and how much water to use for precision irrigation.
- ✓ when, how much, and what kind of nutrients and plant protection products to apply.
- ✓ what kind of tillage works best with a given type of soil.

Agricultural experts agree that the most valuable tools and technologies of digital agriculture regarding competitive advantages are cutting-edge farm management software, space-based solutions (especially those that provide high-resolution satellite images), proximal sensors, connectivity instruments, and data-driven algorithms for threat prediction.

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Laser Land Leveling: Enhancing Agricultural Efficiency and Sustainability

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Introduction

In the context of modern agriculture, particularly within water-scarce regions like the Indo-Gangetic Plains (IGP), the urgency to adopt resource-conserving technologies is paramount. Traditional irrigation practices have led to excessive water use, inefficient nutrient distribution, and suboptimal crop yields. One of the key advancements aimed at mitigating these challenges is **laser land leveling (LLL)** — a precision technology that creates a uniformly leveled field surface. This technique is recognized for improving irrigation efficiency, reducing water wastage, and increasing agricultural productivity. Precision leveling not only enhances the effectiveness of water and fertilizer usage but also contributes to better crop stands and yields while reducing the intensity of abiotic stresses.

Concept of Laser Land Leveling

Laser land leveling is the process of **smoothing and grading the land surface** to a desired flatness or slope using laser-guided machinery. It typically achieves an accuracy of ±2 cm or better. This method contrasts sharply with traditional leveling, which often relies on visual estimates and basic tools like animal-drawn plankers or tractor-mounted blades. Laser leveling uses a **laser transmitter**, a **receiver**, and a **hydraulic-controlled scraper** to automatically adjust the ground level across the field. By ensuring an even distribution of irrigation water and nutrients, LLL becomes a crucial tool for improving water-use efficiency and reducing labor and input costs.

Types of Laser Land Levelers

There are several types of laser leveling systems, distinguished by their degree of automation and precision:

1. **Manual Leveling Lasers**: Require manual adjustments using bubble vials. They are cost-effective but less precise (±1 cm at 100 m).
2. **Semi Self-Leveling Lasers**: Equipped with compensators and indicator lights for alignment. These lasers shut off automatically if disturbed.
3. **Fully Self-Leveling Lasers**: Use electronic level vials and servo motors for automatic alignment and offer higher accuracy (±2.5 mm at 100 m).
4. **Split-Beam Lasers**: Emit horizontal and vertical laser beams simultaneously for establishing both level and plumb lines.

Each system offers varying levels of convenience, accuracy, and cost-efficiency, making them suitable for different types of farms and operational requirements.

Components of Laser Land Leveling System

A typical laser land leveling setup consists of five core components:

- **Laser Transmitter (Rotating Laser)**: Mounted on a tripod, this emits a rotating laser beam across the field, serving as the reference plane.
- **Laser Receiver**: Mounted on the mast of the scraper or drag bucket, it detects the laser beam and communicates the height variation.
- **Control Box**: Processes signals from the receiver and directs the hydraulic system to adjust the bucket height accordingly.

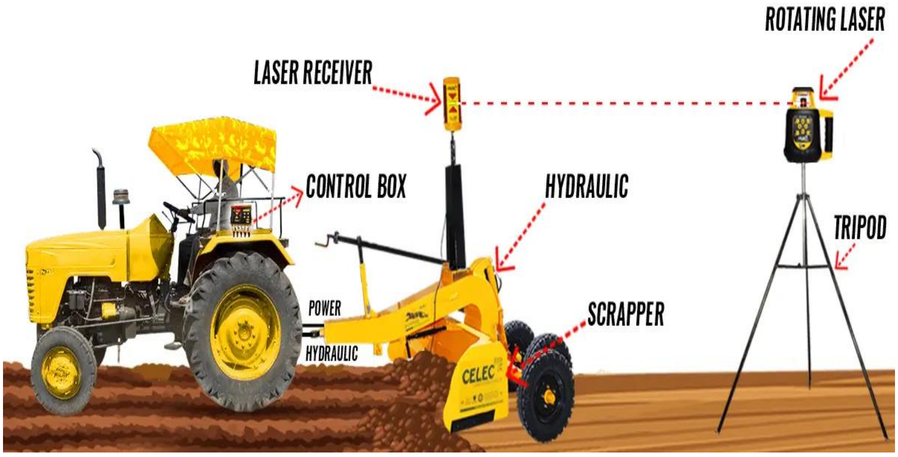

Figure 1. Functioning of Laser Land Leveler

- **Hydraulic Control System**: Automatically lifts or lowers the scraper blade in response to control box instructions.
- **Drag Bucket or Scraper**: Attached to a tractor, this unit levels the land by cutting or filling soil based on hydraulic cues.

This integration of technology ensures high precision and eliminates human error in field leveling.

Steps in Laser Land Leveling

The process of laser land leveling is generally conducted in the following steps:

1. **Field Ploughing**: Initial loosening of soil to facilitate movement.
2. **Topographic Survey**: Measurement of existing land elevations to determine the required soil cuts and fills.
3. **Laser Leveling**: Actual leveling is done using laser-guided equipment that adjusts the scraper blade to remove soil from elevated areas and deposit it in low areas.

The entire operation aims to achieve a zero or minimal slope field which enhances irrigation uniformity and reduces runoff and percolation losses.

Benefits of Laser Land Leveling

The advantages of laser-assisted land leveling over conventional methods are significant and multifaceted:

- **Water Conservation**: Reduces water requirement by 20–30% and improves water application efficiency by up to 50%.
- **Higher Yields**: Increases yields of wheat (up to 15%), sugarcane (42%), rice (61%), and cotton (66%).
- **Uniform Crop Growth**: Provides a consistent soil moisture profile that promotes uniform seed germination and crop maturity.
- **Input Efficiency**: Requires less seed, fertilizer, and pesticides due to even application conditions.
- **Increased Cultivable Area**: Removes field bunds and channels, making an additional 3–5% of land available for cultivation.
- **Enhanced Field Trafficability**: Smooth terrain facilitates mechanized operations, reducing energy and fuel consumption.

Limitations of Laser Land Leveling

Despite its advantages, laser land leveling has a few limitations that can affect its adoption, particularly among small-scale farmers:

- **High Initial Cost**: Equipment and setup are capital-intensive.
- **Skill Requirements**: Requires trained operators to manage laser settings and tractor operations.
- **Field Constraints**: Less effective in small, irregularly shaped, or fragmented landholdings, which are common in many parts of India.

To address these issues, initiatives such as custom hiring centers and training programs for operators are essential.

Conclusion

Laser land leveling represents a transformative step in the direction of resource conservation, precision agriculture, and sustainable food production. Its adoption not only contributes to increased agricultural productivity and water use efficiency but also aligns with the larger goals of climate-smart farming and environmental sustainability. To maximize its potential, it is imperative that policymakers, researchers, and extension services work together to promote this technology through financial support, awareness programs, and capacity building among farmers. As India faces growing pressure on its water and land resources, LLL is a powerful tool that can help ensure a resilient agricultural future.

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The Role of Crop Rotation in Sustainable Farming Practices

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Agricultural sustainability has become a central theme in the face of climate change, soil degradation, and increasing demand for food. Among the many techniques promoted for sustainable agriculture, crop rotation stands out as a time-tested and scientifically endorsed practice. **Crop rotation** refers to the **systematic and sequential growing of different types of crops on the same piece of land over a period of time**. It is done with the aim of maintaining soil health, enhancing crop yield, and preventing pest and disease cycles. Unlike mono-cropping (growing the same crop year after year), crop rotation breaks cycles of nutrient depletion and pest build-up by alternating crops with different characteristics.

Although crop rotation and crop sequence are often used interchangeably, crop rotation implies a planned, repeated pattern of crops over multiple seasons or years.

The main objective is to choose crop combinations that sustain or improve soil fertility, reduce erosion, and maximize use of available resources (like nutrients, moisture, and labor).

Principles of Crop Rotation

1. **Root Depth Variation:**
   - A deep-rooted crop (like pigeon pea or cotton) should be followed by a shallow-rooted crop (like wheat or rice).
   - This helps optimize nutrient and moisture extraction from different soil layers and avoids continuous depletion from a single soil depth.
2. **Leguminous after Non-Leguminous:**
   - A leguminous crop (such as gram, groundnut, or beans) should follow a non-leguminous crop (like maize or wheat).
   - Legumes fix atmospheric nitrogen through Rhizobium bacteria in their root nodules, enriching the soil for the next crop.
3. **Fertility-Depleting after Fertility-Building Crops:**
   - Crops that add nutrients to the soil (like legumes or green manure crops) should precede nutrient-exhausting crops (like maize or sugarcane).
   - This helps in maintaining a balance in soil nutrient levels.
4. **Erosion Resistance:**
   - In erosion-prone areas (like sloping land), follow an erosion-permitting crop (like maize or tobacco) with an erosion-resistant crop (like grass, legumes, or cover crops).
   - This reduces soil degradation and runoff.
5. **Water Requirement:**
   - In dryland or water-scarce regions, follow a low water-requiring crop (e.g., millet) with a high water-requiring crop (e.g., paddy), or vice versa.
   - This ensures efficient use of available moisture and reduces water stress.
6. **Crop Family Rotation:**
   - Rotating crops of different botanical families helps break cycles of pests, weeds, and diseases, which often target specific crop groups.
   - For example, avoid planting tomatoes after potatoes, as both belong to the Solanaceae family and may suffer from similar diseases.
7. **Year-Round Resource Utilization:**
   - Choose crops such that land, labor, and other farm resources are utilized throughout the year.
   - The rotation should meet the household's needs for food, fodder, and income while keeping the land productive year-round.

Ideal Crop Rotation

An ideal crop rotation satisfies the following conditions:

- Provides food and nutritional security to the family.
- Supplies fodder for livestock.
- Generates employment opportunities by involving farm labor throughout the year.
- Maintains or improves soil fertility and productivity.
- Is economically viable and suits the local climate and market conditions.
- Ensures diversified production to reduce risk from crop failure or market fluctuations.

Advantages of Crop Rotation

1. Improved Soil Fertility

- Biological Nitrogen Fixation: Leguminous crops like peas, beans, and clover form symbiotic relationships with nitrogen-fixing bacteria (Rhizobium spp.) in their root nodules. These bacteria convert atmospheric nitrogen into a usable form for plants, enriching the soil with nitrogen naturally.
- Enhanced Microbial Activity: Different crops support diverse soil microbial populations. This microbial diversity promotes better nutrient cycling, mineralization, and organic matter decomposition, all of which improve fertility.

2. Enhanced Soil Structure and Soil Chemistry

- Improved Soil Texture and Aeration: Rotating deep-rooted and shallow-rooted crops helps break up soil compaction and promotes better soil porosity, which enhances root penetration and water movement.
- pH and Chemical Balance: Repeated cultivation of the same crop can alter soil pH and lead to salinity or acidity issues. Rotating crops helps buffer these effects and stabilize chemical properties.
- Increased Organic Matter: Different crops add varying amounts and types of organic residues (roots, leaves, stems) to the soil, improving its organic matter content, which boosts water retention, nutrient-holding capacity, and biological activity.

3. Reduced Soil Erosion and Land Degradation

- Ground Cover from Rotation and Cover Crops: Alternating crops, especially with ground-covering species (e.g., legumes, cereals), protects soil from the erosive effects of rain and wind.
- Stronger Root Systems: Different root architectures bind soil at multiple depths, preventing surface and subsurface erosion.
- Reduced Degradation Risk: By maintaining a dynamic and healthy soil system, rotation improves land resilience to degradation caused by overexploitation or extreme weather.

4. Reduced Pest and Disease Incidence

- Breaking Pest Cycles: Monoculture farming allows pests to build up in large numbers. Rotating crops disrupts their life cycles. For example, rotating corn with soybeans can reduce corn rootworm populations, as the pest cannot survive without its host.
- Suppression of Soil-borne Diseases: Pathogens like fusarium wilt, verticillium, and clubroot rely on continuous presence of host crops. Crop rotation denies them the environment they need to persist, naturally reducing disease incidence.
- Healthier Crops: With fewer pests and pathogens present, plants grow stronger and are less reliant on synthetic chemical treatments.

5. Weed Suppression

- Different Canopies and Growth Rates: Crops like rye or barley grow quickly and form dense canopies that block sunlight, shading out weeds.
- Allelopathic Effects: Some crops release natural chemicals that inhibit weed seed germination and growth (e.g., rye produces allelopathic compounds).
- Growth Pattern Diversity: Alternating crops with different life cycles (cool-season vs.

warm-season, tall vs. low-growing) prevents weeds from adapting and dominating the field.

6. Efficient Use of Resources

- Balanced Fertilizer and Water Use: Different crops have varying nutrient and water needs. Rotating them spreads out the use of these inputs more evenly, reducing overuse or depletion.
- Labor and Equipment Utilization: With staggered planting and harvesting times, machinery and labor can be employed more consistently throughout the year, improving overall farm efficiency.

7. Timely Operations and Reduced Competition

- Staggered Scheduling: By growing crops at different times of the year, farmers can reduce peak labor demands and manage time-sensitive tasks more smoothly.
- Avoiding Intra-Crop Competition: Different crops have different nutrient and water uptake patterns, so rotation helps avoid resource competition and maximizes use of available resources.

8. Better Market Opportunities and Profitability

- Crop Diversification: A variety of crops allows farmers to meet broader market demands and reduces dependence on a single commodity.
- Higher Quality Produce: Rotations often lead to improved soil and plant health, which can enhance the taste, texture, and storage life of produce, making it more attractive to buyers.

9. Reduced Dependency on Chemical Inputs

- Lower Fertilizer Needs: Legumes reduce the need for nitrogen fertilizers. Balanced nutrient use across crop sequences minimizes excessive input application.
- Reduced Pesticide Use: By managing pests through biological disruption, crop rotation cuts down on pesticide applications, lowering costs and environmental risks.
- Herbicide Resistance Management: Rotating crops that require different weed control strategies helps prevent the development of herbicide-resistant weeds, preserving herbicide effectiveness over time.

10. Economic and Environmental Benefits

- Higher Yields Over Time: Crop rotation improves soil health and reduces biotic stress (pests, diseases), which leads to better crop performance and higher yields compared to monoculture systems.
- Risk Mitigation: Income from a variety of crops protects farmers from price crashes or poor performance of a single crop due to weather or market issues.
- Climate Resilience: Including cover crops and deep-rooted species enhances soil moisture retention, reduces runoff, and increases drought and flood resilience.
- Carbon Sequestration: Improved organic matter levels in rotational systems enhance soil carbon storage, helping mitigate greenhouse gas emissions and fight climate change.

Current Challenges in Crop Rotation Adoption

Despite its proven benefits, the adoption of crop rotation in modern Indian agriculture faces several hurdles:

1. **Market Pressures:** Farmers prefer to grow high-value or assured market crops repeatedly, like paddy or sugarcane, which discourages rotational diversity.
2. **Policy Bias:** Government procurement and Minimum Support Price (MSP) schemes favor cereals like rice and wheat, making alternative rotations less profitable.
3. **Lack of Awareness:** Many farmers, especially in semi-arid and marginal areas, are unaware of scientific rotation benefits and modern rotation models.
4. **Short-Term Focus:** The immediate yield and income focus overshadows long-term soil health and sustainability concerns.

5. **Irrigation Constraints:** In water-scarce regions, crop choice is often dictated by irrigation availability, limiting rotational options.

The Way Forward

To make crop rotation a mainstream practice in Indian agriculture, a multi-pronged strategy is essential:

- **Policy Reforms:** Include rotational crops in MSP schemes and public procurement to incentivize adoption.
- **Capacity Building:** Train farmers through digital platforms, extension services, and field demonstrations.
- **Agro-Economic Research:** Study region-specific economic viability of different rotations and integrate findings into rural planning.
- **Market Linkages:** Develop robust value chains for pulses, oilseeds, and millets to support diversified farming.
- **Climate Adaptation:** Integrate crop rotation in climate-resilient agriculture plans at district and state levels.

Conclusion

Crop rotation, once a cornerstone of Indian farming, has the potential to address many of the current challenges plaguing Indian agriculture from declining soil fertility to overuse of water and agrochemicals. Reviving and modernizing this ancient wisdom through scientific innovation and supportive policies can make Indian agriculture more resilient, profitable, and sustainable. As India aspires to lead the world in sustainable food systems, crop rotation must reclaim its rightful place in the country's agricultural discourse.

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