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Bacterial Soft rot of Onion

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INTRODUCTION

Onion is one of the most important vegetable crops grown widely for domestic use and commercial purposes. However, its production and storage are seriously affected by several diseases, among which bacterial soft rot is one of the most destructive. This disease causes heavy losses both in the field and during storage, especially under warm and humid conditions. Understanding its symptoms and management practices is essential for farmers and students of agriculture.

What is Bacterial Soft Rot?

Bacterial soft rot of onion is mainly caused by bacteria belonging to the genus *Pectobacterium* (earlier *Erwinia* spp.), *Pseudomonas*, *Burkholderia* and *Dickeya* spp. These bacteria are soil- and water-borne and can easily infect onion bulbs through wounds, cuts, or natural openings.

Identification and Symptoms

Early identification of bacterial soft rot helps in reducing losses. The disease can be recognized by the following symptoms:

- Water-soaked lesions at the neck or base of the bulb
- Softening of bulb tissues, which later become mushy
- Foul-smelling rotting tissue, a key characteristic of the disease
- In advanced stages, the entire bulb collapses, leaving only the dry outer scales
- During storage, infected bulbs may leak fluid and spread infection to healthy bulbs

In the field, plants may show yellowing and wilting of leaves, and infected bulbs may rot before harvest.



Favorable Conditions for Disease Development

Bacterial soft rot develops rapidly under:

- High temperature (25–35°C)
- High humidity and poor drainage
- Mechanical injuries during harvesting and handling
- Excessive nitrogen fertilization
- Poor ventilation during storage

Disease Management Practices

Since bacterial diseases are difficult to control with chemicals, integrated management practices are most effective.

1. Cultural Practices

- Use healthy, disease-free planting material
- Avoid waterlogging by ensuring proper field drainage
- Follow crop rotation with non-host crops
- Avoid excessive use of nitrogen fertilizers
- Harvest bulbs only after proper maturity

2. Field and Post-Harvest Care

- Avoid injuries during harvesting, transportation, and storage
- Cure onions properly by drying them in shade with good ventilation
- Remove and destroy infected bulbs immediately
- Store onions in cool, dry, and well-ventilated conditions

3. Sanitation

- Keep storage structures clean and dry
- Disinfect tools and containers used during harvesting and handling



4. Chemical and Biological Measures

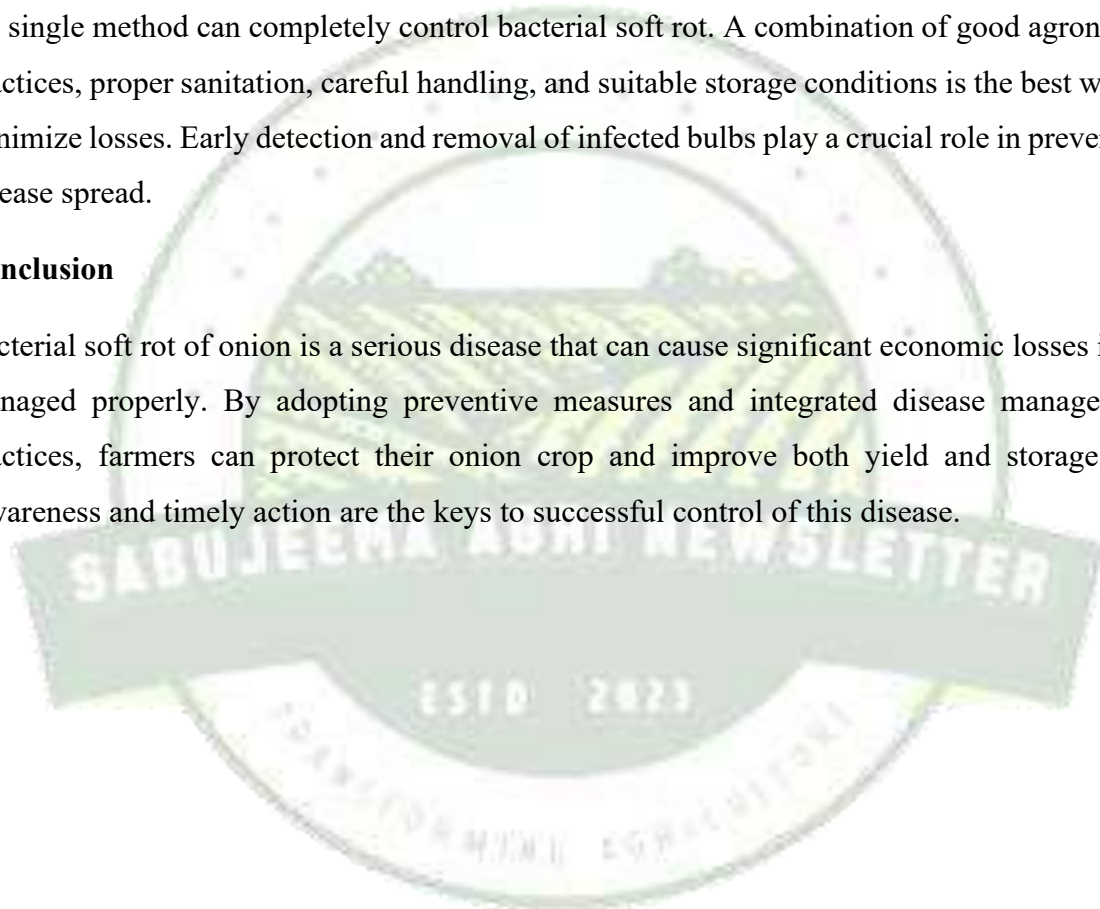
- Chemical control is limited, but copper-based bactericides may help reduce surface contamination
- Use of biological control agents like *Bacillus* spp. can help suppress bacterial populations
- Seed or bulb treatment with recommended bio-agents may reduce infection

Importance of Integrated Management

No single method can completely control bacterial soft rot. A combination of good agronomic practices, proper sanitation, careful handling, and suitable storage conditions is the best way to minimize losses. Early detection and removal of infected bulbs play a crucial role in preventing disease spread.

Conclusion

Bacterial soft rot of onion is a serious disease that can cause significant economic losses if not managed properly. By adopting preventive measures and integrated disease management practices, farmers can protect their onion crop and improve both yield and storage life. Awareness and timely action are the keys to successful control of this disease.





Invasive Plants for Food Security

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INTRODUCTION

Food security is a fundamental aspect of human well-being, guaranteeing that every individual has consistent access to adequate, safe, and nutritious food to lead an active and healthy life (Pérez-Escamilla, R., 2017). Invasive plant species are no longer viewed solely as enemies; today, they are being transformed for the production of biochar and bioactive components with nutritional, medicinal, or economic value, as well as for sustainable management (Valiño, A. et al., 2023; Fartyal, A. et al., 2025).

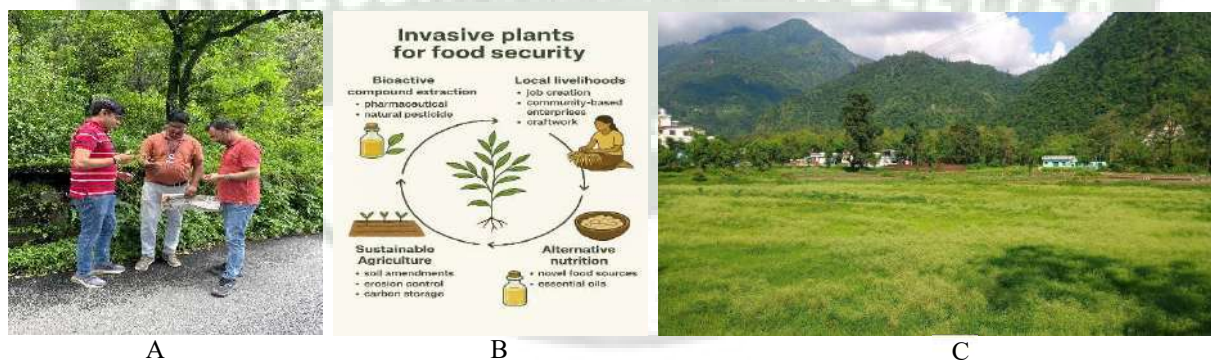


Fig 1. (A) Identification of invasive plant species and discussing its impact. (B) Role of invasive plants for food security. (C) *Parthenium hysterophorus* (an invasive weed) infestation in an open field.

Climate change creates favourable conditions for invasive plants by altering temperatures, extreme weather, and precipitation patterns, accelerating their spread and allowing them to outcompete native species (Finch, D. M., et al., 2021). Hence, it becomes more important to convert invasive alien species into resources.



Invasive Plants: Challenge or Opportunity?

Alien plants are typically seen as agricultural enemies, overrunning farmlands, draining water resources, and outcompeting native crops. However, a growing number of scientists and communities are beginning to view these fast-growing plants differently (Poorter, H. et al., 2012). Could they help address one of India's most pressing challenges: food security? While invasive species can negatively impact biodiversity and soil health, some species possess nutritional, medicinal, or economic value. As climate change and population growth strain India's food systems, researchers are exploring invasive plants not just as pests but also as potential food sources.

Impact of Invasive Plants on Food Security and Nutrition

The spread of invasive plant species leads to declining crop productivity, growing threats to farmers' livelihoods and rising labour and input costs. Consequently, food insecurity increases. Transforming invasive plants, often considered waste, into value-added products could offer sustainable management, reduce agricultural pressure, create eco-friendly livelihoods, and enhance food security by providing alternative food and nutrient sources.

Some invasive species growing across India have shown promise as food sources: *Ageratum houstonianum* (Jungle Pudina) offers antibacterial and antioxidant benefits (Zeeshan et al., 2012). Similarly, *Lantana camara* (Raimuniya, Bhoot Jhad) contains bioactive compounds (Mansoori et al., 2020); *Ageratina adenophora* (Kala Bhansa) is a source of quinic acid derivatives; *Parthenium hysterophorus* (Congress grass, Gajar ghas) is explored for controlled composting or medicinal uses; and *Eichhornia crassipes* (Water hyacinth, Jalkhumbi) shows promise for nutraceuticals and alternative protein sources. These plants require minimal care, grow on degraded land, and could offer nutritional support in rural areas.



Fig 2. Invasive plant species (A) *Lantana camara*, (B) *Ageratum houstonianum*, (C) *Parthenium hysterophorus*, (D) *Ageratina adenophora*, (E) *Eichhornia crassipes*



Food Security Context in India

Every year, India faces a growing food security challenge. According to the Global Hunger Index (2024), India ranks 111 out of 125 countries, indicating serious levels of hunger. Factors contributing to this include population growth, climate change, soil degradation, rapid urbanization, invasive species, insufficient public distribution systems, economic shocks, and unequal access to nutritious food. In India, where more than half of the population depends on farming, low-input food sources are urgently needed.

Field Study and Community Perspective

Ms Ridhima Gaur, Junior Project Fellow at Graphic Era University, Dehradun, is involved in the NMHS-funded project titled “Sustainable Utilization of Invasive Plant Biomass for Bioactive Components Recovery & Biochar Generation: A Unique Solution for Improving Rural Livelihood in Uttarakhand,” alongside B. Tech Biotechnology students Divyansh Pathak and Aman Sharma. A recent field survey in Kheri Mansingh village, Dehradun, observed how invasive plants such as *Ageratum*, *Parthenium*, *Ageratina*, and *Lantana* are damaging crops, reducing soil fertility, and intermixing with native species. Farmers expressed concerns about crop damage, reduced productivity, and allergies. Traditional and chemical methods are commonly used for removal, but are insufficient.

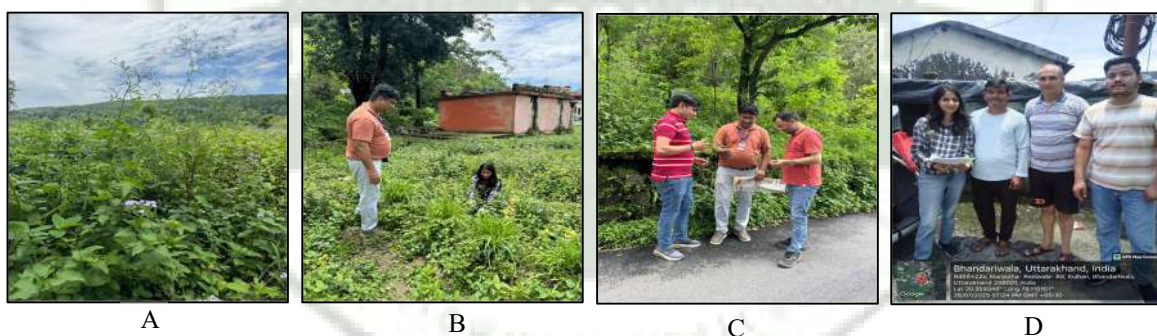


Fig 3. The survey of invasive plant species, observation, species identification, collection, and farmers' interaction. (A) Observing the intermixing of three different alien species in cropland. (B) Collection of *Ageratum houstonianum* in a crop field. (C) Identification of *Eupatorium* (*Ageratina adenophora*), *Lantana camara*, and discussing its impact (D) Interaction with local farmers of the Kheri Mansingh Village, and discussing the invasive plant species effect and their ecological impact on agricultural land.

Commercialisation, Biochar, and Future Perspective of Invasive Plants

Invasive plant species offer unique opportunities to enhance food security through their commercialisation, extraction of bioactive compounds, production of biochar, and improvement of local livelihoods (Fartyal et al., 2025). Many invasive plants contain valuable proteins and phenolics with nutritional, medicinal and antimicrobial properties (Raudone, L.,



& Savickiene, N., 2024). Converting invasive biomass into biochar enhances soil quality, reduces pollution, and generates income for farmers and communities. (Obahiagbon, E. G., & Ogwu, M. C., 2024). The perception of plants such as *Ageratina*, *Parthenium*, *Eichhornia*, *Lantana*, and *Ageratum* is shifting toward sustainable nutrition, functional food production, and conservation (Deshmukh, V., and Gutte, R. K., 2024). Therefore, with appropriate safety assessments, public awareness, collaboration among researchers, policymakers, and local communities, invasive plant species can become a sustainable option for future food security (Imoro, Z. A., et al., 2021). Advances in biotechnology, ecological process modelling, and value-added production, such as extracting bioactive components and producing biochar, will boost the efficiency and safety of using invasive biomass, shifting from an ecological threat to contributing sustainably to nutrition, livelihoods, and resilient food systems.

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Genomic Models in Prediction of Breeding Value of Cattle

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INTRODUCTION

Single nucleotide polymorphisms (SNPs) account for most genome sequence diversity, according to one of the most fascinating discoveries of the Human Genome Project's first draft, published in 2001. Actually, SNP markers have become the cornerstone of DNA sequence variation and are now an essential tool for evaluating the genetic potential of cattle. This is because SNPs are found throughout the genome, including in exons, introns, promoters, enhancers and intergenic regions. The roughly three billion nucleotides that comprise the bovine genome contain about 30 million SNPs or one SNP for every 100 nucleotides. Another reason is that, in contrast to microsatellites, SNP genotyping became automated, relatively cheap, efficient (the majority of loci are read) and highly reproducible (e.g., across laboratories).

Meuwissen *et al.* (2001) state that genomic data could help animal breeders produce more accurate breeding values if a dense assay covering the entire genome becomes available. They developed the idea of utilizing marker information in best linear unbiased prediction (BLUP), which is now known as genome-wide selection or genomic selection (GS). Using pseudo-phenotypes (i.e., estimated breeding values or EBVs adjusted for parent average and accuracy or progeny deviations) exclusively for genotyped animals as bulls was a simple adaptation of the Bayesian models presented in Meuwissen *et al.* (2001). These models provide SNP effects and direct genomic values (DGVs) based on joint analyses of genotypes and phenotypes. Accordingly, VanRaden (2008) developed a similar method called genomic BLUP (GBLUP), which bases predictions for genotyped animals on genomic relationships (i.e., the percentage of alleles shared between animals) rather than pedigree relationships. **G** is a representation of this genomic relationship matrix.



Since pedigree information must be taken into account after using GBLUP or Bayesian approaches, which necessitate a post-processing phase, the traditional BLUP evaluation is still necessary. The phrase "multistep" describes the fact that retrieving genomic EBV (GEBV) necessitates several steps. The main advantages of this approach are the ability to perform genomic selection using supplementary analyses, the preservation of the traditional BLUP evaluation and a significant cost reduction (only selection candidates and highly represented animals, like bulls are genotyped). However, the multi-step approach has some disadvantages: (a) The model only includes genotyped animals (b) DGVs are only generated for simple models, such as single trait, non-maternal models, which is not how genetic evaluations actually work (c) it requires pseudo-phenotypes, which are difficult to obtain and may rely on accuracy obtained via approximated algorithms (Legarra *et al.*, 2014).

Beginning in 2009, multistep approaches were widely used for genomic evaluations, but they were not going to be the long-term solution for computing genomic predictions. Since only a small portion of pedigreed animals have been genotyped and the genomic information cannot be transferred to non-genotyped animals, genotyped animals have GEBV while non-genotyped animals have EBV. Many changes were made, especially in dairy cattle, to make EBV comparable to GEBV under multistep evaluations (Wiggans *et al.*, 2012). Additionally, it was acknowledged that because BLUP predictions would overlook the effects of genomic selection, multi-step methods would eventually produce biased predictions (Party and Ducrocq, 2011). Misztal *et al.* (2009) proposed a method that integrates phenotypes, pedigree and genotypes into a single evaluation in order to address these problems and reduce the effort involved in obtaining genomic predictions. This technique, known as single-step genomic BLUP (ssGBLUP), replaces the traditional BLUP's pedigree relationship matrix with a realized relationship matrix that integrates genomic and pedigree relationships. The H matrix is the name given to this realized relationship matrix. The answer to the question "why H" is very straightforward: simply choose the following letter in the alphabet if G represents the genomic relationship.

According to Legarra *et al.* (2009), the pedigree relationship can be considered an a priori relationship, whereas the genetic relationship is the observed association. By figuring out the simultaneous distribution of pedigree and genomic links, it would be feasible to extend (or impute) genomic information to non-genotyped animals. This suggests that for non-genotyped animals in ssGBLUP, the genomic information of their ancestors enhances pedigree relationships. Lastly, Aguilar *et al.* (2010) and Christensen *et al.* (2010) showed that although



H is very complex, its inverse is rather straightforward. This finding enabled the application of ssGBLUP in animal populations. After more than ten years, ssGBLUP has become the standard technique for genomic evaluation and selection in almost all animal species including dairy and beef cattle.

The average additive effects of an individual gene from both parents are represented by the additive genetic value also known as the breeding value. The true potential or genetic transmission capacity of an animal is reflected in its estimated breeding value. After accounting for a number of environmental factors, including herd, year of calving, month of milk record, age at first calving, etc., it was estimated for each individual animal based on performance records of parents, siblings, progenies and their own.

Prediction Methods are -

- BLUP- Best Linear Unbiased Prediction (no genotype only phenotype and pedigree)
- GBLUP-Genomic Best Linear Unbiased Prediction (no pedigree only genotype and phenotype)
- ssGBLUP- Single-Step Genomic Best Linear Unbiased Prediction (phenotype + genotype + pedigree)
- SNP-BLUP - single nucleotide polymorphisms Best Linear Unbiased Prediction (no pedigree only genotype and phenotype)

Preludes of Genomic estimated breeding values

Early in the 1980s, Soller *et al.* (1983) proposed that DNA markers such as restriction fragment length polymorphisms (RFLPs) would be useful in determining parentage and identifying quantitative trait loci (QTL) in order to create more accurate genetic relationships.

One of the most exciting revelations of the Human Genome Project's first draft in 2001 was that single nucleotide polymorphisms (SNPs) accounted for most genome sequence variation.

According to Meuwissen *et al.* (2001), if a dense assay covering the entire genome becomes available, genomic information could aid animal breeders in producing more accurate breeding values. In addition to proposing what is now known as genome wide selection or genomic selection (GS), he extended the concept of incorporating marker information into best linear unbiased prediction (BLUP). SNP effects and direct genomic values (DGVs) based on joint analyses of genotypes and phenotypes are provided by the Bayesian models described in



Meuwissen *et al.* (2001). This method was easily modified to use pseudo-phenotypes only for genotyped animals as bulls.

Genomic BLUP (GBLUP), an analogous technique proposed by VanRaden, bases predictions for genotyped animals on genomic relationships (i.e., the percentage of alleles shared between animals) rather than pedigree relationships. G is a representation of this genomic relationship matrix.

The conventional BLUP evaluation is still required because a post-processing step is required to account for pedigree information after using GBLUP or Bayesian methods. This class of techniques is known as multistep because retrieving genomic EBV (GEBV) requires multiple steps.

Misztal suggested a technique that integrates genotypes, pedigree and phenotypes into a single assessment. This technique, known as single-step genomic BLUP (ssGBLUP), replaces the traditional BLUP's pedigree relationship matrix with a realized relationship matrix that integrates genomic and pedigree relationships. This realized relationship matrix is referred to as the H matrix. $(\text{var}(\mathbf{u}, \mathbf{e}) = \begin{bmatrix} H\sigma_u^2 & \mathbf{0} \\ \mathbf{0} & R \end{bmatrix})$

Legarra demonstrated in 2009 that the extension (or imputation) of genomic information to non-genotyped animals would be possible through the derivation of the joint distribution of pedigree and genomic relationships. This indicates that the genomic data of non-genotyped animals' relatives improves their pedigree relationships in ssGBLUP.

$$\mathbf{H} = \begin{bmatrix} \mathbf{A}_{11} + \mathbf{A}_{12}\mathbf{A}_{22}^{-1}(\mathbf{G} - \mathbf{A}_{22})\mathbf{A}_{22}^{-1}\mathbf{A}_{21} & \mathbf{A}_{12}\mathbf{A}_{22}^{-1}\mathbf{G} \\ \mathbf{G}\mathbf{A}_{22}^{-1}\mathbf{A}_{21} & \mathbf{G} \end{bmatrix}$$

Aguilar *et al.* (2010) and Christensen and Lund (2010) were developed simple form of \mathbf{H}^{-1}

$$\mathbf{H}^{-1} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} + \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix} = \mathbf{A}^{-1} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix}$$

BLUPF90 Software Suite

BLUPF90 is a set of computation software with an emphasis on genetic and breeding applications. Ignacy Misztal created it in 1997.



The first software developed was called blupf90 and the original concept was to have a basic BLUP program to calculate solutions for the mixed model equations (MME). General multiple-trait models, distinct model designs for each trait, multiple effects, missing data, random correlated and non-correlated effects, dominance effects, and the ability to use multiple pedigree files or various covariance structures provided by the user are all supported by this software.

A number of programs were created,

- Linear threshold models (thrgibbsf90), variance component estimation for linear models (such as remlf90, airemlf90, and gibbsf90)

Large-scale genetic assessments utilizing linear models (blup90iod), linear-threshold models (cblup90iod), and accuracy approximation (accf90)

- Renumbering program (renumf90)
- To carry out genomic data preprocessing and quality control (pregsf90).

While we concentrate on BLUPF90, other packages can be used to compute BLUP-based predictions both with and without genomic data. ASREML, Wombat, Mix99, DMU, MTG2, and GCTA are a few examples.

Genomic Relationship-Based Methods

- GBLUP
- ssGBLUP

GBLUP

This method uses SNPs to infer relationships among individuals, quantifying the number of alleles shared between two individuals. Genomic relationships are identical by state (IBS) because they account for the probability that two alleles randomly picked from each individual are identical, independently of origin.

Going from one to several markers, the breeding value of an animal can be calculated as the sum of SNP effects weighted by the genotype content ($u = Za$). Assuming the same variance per locus. According to VanRaden, 2008, the genomic relationship matrix (G) is given as

$$G = \frac{ZZ'}{2 \sum P_j(1-P_j)}$$



Assuming a matrix of SNPs inherited by each animal (M), with dimension $n \times m$ where n is the number of animals and m the number of SNPs. Several parametrizations exist, but if $AA = 0$, $AB = 1$, and $BB = 2$, M has to be centered by allele frequency. Assuming a vector p with elements equal to p_i , the frequency of allele B at locus i : $Z = M - 2p$

We will incorporate this G (Genomic relationship matrix) in MME (Mixed Model Equation) instead of A (Numerated Relationship Matrix).

ssGBLUP

Single-step genomic best linear unbiased prediction (ssGBLUP), a method based on the GBLUP architecture, was presented by Misztal *et al.* 2009. It simultaneously uses all pedigree, genotypic and phenotypic data from both genotyped and non-genotyped individuals. This method creates a single matrix called (H) by combining the relationship matrix for the genotype-based numerator and the relationship matrix for the numerator based on pedigree. The single step genomic BLUP is obtained by fitting H^{-1} in Henderson MME.

$$H^{-1} = A^{-1} + \begin{bmatrix} 0 & 0 \\ 0 & G^{-1} - A_{22}^{-1} \end{bmatrix}$$

Where, A_{22}^{-1} was inverse of numerated relationship matrix of genotyped animals.

Single-step genomic evaluation became a standard procedure in livestock breeding, and the main reason is the ability to combine all pedigree, phenotypes and genotypes available into one single evaluation, without the need of post-analysis processing. Therefore, the incorporation of data on genotyped and non-genotyped animals in this method is straightforward

Single-step GBLUP (ssGBLUP) has now been applied to nearly all major livestock species by researchers, private companies, and breeders' associations. Mehrban *et al.* (2019), pigs (Christensen *et al.*, 2012), Holstein cattle (Ismael *et al.*, 2017), purebred dairy populations worldwide (Ismael *et al.*, 2017, Cifuentes, 2024), and goats (Teissier *et al.*, 2018) have all successfully estimated breeding values using this method.

Due to the lack of large, well-organized farms and the "production by mass" nature of the livestock industry, ssGBLUP is particularly appropriate in India, where a significant percentage of animals are still ungenotyped and pedigrees are frequently incomplete. According to Gowane *et al.* (2022), ssGBLUP increases accuracy even in cases of shallow pedigree depth. Similar improvements in accuracy using ssGBLUP have been reported in Karan Fries cattle (Ilayaraja *et al.*, 2025) and Indian crossbred cattle (Khan *et al.*, 2025).



SNP-BLUP

The model for SNP-BLUP,

$$y = 1\mu + Mg + e$$

where y is the vector of phenotype, μ is the intercept, g is the vector of random unknown marker effects, and e is the vector of random residuals. The marker effects g_i were assumed to be identically and independently distributed with mean zero and variance σ_g^2 ; that is, $g \sim N(0, I\sigma_g^2)$. Estimated solutions from the SNP-BLUP were used to estimate DGV by

$$a = 1\mu + Mg$$

The model used in G-BLUP was equivalent to SNP-BLUP but instead of estimating the SNP effects only the sum of the SNP effects $a = Zg$ corresponding the DGV (direct genomic values) above were estimated.

Example

- For genomic estimated breeding value, we need SNP file which should be in 0,1,2,5(missing) format and SNP matrix should have fixed width and should start with fixed column only.
- We need phenotypic and genotype data for both GBLUP and ssGBLUP
- Phenotypic, genotypic and pedigree file for only ssGBLUP
- If any observation was missing then specify this as missing -999 in parameter file.

First run the RENUMF90 software for proper renumbering (fill the needed parameters, like data (data.prn) file name, traits position in data file, residual variances (matrix if more than one trait), specify the fixed or covariate in effect and consider animal as random effect, file (pedigree file name) and file position is nothing but of animal, sir and dam columns. Specify SNP FILE name (numerical farm only) and covariance (matrix if more than one trait)

Conclusion

BLUPF90 is powerful software used to estimate genetic values and breeding values in animals. It works well even with large and complex data and supports many types of genetic models. One major advantage is that it can use information from both genotyped and non-genotyped animals, making evaluations more accurate. The single-step genomic BLUP (ssGBLUP) method in BLUPF90 is especially useful in India, where pedigree records are often incomplete



and fewer animals are genotyped. Research shows that ssGBLUP improves the accuracy of genetic evaluations by combining genomic, pedigree and performance data together to produce more reliable breeding values.

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Genomic Models in Prediction of Breeding Value of Cattle

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INTRODUCTION

Single nucleotide polymorphisms (SNPs) account for most genome sequence diversity, according to one of the most fascinating discoveries of the Human Genome Project's first draft, published in 2001. Actually, SNP markers have become the cornerstone of DNA sequence variation and are now an essential tool for evaluating the genetic potential of cattle. This is because SNPs are found throughout the genome, including in exons, introns, promoters, enhancers and intergenic regions. The roughly three billion nucleotides that comprise the bovine genome contain about 30 million SNPs or one SNP for every 100 nucleotides. Another reason is that, in contrast to microsatellites, SNP genotyping became automated, relatively cheap, efficient (the majority of loci are read) and highly reproducible (e.g., across laboratories).

Meuwissen *et al.* (2001) state that genomic data could help animal breeders produce more accurate breeding values if a dense assay covering the entire genome becomes available. They developed the idea of utilizing marker information in best linear unbiased prediction (BLUP), which is now known as genome-wide selection or genomic selection (GS). Using pseudo-phenotypes (i.e., estimated breeding values or EBVs adjusted for parent average and accuracy or progeny deviations) exclusively for genotyped animals as bulls was a simple adaptation of the Bayesian models presented in Meuwissen *et al.* (2001). These models provide SNP effects and direct genomic values (DGVs) based on joint analyses of genotypes and phenotypes. Accordingly, VanRaden (2008) developed a similar method called genomic BLUP (GBLUP), which bases predictions for genotyped animals on genomic relationships (i.e., the percentage of alleles shared between animals) rather than pedigree relationships. **G** is a representation of this genomic relationship matrix.



Since pedigree information must be taken into account after using GBLUP or Bayesian approaches, which necessitate a post-processing phase, the traditional BLUP evaluation is still necessary. The phrase "multistep" describes the fact that retrieving genomic EBV (GEBV) necessitates several steps. The main advantages of this approach are the ability to perform genomic selection using supplementary analyses, the preservation of the traditional BLUP evaluation and a significant cost reduction (only selection candidates and highly represented animals, like bulls are genotyped). However, the multi-step approach has some disadvantages: (a) The model only includes genotyped animals (b) DGVs are only generated for simple models, such as single trait, non-maternal models, which is not how genetic evaluations actually work (c) it requires pseudo-phenotypes, which are difficult to obtain and may rely on accuracy obtained via approximated algorithms (Legarra *et al.*, 2014).

Beginning in 2009, multistep approaches were widely used for genomic evaluations, but they were not going to be the long-term solution for computing genomic predictions. Since only a small portion of pedigreed animals have been genotyped and the genomic information cannot be transferred to non-genotyped animals, genotyped animals have GEBV while non-genotyped animals have EBV. Many changes were made, especially in dairy cattle, to make EBV comparable to GEBV under multistep evaluations (Wiggans *et al.*, 2012). Additionally, it was acknowledged that because BLUP predictions would overlook the effects of genomic selection, multi-step methods would eventually produce biased predictions (Party and Ducrocq, 2011). Misztal *et al.* (2009) proposed a method that integrates phenotypes, pedigree and genotypes into a single evaluation in order to address these problems and reduce the effort involved in obtaining genomic predictions. This technique, known as single-step genomic BLUP (ssGBLUP), replaces the traditional BLUP's pedigree relationship matrix with a realized relationship matrix that integrates genomic and pedigree relationships. The H matrix is the name given to this realized relationship matrix. The answer to the question "why H" is very straightforward: simply choose the following letter in the alphabet if G represents the genomic relationship.

According to Legarra *et al.* (2009), the pedigree relationship can be considered an a priori relationship, whereas the genetic relationship is the observed association. By figuring out the simultaneous distribution of pedigree and genomic links, it would be feasible to extend (or impute) genomic information to non-genotyped animals. This suggests that for non-genotyped animals in ssGBLUP, the genomic information of their ancestors enhances pedigree relationships. Lastly, Aguilar *et al.* (2010) and Christensen *et al.* (2010) showed that although



H is very complex, its inverse is rather straightforward. This finding enabled the application of ssGBLUP in animal populations. After more than ten years, ssGBLUP has become the standard technique for genomic evaluation and selection in almost all animal species including dairy and beef cattle.

The average additive effects of an individual gene from both parents are represented by the additive genetic value also known as the breeding value. The true potential or genetic transmission capacity of an animal is reflected in its estimated breeding value. After accounting for a number of environmental factors, including herd, year of calving, month of milk record, age at first calving, etc., it was estimated for each individual animal based on performance records of parents, siblings, progenies and their own.

Prediction Methods are -

- BLUP- Best Linear Unbiased Prediction (no genotype only phenotype and pedigree)
- GBLUP-Genomic Best Linear Unbiased Prediction (no pedigree only genotype and phenotype)
- ssGBLUP- Single-Step Genomic Best Linear Unbiased Prediction (phenotype + genotype + pedigree)
- SNP-BLUP - single nucleotide polymorphisms Best Linear Unbiased Prediction (no pedigree only genotype and phenotype)

Preludes of Genomic estimated breeding values

Early in the 1980s, Soller *et al.* (1983) proposed that DNA markers such as restriction fragment length polymorphisms (RFLPs) would be useful in determining parentage and identifying quantitative trait loci (QTL) in order to create more accurate genetic relationships.

One of the most exciting revelations of the Human Genome Project's first draft in 2001 was that single nucleotide polymorphisms (SNPs) accounted for most genome sequence variation.

According to Meuwissen *et al.* (2001), if a dense assay covering the entire genome becomes available, genomic information could aid animal breeders in producing more accurate breeding values. In addition to proposing what is now known as genome wide selection or genomic selection (GS), he extended the concept of incorporating marker information into best linear unbiased prediction (BLUP). SNP effects and direct genomic values (DGVs) based on joint analyses of genotypes and phenotypes are provided by the Bayesian models described in



Meuwissen *et al.* (2001). This method was easily modified to use pseudo-phenotypes only for genotyped animals as bulls.

Genomic BLUP (GBLUP), an analogous technique proposed by VanRaden, bases predictions for genotyped animals on genomic relationships (i.e., the percentage of alleles shared between animals) rather than pedigree relationships. G is a representation of this genomic relationship matrix.

The conventional BLUP evaluation is still required because a post-processing step is required to account for pedigree information after using GBLUP or Bayesian methods. This class of techniques is known as multistep because retrieving genomic EBV (GEBV) requires multiple steps.

Misztal suggested a technique that integrates genotypes, pedigree and phenotypes into a single assessment. This technique, known as single-step genomic BLUP (ssGBLUP), replaces the traditional BLUP's pedigree relationship matrix with a realized relationship matrix that integrates genomic and pedigree relationships. This realized relationship matrix is referred to as the H matrix. $(\text{var}(\mathbf{u}, \mathbf{e}) = \begin{bmatrix} H\sigma_u^2 & \mathbf{0} \\ \mathbf{0} & R \end{bmatrix})$

Legarra demonstrated in 2009 that the extension (or imputation) of genomic information to non-genotyped animals would be possible through the derivation of the joint distribution of pedigree and genomic relationships. This indicates that the genomic data of non-genotyped animals' relatives improves their pedigree relationships in ssGBLUP.

$$\mathbf{H} = \begin{bmatrix} \mathbf{A}_{11} + \mathbf{A}_{12}\mathbf{A}_{22}^{-1}(\mathbf{G} - \mathbf{A}_{22})\mathbf{A}_{22}^{-1}\mathbf{A}_{21} & \mathbf{A}_{12}\mathbf{A}_{22}^{-1}\mathbf{G} \\ \mathbf{G}\mathbf{A}_{22}^{-1}\mathbf{A}_{21} & \mathbf{G} \end{bmatrix}$$

Aguilar *et al.* (2010) and Christensen and Lund (2010) were developed simple form of \mathbf{H}^{-1}

$$\mathbf{H}^{-1} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} + \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix} = \mathbf{A}^{-1} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix}$$

BLUPF90 Software Suite

BLUPF90 is a set of computation software with an emphasis on genetic and breeding applications. Ignacy Misztal created it in 1997.



The first software developed was called blupf90 and the original concept was to have a basic BLUP program to calculate solutions for the mixed model equations (MME). General multiple-trait models, distinct model designs for each trait, multiple effects, missing data, random correlated and non-correlated effects, dominance effects, and the ability to use multiple pedigree files or various covariance structures provided by the user are all supported by this software.

A number of programs were created,

- Linear threshold models (thrgibbsf90), variance component estimation for linear models (such as remlf90, airemlf90, and gibbsf90)

Large-scale genetic assessments utilizing linear models (blup90iod), linear-threshold models (cblup90iod), and accuracy approximation (accf90)

- Renumbering program (renumf90)
- To carry out genomic data preprocessing and quality control (pregsf90).

While we concentrate on BLUPF90, other packages can be used to compute BLUP-based predictions both with and without genomic data. ASREML, Wombat, Mix99, DMU, MTG2, and GCTA are a few examples.

Genomic Relationship-Based Methods

- GBLUP
- ssGBLUP

GBLUP

This method uses SNPs to infer relationships among individuals, quantifying the number of alleles shared between two individuals. Genomic relationships are identical by state (IBS) because they account for the probability that two alleles randomly picked from each individual are identical, independently of origin.

Going from one to several markers, the breeding value of an animal can be calculated as the sum of SNP effects weighted by the genotype content ($u = Za$). Assuming the same variance per locus. According to VanRaden, 2008, the genomic relationship matrix (G) is given as

$$G = \frac{ZZ'}{2 \sum P_j(1-P_j)}$$



Assuming a matrix of SNPs inherited by each animal (M), with dimension $n \times m$ where n is the number of animals and m the number of SNPs. Several parametrizations exist, but if $AA = 0$, $AB = 1$, and $BB = 2$, M has to be centered by allele frequency. Assuming a vector p with elements equal to p_i , the frequency of allele B at locus i : $Z = M - 2p$

We will incorporate this G (Genomic relationship matrix) in MME (Mixed Model Equation) instead of A (Numerated Relationship Matrix).

ssGBLUP

Single-step genomic best linear unbiased prediction (ssGBLUP), a method based on the GBLUP architecture, was presented by Misztal *et al.* 2009. It simultaneously uses all pedigree, genotypic and phenotypic data from both genotyped and non-genotyped individuals. This method creates a single matrix called (H) by combining the relationship matrix for the genotype-based numerator and the relationship matrix for the numerator based on pedigree. The single step genomic BLUP is obtained by fitting H^{-1} in Henderson MME.

$$H^{-1} = A^{-1} + \begin{bmatrix} 0 & 0 \\ 0 & G^{-1} - A_{22}^{-1} \end{bmatrix}$$

Where, A_{22}^{-1} was inverse of numerated relationship matrix of genotyped animals.

Single-step genomic evaluation became a standard procedure in livestock breeding, and the main reason is the ability to combine all pedigree, phenotypes and genotypes available into one single evaluation, without the need of post-analysis processing. Therefore, the incorporation of data on genotyped and non-genotyped animals in this method is straightforward

Single-step GBLUP (ssGBLUP) has now been applied to nearly all major livestock species by researchers, private companies, and breeders' associations. Mehrban *et al.* (2019), pigs (Christensen *et al.*, 2012), Holstein cattle (Ismael *et al.*, 2017), purebred dairy populations worldwide (Ismael *et al.*, 2017, Cifuentes, 2024), and goats (Teissier *et al.*, 2018) have all successfully estimated breeding values using this method.

Due to the lack of large, well-organized farms and the "production by mass" nature of the livestock industry, ssGBLUP is particularly appropriate in India, where a significant percentage of animals are still ungenotyped and pedigrees are frequently incomplete. According to Gowane *et al.* (2022), ssGBLUP increases accuracy even in cases of shallow pedigree depth. Similar improvements in accuracy using ssGBLUP have been reported in Karan Fries cattle (Ilayaraja *et al.*, 2025) and Indian crossbred cattle (Khan *et al.*, 2025).



SNP-BLUP

The model for SNP-BLUP,

$$y = 1\mu + Mg + e$$

where y is the vector of phenotype, μ is the intercept, g is the vector of random unknown marker effects, and e is the vector of random residuals. The marker effects g_i were assumed to be identically and independently distributed with mean zero and variance σ_g^2 ; that is, $g \sim N(0, I\sigma_g^2)$. Estimated solutions from the SNP-BLUP were used to estimate DGV by

$$a = 1\mu + Mg$$

The model used in G-BLUP was equivalent to SNP-BLUP but instead of estimating the SNP effects only the sum of the SNP effects $a = Zg$ corresponding the DGV (direct genomic values) above were estimated.

Example

- For genomic estimated breeding value, we need SNP file which should be in 0,1,2,5(missing) format and SNP matrix should have fixed width and should start with fixed column only.
- We need phenotypic and genotype data for both GBLUP and ssGBLUP
- Phenotypic, genotypic and pedigree file for only ssGBLUP
- If any observation was missing then specify this as missing -999 in parameter file.

First run the RENUMF90 software for proper renumbering (fill the needed parameters, like data (data.prn) file name, traits position in data file, residual variances (matrix if more than one trait), specify the fixed or covariate in effect and consider animal as random effect, file (pedigree file name) and file position is nothing but of animal, sir and dam columns. Specify SNP FILE name (numerical farm only) and covariance (matrix if more than one trait)

Conclusion

BLUPF90 is powerful software used to estimate genetic values and breeding values in animals. It works well even with large and complex data and supports many types of genetic models. One major advantage is that it can use information from both genotyped and non-genotyped animals, making evaluations more accurate. The single-step genomic BLUP (ssGBLUP) method in BLUPF90 is especially useful in India, where pedigree records are often incomplete



and fewer animals are genotyped. Research shows that ssGBLUP improves the accuracy of genetic evaluations by combining genomic, pedigree and performance data together to produce more reliable breeding values.

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Green Extraction Technology in Food Preservation: A Sustainable Revolution

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INTRODUCTION

Food preservation has always been a balancing act between keeping products fresh, safe, and nutritious while minimizing waste. From ancient salting and drying to modern refrigeration and chemical additives, humanity has continuously sought ways to extend shelf life. Today, however, the challenge is not just about preservation it's about doing so sustainably. The concept of green extraction technology, a cutting-edge approach that harnesses eco-friendly methods to recover natural compounds for food preservation.

Green Extraction Technology

Green extraction technology in food preservation is a rapidly growing field focused on sustainable, eco-friendly methods to extract bioactive compounds from natural sources. These technologies such as ultrasound-assisted extraction, enzyme-assisted extraction, microwave-assisted extraction, and supercritical fluid extraction minimize energy and solvent use, reduce environmental impact, and help to preserve valuable antioxidants, polyphenols, and antimicrobials essential for extending shelf life and enhancing food safety. By leveraging green extraction, food producers can create clean-label, functional foods that meet consumer demand for healthier, more sustainable options while also valorizing agricultural by-products and supporting circular economy principles

Green extraction refers to environmentally sustainable methods of isolating bioactive compounds such as antioxidants, antimicrobials, and natural preservatives from plants, food by-products, or agro-industrial waste. Unlike conventional extraction, which often relies on toxic solvents, high energy input, and long processing times, green extraction emphasizes:

- Low environmental impact (minimal solvent use, reduced emissions)
- Safety for consumers (no harmful residues)



- Efficiency (higher yields, shorter processing times)
- Preservation of sensitive compounds (avoiding degradation of vitamins, polyphenols, and essential oils)

Role of Green extraction technology in Food Preservation

Food spoilage is a global issue. According to the FAO, nearly one-third of food produced worldwide is lost or wasted. Much of this is due to microbial contamination, oxidation, and nutrient degradation. Green extraction technologies provide natural solutions by:

- Recovering antioxidants to slow down rancidity in oils and fats.
- Extracting antimicrobials to inhibit bacterial and fungal growth.
- Isolating pigments and flavors that enhance sensory appeal while maintaining safety.
- Utilizing food waste (like fruit peels or seeds) to create value-added preservatives.

Methods of Green Extraction technology

The most promising methods of green extraction techniques for reshaping food preservation are

1. Supercritical Fluid Extraction (SFE)

This method uses carbon dioxide (CO₂) at high pressure and temperature, where it behaves like both a liquid and a gas. In this state, CO₂ acts as a powerful solvent to extract bioactive compounds such as essential oils, antioxidants, and flavors. The process is clean, leaves no toxic residues, and is ideal for preserving delicate compounds in food.

2. Ultrasound-Assisted Extraction (UAE)

High-frequency sound waves generate microscopic bubbles in the solvent, which collapse violently and rupture plant cell walls. This phenomenon, called cavitation, releases valuable compounds quickly and efficiently. UAE is energy-saving, requires less solvent, and is widely used to recover polyphenols and natural antimicrobials from fruit peels and herbs.

3. Microwave-Assisted Extraction (MAE)

Microwaves penetrate plant material and heat it internally, causing rapid cell disruption and release of bioactive compounds. This method is faster than conventional extraction, reduces



solvent use, and preserves sensitive compounds like flavonoids, pigments, and nutraceuticals. It is especially useful for extracting antioxidants from cereals and fruits.

4. Pressurized Liquid Extraction (PLE)

Also known as accelerated solvent extraction, PLE uses water or ethanol under controlled pressure and moderate temperatures to extract compounds. It is scalable, efficient, and environmentally friendly, making it suitable for isolating antioxidants and functional compounds from cereals, legumes, and agro-industrial by-products.

5. Pulsed Electric Field (PEF)

Pulsed Electric Field (PEF) is a non-thermal green extraction technology that applies short high-voltage pulses to permeabilize cell membranes via electroporation, enhancing mass transfer and bioactive compound release from plant and food matrices at low temperatures. It supports sustainable post-harvest processing in horticulture by reducing solvent use, energy, and waste while preserving heat-sensitive compounds like polyphenols and anthocyanins from fruits.

6. Enzyme-Assisted Extraction (EAE)

Natural enzymes such as cellulases and pectinases are used to break down plant cell walls, releasing bioactive compounds gently and selectively. This method avoids harsh chemicals, is highly specific, and works well for extracting bioactive peptides, natural preservatives, and functional ingredients from dairy and plant sources.

7. High Hydrostatic Pressure-Assisted Extraction (HHPAE)

High Hydrostatic Pressure-Assisted Extraction (HHPAE), also known as High-Pressure-Assisted Extraction (HPAE), applies uniform isostatic pressure (typically 100–600 MPa) to plant matrices mixed with solvent, disrupting cell walls and enhancing mass transfer for bioactive recovery without high heat. This non-thermal green technique reduces solvent use, extraction time, and energy while preserving heat-sensitive compounds like phenolics from horticultural by-products.

**Table 1: Comparison of Green Extraction Technologies**

Method	Principle	Advantages	Disadvantages	Typical Applications
Supercritical Fluid Extraction (SFE)	Supercritical CO ₂ as tunable solvent at high pressure	Solvent-free residue, high purity, eco-friendly	High equipment cost, best for lipophilics	Lipophilic compounds, aromas from spices
Ultrasound-Assisted Extraction (UAE)	Cavitation disrupts cell walls via sound waves (20-100 kHz)	Fast, low solvent/energy use, suitable for heat-sensitive compounds	Non-uniform cavitation, scale-up challenges	Polyphenols, essential oils from fruits/plants
Microwave-Assisted Extraction (MAE)	Rapid internal heating via dielectric effects	Short time, high yield, reduced solvent	Thermal degradation risk, uneven heating	Heat-stable bioactives like carotenoids
Pressurised Liquid Extraction (PLE)/Subcritical Water (SWE)	Elevated T/P enhances solvent power/diffusion	Fast, low solvent volume, water-based	Heat sensitivity for soe analytes	Polar compounds from food waste
Pulsed Electric Field (PEF)	High-voltage pulses permeabilize membranes	Room temperature, enhances mass transfer, non-thermal	Equipment cost, needs pretreatment	Pretreatment for fruits, anthocyanins
Enzyme-Assisted Extraction (EAE)	Enzymes degrade cell walls (e.g., cellulases)	Mild conditions, high specificity	Enzyme cost, optimization needed	Proteins/polyphenols from by-products
High Hydrostatic Pressure-Assisted (HHPAE)	Pressure (e.g., 300 MPa) improves extraction	High yield/efficiency, preserves bioactivity	Expensive setup, pressure limits	Anthocyanins from onion peels

Applications of Green Extraction Technology in Food Preservation

- Fruit Juices & Beverages: Natural antioxidants from citrus peels extend shelf life without synthetic additives.
- Meat & Seafood: Plant-derived antimicrobials reduce microbial spoilage, offering safer alternatives to nitrates.
- Dairy Products: Herbal extracts enhance flavor and inhibit spoilage bacteria.
- Bakery Items: Polyphenols from grape seeds delay staling and oxidation.



- **Functional Foods:** Nutraceutical compounds (like carotenoids and flavonoids) improve both health benefits and stability.

Environmental and Economic Benefits

Green extraction is not just about better food it's about better systems:

- **Waste Valorization:** Agro-industrial by-products (fruit skins, seeds, pulp) become valuable sources of preservatives.
- **Reduced Carbon Footprint:** Less reliance on synthetic chemicals and energy-intensive processes.
- **Consumer Trust:** Growing demand for “clean-label” foods makes natural preservation a market advantage.
- **Circular Economy:** Turning waste into resources aligns with global sustainability goals.

Challenges and Future Directions

Despite its promise, green extraction faces hurdles:

- High initial investment in equipment like supercritical CO₂ systems.
- Scaling up from lab to industry while maintaining efficiency.
- Regulatory frameworks ensuring safety and standardization of natural extracts.
- Consumer education to build awareness and acceptance of natural preservatives.

The future research is focusing on nanotechnology encapsulation (to stabilize bioactives), hybrid extraction methods (combining ultrasound with enzymes), and AI-driven optimization of processes.

Conclusion

Green extraction technology represents a paradigm shift in food preservation. By combining sustainability, safety, and efficiency, it offers a way to keep food fresh while protecting both human health and the planet. As industries adopt these methods, consumers can look forward to foods that are not only longer-lasting but also more natural and environmentally responsible.



POST-HARVEST HANDLING AND STORAGE OF ONIONS AND GARLIC

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INTRODUCTION

Onions (*Allium cepa* L.) and garlic (*A. sativum*) are economically and nutritionally important spice crops grown globally, but their seasonal nature and semi-perishable quality make post-harvest management critical for year-round availability. Post-harvest losses in these crops are substantial, often estimated at 35-40% in various operations including handling and storage, with major causes being moisture loss, sprouting, and rotting. Proper curing is the essential post-harvest treatment for long-term storage, as it dries the neck and outer scales to prevent moisture loss and decay. Following curing, grading, and appropriate storage structures with good ventilation and controlled temperature/humidity are crucial for minimizing losses and maintaining bulb quality and shelf life. Adopting improved post-harvest technologies is vital to reducing losses and enhance the profitability of these crops.

Keywords: Onion, Garlic, Curing, Storage, Post-harvest management, Shelf-life

Introduction:

Onion and garlic are indispensable ingredients in kitchens worldwide, valued for their special flavour and pungency. Globally, onions rank third in production volume among vegetables, after tomatoes and cabbages. Despite significant production, **maintaining quality** and **extending shelf life** remain major challenges, leading to high post-harvest losses. These losses, caused by physiological weight loss, sprouting, and deterioration, affect both the economic returns for growers and the continuous market supply. The successful long-term storage of these semi-perishable bulbs hinges on the meticulous application of post-harvest technologies, starting with proper preparation.

Post-harvest Handling Steps:

1. Harvesting:

Harvest when tops fall over and bulbs are fully mature. Avoid mechanical damage during lifting and handling.



2.Curing:

Curing is the single most important post-harvest treatment for the long storage of bulb onions and garlic. It is a drying process aimed at drying off the neck and the outer scale leaves of the bulbs.

- ❖ A properly dried skin acts as a barrier against moisture loss and microbial contamination, which prevents decay during storage.
- ❖ Onions are considered cured when the neck is tight and the outer scales are dry until they rustle when handled; this condition is reached when they have lost 3 to 5% of their weight.
- ❖ The essentials for curing are heat and good ventilation with low humidity.
- ❖ Curing can be done in the field (in windrows, with leaves covering the bulbs to prevent sun damage) or in trays stacked in a warm, covered, well-ventilated area.
- ❖ Garlic curing can take 7–14 days for just the bulb, or 90–120 days if the entire plant is cured. Shade drying is often preferred over sun drying to preserve quality.



ONION AND GARLIC CURING

3. Cleaning and Sorting:

- ❖ Remove soil, roots, and damaged outer scales.
- ❖ Sort bulbs based on size and quality.

4.Packaging:

Careful handling is essential to prevent mechanical injuries that lead to rot.

- ❖ Onions are often packed in **open mesh jute bags** or **nylon net bags** for transport and storage, as these provide good ventilation and result in less storage loss.
- ❖ For small-scale storage, a very effective method is **stringing** the bulbs by weaving the dried tops and hanging them in a well-ventilated, dry place.



- ❖ Bulbs intended for storage must be **free from cuts** and handled with care to avoid damage.

Storage of Onions and Garlic:



Proper storage depends on maintaining ideal environmental conditions such as temperature, humidity, and air circulation.

Recommended Storage Conditions:

- ❖ Temperature: 0–5°C for long-term storage.
- ❖ Relative Humidity: 60–70%.
- ❖ Ventilation: Essential to avoid sprouting and rotting.

Factors Affecting Storage Quality:

1. **Moisture** – Excess moisture leads to fungal attack.
2. **Mechanical Damage** – Makes bulbs prone to rot.
3. **Temperature Fluctuation** – Causes sprouting.
4. **Ventilation** – Poor airflow increases spoilage.

Conclusion:

The post-harvest phase for onions and garlic is a significant determinant of their economic value and availability. Proper curing is the foundational step, followed by careful grading, handling, and storage under low temperature (0-5°C) and low humidity (65-70% RH) conditions. The use of well-ventilated storage structures and the selection of long-storing cultivars are critical to minimizing the high losses associated with sprouting and rot. Continued adoption of improved post-harvest technologies and infrastructure will be vital to ensure a steady, high-quality supply of these essential alliums.



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PRODUCTION TECHNOLOGY OF ANNUAL MORINGA PKM – 1

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ABSTRACT

PKM -1 is a high – yielding annual moringa (*Moringa oleifera*) variety developed for intensive cultivation, uniform pod production, and suitability for commercial farming. Its production technology emphasizes optimal agronomic practices that enhance growth, flowering, and pod yield. PKM-1 performs best in warm tropical climates with well – drained loamy soils and adequate sunlight. Land preparation involves deep ploughing and incorporation of organic matter to improve soil structure. Direct seedling or transplanting can be adopted, with recommended spacings of 1.2 x 1.2m or sole cropping or 2.5x2.5 m for wider canopy management. Balanced 2.5m for wider-canopy management. Balanced nutrient application - particularly nitrogen, phosphorus and potassium-support vegetative vigor and reproductive performance, while organic amendments enhance soil health. Irrigation is crucial during early establishment and pod development, though the crop remains relatively drought-tolerant once established. Regular weeding, pinching of terminal buds, and timely plant protection measures against common pests (such as fruit flies and pod borers) ensure steady growth. Harvesting typically begins possible due to continuous flowering. PKM-1 is valued for its uniform, fleshy, long pods and high nutrient quality. Adoption of recommended practices significantly increases long pods and high nutritive quality. Adoption of recommended practices significantly increases productivity, making PKM-1 an economically viable crop for smallholders and commercial growers in tropical regions.

Introduction:

Moringa (*Moringa oleifera*) is one of the most versatile and valuable multipurpose trees grown in the tropics and subtropics. It belongs to the family: Moringaceae and is widely known as the “Drumstick tree” or “Horseradish tree.” India is considered its center of origin and diversity, with Tamil Nadu being a major cultivation zone. Traditionally, moringa was cultivated as a perennial tree propagated by stem cuttings, but the introduction of annual seed-propagated varieties like PKM 1 and PKM 2 has transformed its cultivation. These varieties offer short duration (8–10 months), high yield, and uniform quality pods, which make them commercially profitable even under limited land holdings.

**Importance of Moringa:**

- ❖ Moringa is often called a “Miracle Tree” because of its nutritional, medicinal, and industrial values.
- ❖ Nutritional value: Tender pods, leaves, and flowers are rich in vitamins (A, B, and C), minerals (iron, calcium, phosphorus), and protein.
- ❖ Medicinal uses: The plant has antibacterial, anti-inflammatory, and antioxidant properties. It is used in traditional medicine to treat anemia, hypertension, and malnutrition.
- ❖ Industrial uses: Seeds yield Ben oil, a high-quality edible oil used in cosmetics and lubrication. The seed cake acts as a natural water purifier.
- ❖ Agronomic importance: Short duration, high yield, and adaptability make it an ideal crop for multi-cropping and intercropping systems.

Origin and Development of PKM 1:

The PKM 1 (Periyakulam 1) variety was developed at the Horticultural Research Station, Periyakulam, under Tamil Nadu Agricultural University (TNAU). It was released in 1989 and was derived through pure line selection from a local annual moringa population.

Salient Features of PKM 1:

- ❖ Annual type, propagated by seeds.
- ❖ First flowering in 90–100 days.
- ❖ Pods are 65–70 cm long, green, slender, and tender.
- ❖ Highly suitable for vegetable production and short duration cropping.
- ❖ Average yield: 35–40 tonnes/ha or 250–300 fruits per tree.
- ❖ Pods are fleshy, non-fibrous, and of uniform quality, making them ideal for both domestic and export markets.

Botanical Description:

Moringa is a fast-growing, soft-wooded, deciduous tree. It has a deep tap root system, which enables drought tolerance. The leaves are compound, tripinnate, and bright green. Flowers are small, creamy-white, borne in axillary clusters. Fruits are long, ribbed capsules called pods, containing numerous winged seeds. The crop completes its economic life in 8–10 months, after which yield and pod quality decline, and replanting is usually recommended.

Climate and Soil Requirements:**Moringa is highly adaptable but performs best under:**

- ❖ Temperature: 25–35°C (optimum); tolerates up to 40°C.
- ❖ Rainfall: 500–1500 mm annually.
- ❖ Altitude: Up to 1000 m above mean sea level.
- ❖ Soil: Well-drained sandy loam to loamy soil, pH 6.5–8.0.

Avoid clayey or waterlogged soils, as these lead to root rot and poor establishment.

Propagation:

Method: By seeds (for annual types like PKM 1) and by stem cuttings (for perennial types).

Seed rate: 500 g/ha (approx. 2500–3000 seeds).

Seed treatment:

- ❖ Soak seeds in water for 12–24 hours to enhance germination.
- ❖ Treat with *Trichoderma viride* @ 4 g/kg to prevent soil-borne diseases.



- ❖ Nursery raising: Seeds can be sown directly in the main field or raised in polybags for 30–35 days before transplanting.

Land Preparation:

- ❖ Deep ploughing 2–3 times followed by harrowing.
- ❖ Prepare ridges and furrows at 3 × 2 m spacing.
- ❖ Dig pits of 45 × 45 × 45 cm size and fill them with:
- ❖ Topsoil + 10–15 kg FYM + 100 g Neem cake + 10 g Azospirillum + 10 g Phosphobacteria.

Planting:

- ❖ **Rainfed crop:** June–July (southwest monsoon).
- ❖ **Irrigated crop:** January–February.
- ❖ **Spacing:** 3 m × 2 m (1666 plants/ha).
- ❖ **Method:** Direct seed sowing or transplanting of 30-day-old seedlings.
- ❖ **Irrigation:** Provide light irrigation immediately after planting.

Manures and Fertilizers:

Balanced nutrition is essential for high production. Fertilizer Recommendation per Plant basal dose: 25 kg FYM + 45 g N + 23 g P + 23 g K. Top dressing repeat the same dose after every flush of flowering or harvest. Apply fertilizers in shallow circular trenches 30 cm away from the base and cover with soil.

Biofertilizers:

Application of Azospirillum and Phosphobacteria enhances nutrient uptake and improves yield by 10–15%.

Irrigation Management:

- ❖ First irrigation immediately after planting.
- ❖ Subsequent irrigations at 5–7 day intervals during summer and 10–15 days during winter.
- ❖ Avoid water stagnation, as moringa is highly susceptible to root rot.
- ❖ Drip irrigation is recommended for efficient water use and better yield.

Training and Pruning:

Pinching: When the plant reaches 75 cm height, pinch the terminal bud to promote lateral branching. Retain 4–6 main branches evenly spaced around the stem. After each harvest, prune the plant to 1–1.2 m height to induce new vegetative flushes and ensure continuous bearing.

Intercultural Operations:

Weeding: Regular weeding is essential, especially during early growth.

Mulching: Apply organic mulch to conserve soil moisture and suppress weeds.

Earthing up: Carried out after each harvest to strengthen the plant base.

Intercropping: Short-duration vegetables like cowpea, bhendi, or coriander can be grown between moringa rows during the initial months.

**Pest and Disease Management****Major Pests:**

Pest	Symptoms	Control
Hairy caterpillar	Defoliation	Spray neem oil 5% or Chlorpyrifos 0.05%
Pod fly	Maggot tunnels inside pods	Spray Dimethoate 0.05%
Bark caterpillar	Holes on stem, excreta on bark	Swab trunk with kerosene + cotton waste removal

Major Diseases:

Disease	Symptoms	Control
Fruit rot	Black lesions on pods	Spray Mancozeb 0.2%
Fruit rot	Black lesions on pods	Spray Mancozeb 0.2%
Leaf spot	Brown circular spots	Spray Carbendazim 0.1%

Use integrated pest management (IPM) combining cultural, biological, and safe chemical methods.

Flowering and Fruiting:

PKM 1 starts flowering 3 months (90–100 days) after planting. Flowering is profuse and continuous under favorable moisture conditions. Pods develop rapidly and are ready for harvest in 160–180 days. Fruit set is improved by maintaining adequate soil moisture and applying micronutrients like boron and zinc during the pre-flowering stage.

Harvesting and Yield:

Harvesting: Tender green pods are ready for harvest every 35–40 days after flowering. Harvest manually to prevent mechanical injury.

Yield: 250–300 pods/tree/year or 35–40 tonnes/ha under good management.

Post-harvest: Pods are graded by size, color, and tenderness before marketing.

Post-Harvest Handling and Storage

- ❖ Harvest early in the morning to minimize moisture loss.
- ❖ Pack in bamboo baskets or ventilated crates lined with banana leaves or paper.
- ❖ Pods can be stored for 2–3 days at room temperature or up to 7 days at 10°C and 90% RH.

Uses and Value Addition:

Leaves: Used as vegetable, fodder, and in herbal formulations.

Pods: Popular as vegetable and for export.

Seeds: Source of ben oil used in cosmetic and pharmaceutical industries.

Powder: Leaf powder is processed for nutritional supplements.

By-products: Seed cake used in water purification and organic fertilizer.

Conclusion:

The cultivation of annual moringa PKM 1 has become a profitable venture due to its short duration, high yield, and nutritional value. Its adaptability to diverse conditions and low input requirement make it ideal for sustainable horticultural production. With proper management balanced fertilization, timely irrigation, pruning, and integrated pest control farmers can obtain consistent, high-quality yields throughout the year.



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SEED EXTRACTION METHODS - TOMATO

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ABSTRACT

Tomato is one of the most important vegetable crops grown in India, especially in Andhra Pradesh, where it is a leading crop in Chittoor district. Efficient seed extraction is essential for maintaining seed quality and ensuring successful crop production. Tomato seeds can be extracted using fermentation, alkali treatment, or acid treatment, each suited to different fruit types and scales of operation. Mechanical extraction using a tomato seed extractor further enhances speed and efficiency. Proper drying, grading, and storage ensure high-quality seeds with longer shelf life.

Keywords: Tomato seed extraction, Fermentation method, Alkali treatment, Acid treatment, Seed processing and storage

Introduction

Tomato occupies a significant place in Indian vegetable cultivation and ranks third in importance after potato and sweet potato. In Andhra Pradesh, it is widely grown, especially in Chittoor district, which is known for large-scale tomato production. High-quality seed is crucial for achieving good crop establishment and uniform plant growth. Tomato seeds are embedded in a gelatinous material that must be removed effectively to avoid poor germination and storage issues. Several traditional and mechanical methods are available for seed extraction, each with specific advantages depending on the scale of production, fruit size, and seed quantity. Understanding these methods helps ensure efficient seed recovery and improved seed quality. Tomato is one of the important vegetable crops of India and Andhra Pradesh. It is the leading crop of Chittoor district. It occupies third position after Potato and sweet potato in its importance. Seed can be extracted from the tomato fruit by one of the following three methods:

- ❖ FERMENTATION METHOD
- ❖ ALKALI TREATMENT METHOD
- ❖ QUICKEST METHOD OR ACID TREATMENT METHOD

FERMENTATION METHOD:

This method is employed when tomato fruits are generally not very big and they possess a large no. of seeds. The fruits selected for seed are completely lost and nothing can be used as food or otherwise. The selected ripe fruits are harvested from the plants and allowed to ripe further



for a day or two in a heap or in an earthen pot. They are then crushed well in an earthen pot by hand or by any mechanical method to make a paste.

No fruit juice should be allowed to drain out. Now the entire mass is kept in the vat for a day or two to ferment. It may be complete in one or two or more days. According to high or low temperature. Profuse foam formation on the top and no adhering of seed to the tomato flesh on stirring the mass vigorously with a wooden stick or hand, indicates that the fermentation is complete. Now the flesh will float on the top, while the seeds will settle down at the bottom of the vat. Remove all the fermented mass on the top and then decant off gently all the liquid. The seeds resting on the bottom of the vat are collected and washed 8-10 times with clear water and then they are spread in the sun to become dry. When they are perfectly dry in the sun store them in air tight containers in a cool dry place. It is the simplest method and can be adopted by any layman. They should not be left too long, otherwise they may germinate in it.

ALKALI TREATMENT METHOD:

When fruits are big enough but the no. of seeds is small, method is adopted. Cut the selected ripe fruits into halves and then scoop out the slimy mass containing the seeds into an earthen or porcelain vessel with the help of the handle of a stainless steel, tea spoon or wooden stick. The flesh thus separated can be easily used for eating raw or for any other purpose.

Treat the slimy mass with an alkali mixture (150 grams of ordinary washing soda is added to 5 liters of boiling water) in equal volumes.) When the alkali mixture is cooled, allow it to stand overnight in an earthen or porcelain vessel. By next day, all the seeds will settle down at the bottom of the container. Decant off the clear liquid at the top. Seeds thus obtained are washed thoroughly with clear water and allowed to dry in the sun and are preserved.

QUICKEST METHOD OR ACID TREATMENT METHOD:

This method is followed where seed production is done on large scale. It can also be adopted



on the home scale. In this method, too, the flesh of the fruit can be saved. Slimy seed mass is separated as mentioned above and kept in an earthen or a porcelain or glass vessel. This is done



by treating with commercial hydrochloric acid in the proportion of 30 ml of fluid per 12kg of the material.

The seeds are separated from the slimy mass within 15-30 min., if acid is thoroughly mixed. The acidified liquid is then decanted off and the seeds remaining at the bottom are immediately washed well with clear water and allowed to dry in the sun. They are then preserved. In this method the seeds can be extracted and dried on the same day and any discoloration of seeds, resulting from the fermentation process, is entirely eliminated. There is also no possibility of seed germination during this process.

TOMATO SEED EXTRACTOR:

Drying and grading:

Seeds are to be dried in the shade. It should never be dried in hot sun. The safe moisture content of the seed for grading is 8 to 9 per cent. Seeds can be graded using 6/64" round perforated sieve.

Storage:

The seeds dried to safe moisture content after treating either with captan or thiram @ 2 g/kg can be stored for 15 months in moisture vapour pervious containers, while it can be stored in



Mechanical Crushing



Extracted seed



Acid treatment



Washing of seeds

moisture vapour proof containers for 30 months.

TOMATO SEED EXTRACTOR:

1.	Function	To extract seed from tomato fruits
2.	Specification :	
	(a) Overall dimension	500 x 450 x 1000 mm
	(b) Capacity	180 kg of fruit (1.8 kg of seed) per hour.
	(c) Power	1 hp for electric motor and 0.5 hp for pump.



3.	General Information	The unit consists of a feed hopper, fruit crushing chamber, seed separation unit, water recycling system and seed collecting trough. In the crushing chamber the tomato fruits are crushed and squeezed by the rotating screw auger. In the seed separation unit, water separates the seed from the flesh and collected in a container placed at the bottom of seed separation unit. The water collected in the trough is recycled by means of a pump. The flesh coming out of the seed separation unit is collected separately.
4.	Cost of the unit	Rs. 15.000
5.	Cost of operation	Cost of Rs. 10 per hour
6.	Salient features	Seed extraction is faster compared to the manual method



TOMATO SEED EXTRACTOR

Conclusion

Tomato seed extraction is a crucial step in producing high-quality seeds essential for successful cultivation. Methods such as fermentation, alkali treatment, and acid treatment offer effective ways to separate seeds from the fruit pulp, depending on production scale and fruit characteristics. Mechanical extraction using a tomato seed extractor further enhances efficiency, especially for large-scale operations. Proper drying, grading, and storage practices help maintain seed viability and extend shelf life. By adopting suitable extraction and handling techniques, farmers can ensure reliable seed production and improved crop performance.

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GINGER: A valuable spice and medicinal crop

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INTRODUCTION

Ginger is one of the most important spice crops grown in tropical and subtropical regions. It is widely used in culinary preparations, ayurvedic medicines, beverages, pickles, and natural home remedies. India is one of the largest producers and consumers of ginger.

Ginger rhizome contains bioactive compounds such as gingerol, shogaol, zingerone, which are responsible for strong, aroma, flavour and medicinal properties. Because of this its versatile uses it is consumed as fresh, dried, powdered, or as tea, paste, and oil.

Botanical name: *Zingiber officinale*

Family name: Zingiberaceae

Common name: ginger / adrak

Medicinal uses and benefits:

1. It gives quick relief from cold, cough, and sore throat
2. It improves digestion and prevents gas and bloating
3. It reduces inflammation and helps in joint pain.
4. It is very effective in reducing nausea and vomiting.
5. It supports weight loss by boosting metabolism.
6. It keeps the skin healthy by fighting infections.
7. It has anti-cancer properties due to strong antioxidants
8. It helps detoxify the liver and keeps the body clean from toxins.
9. It can act as a natural pain reliever for headaches and muscle pain.
10. It improves the heart health by lowering bad cholesterol.

Climate

Grows well in tropical and sub tropical regions wherein the warm and humid climate is ideal. Temperature between 20-30 degree Celsius, rainfall of about 150- 300 cm is ideal. The crop requires moderate shade.

Soil

Well drained loamy soil is best which is rich in organic matter improves rhizome size and quality the Optimum pH of soil should be 5.5- 6.5. Heavy clay soils should be avoided because there is poor rhizome formation. Sandy loam soils helps in easy harvesting of the rhizomes.

Propagation:

Ginger is propagated exclusively through rhizomes and it can be selected from disease free rhizomes are selected from high – yielding plants. Optimum size of rhizomes is 25-30 g



with 1-2 healthy seeds. Seed rate is around 15 quintals/ha. The rhizomes should be treated with *Trichoderma harzianum* to avoid rot.

Nursery preparation:

Raised nursery beds of 1m width and convenient length are prepared. The soil should be mixed with FYM+ Sand + Top soil for good sprouting. The rhizomes are placed in shallow trenches and lightly covered with soil. And the seed rhizomes are kept in shade for 20-25 days to sprout before planting.

Transplanting: April – May.

Spacing: 45 – 60 cm X 20 cm

Mulching with green leaves.

Land should be repeatedly ploughing and harrowing has to be done.

Varieties of ginger:

- Maran
- Ernad
- Rio-de-janerio
- Nadia
- Moran
- Suravi
- Suprabha
- Varada
- Humnabad local
- Karakkal
- Wynad
- Himgiri

Manures and fertilizers:

Organic manures: Well-rotted fym ;10-12 tonnes/acre, Vermicompost; 1-1.5 tonnes/acre

Neem cake: 200-250 kg/acre Chemical fertilizers: 75:50:50 kg/acre in split doses.

1st dose: 30 days after planting

2nd dose: 60-70 days

3rd dose: 90-100 days.

Irrigation and drainage irrigation and drainage:

Ginger requires frequent but light irrigation and first irrigation after planting if rainfall is insufficient. Irrigation should be given every 7-10 days depending on moisture level and proper drainage is crucial to prevent rhizome rot.

Weeding and intercultural operations:

First weeding at 20-25 days and 2-3 additional weeding's at monthly intervals should be done followed by earthing up helps rhizome development. Mulching should be followed periodically to maintain moisture and suppress weeds.

Harvesting:

Ginger is harvested 7-9 months after planting and soil is loosened also rhizomes are carefully lifted. Early harvest: tender ginger for pickles Full maturity: hard fingers ideal for dry ginger /seed.



Yield: Average fresh ginger yield: 8-12 tonnes /acre. Under improved practices:14-15 tonnes/acre. Recovery of dried ginger: 20-25% from fresh weight.

Post harvest practices:

Processing of ginger

Processing of ginger involves converting fresh rhizomes into different value-added products that have longer shelf life and better market value.

The major processing steps are:

1. Cleaning and Washing: Fresh ginger rhizomes are washed thoroughly to remove soil, dirt, and roots.

Clean water or running water is used. Sorting is done to remove damaged or diseased rhizomes.

2. Peeling: Outer skin is removed manually with knives or using mechanical peelers. Peeling helps improve colour and quality of the processed product.

3. Slicing or Cutting: Ginger is cut into thin slices or small pieces depending on the product type.

Uniform slicing helps in better drying and processing.

4. Drying/Curing: Drying is the most important process for making dry ginger (soonth).

Types of Drying: Sun drying: 6–8 days

Mechanical drying: Faster, uniform drying

Solar dryers: More hygienic, better colour

Dry ginger is used for powders, medicines, and spices.

5. Grinding or Pulverization: Dried ginger is ground into fine powder. Powder is sieved and packed in moisture-proof bags.

6. Preparing Value-Added Products

Ginger can be processed into:

a) Ginger Powder: Made by grinding dry ginger .Used in spices, masala, food industries

b) Ginger Oil: Extracted through steam distillation , used in medicines, cosmetics, and aromatherapy

c) Ginger Oleoresin: Concentrated extract containing essential oils and pungent compounds
Used in flavouring industries

d) Ginger Candy / Crystallized Ginger: Fresh ginger is boiled in sugar syrup Dried and coated with sugar

Popular snack and confectionary item

e) Ginger Pickle: Fresh ginger is sliced and mixed with oil, spices, and preservatives
Packed in bottles

f) Ginger Garlic Paste: Widely used in households and hotels it requires grinding, preservatives, and air-tight packing

g) Ginger Tea / Instant Ginger Drink: Dried ginger powder is blended with sugar and tea extracts and packed as sachets

7. Packaging: Processed ginger products are packed in moisture-proof, air-tight containers. Proper labelling and date marking are required for marketing.

8. Storage: Dry ginger and ginger powder must be stored in cool and dry places.

Use of laminated pouches helps in longer shelf life.

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Ginger standing crop



Ginger rhizomes



TURMERIC: A GOLDEN SPICE & CONDIMENT WITH HIGH MEDICINAL AND ECONOMIC VALUE

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INTRODUCTION

Turmeric (*Curcuma longa*) is one of the most important spice crops of India, widely cultivated for its deep orange-yellow rhizomes. It has been used for thousands of years in Ayurveda, Siddha, traditional medicine, cooking, textile dyeing, cosmetics, and religious rituals. The golden colour and exceptional therapeutic qualities of turmeric come from curcuminoids, especially curcumin, the primary bioactive compound responsible for its anti-inflammatory, antioxidant, antimicrobial, and healing properties.

India is the largest producer, consumer, and exporter of turmeric, contributing nearly 80% of the global supply. Due to its expanding use in the food, pharmaceutical, nutraceutical, and cosmetic industries, turmeric cultivation has significant market and export potential.

Botanical information:

Botanical Name: *Curcuma longa*

Family: Zingiberaceae

Common Names: Indian Saffron, Haldi, Golden Spice

Benefits of turmeric:

1. **Anti-inflammatory Action:** Turmeric reduces internal inflammation, helpful in arthritis, joint pain, and muscle swelling.
2. **Immunity Booster :** Boosts resistance to infections and improves cellular immunity.
3. **Strong Antioxidan :** Neutralizes free radicals, slows ageing, protects cells from damage.
5. **Skin Benefits :** Heals wounds, improves complexion, reduces acne and infections.
7. **Heart & Metabolic Health:** Helps regulate cholesterol, supports healthy blood sugar, improves blood circulation.
8. **Liver Protection:** Detoxifies liver, reduces fatty liver conditions.

Climate and soil requirements:

- Turmeric grows best in hot & humid tropical climates and ideal temperature requirement ranges between 20°–30°C
- Requires 1000–2000 mm rainfall
- Sandy loam, clay loam, and alluvial soils are ideal
- Soil pH: 5.5–7.0

Propagation:

- Turmeric is propagated vegetatively through rhizomes.



- Seed rhizomes (mother & finger rhizomes)
- Rhizome pieces must contain at least one healthy bud
- Seed rate: 1500–2500 kg/acre
- Rhizomes treated with fungicides before planting

NURSERY RAISING:

- Pre-sprouting is done using moist sawdust, coir pith, or sand
- Rhizomes sprout in 25–30 days
- Sprouted rhizomes ensure uniform establishment and better yield

Land preparation and transplanting:

- Land ploughed 3–4 times for fine tilth
- Apply 25–30 t/ha well-decomposed FYM
- Prepare ridges & furrows or beds
- Plant sprouted rhizomes at 30 × 20 cm spacing
- Ideal planting time: April–June

Manures and fertilizers:

- Organic Manure : FYM: 25–30 tons/ha
Green manure crops before turmeric enhance soil fertility
- Chemical Fertilizers :

Recommended dose per hectare:

NPK: 100: 50 : 100 kg/ha Nitrogen applied in 3 split doses for better rhizome growth.

Irrigation and drainage:

- First irrigation immediately after planting
- Subsequent irrigation every 7–10 days in dry season
- Must avoid waterlogging
- Proper drainage channels required
- Drip irrigation improves yields and curcumin content

Weed control:

- 2–3 hand weedings during the early stage
- Mulching with leaves or straw improves moisture, controls weeds
- Black polythene mulch is used in high-tech cultivation

Harvesting:

- Crop duration: 7–9 months
- Signs of maturity: leaves and stems turn yellow and Foliage begins to dry
- Rhizomes dug manually or with implements
- Rhizomes cleaned, sorted into mother and finger rhizomes

Yield:

- Fresh rhizome yield: 20–30 tons/ha



- Dry rhizome yield: 4–6 tons/ha
- Powder conversion ratio : 20–25%

Post harvest practices:

1. Cleaning and Sorting: Cleaning fresh rhizomes are washed with clean water or using rotating drum washers. Removes soil and mud particles, stone pieces, unhealthy rhizomes

Sorting Based on: Size and maturity colour absence of pest damage, market standards, diseased rhizomes are rejected to maintain quality.

2. Curing (Boiling or Steaming): Curing is a critical step that determines the colour, aroma, hardness, and shelf life of turmeric. Purposes of Curing : Removes the raw, earthy smell ,Reduces the drying time by gelatinizing starch ,Increases colour intensity by transforming curcuminoids, Kills microbes and insects Hardens rhizomes and gives uniform texture.

- I. Traditional Curing : Boiling in large earthen or metal pots. Water is added until rhizomes are fully submerged Boiling time: 45–60 minutes, test of doneness: Rhizomes become soft and break when pressed between fingers.
- II. Improved/Scientific: Curing is done using steam cookers or autoclave-type processing units, more uniform colour development. Shorter processing time reduced fuel cost. Maintains microbiological safety.

3. Drying: After curing, the rhizomes must be dried immediately

- Traditional Sun Drying: Rhizomes spread on clean platforms, bamboo mats, or concrete floors.

Drying duration: 10–15 days. Rhizomes must be turned frequently for uniform drying.

Final moisture content: 8–10%.

- Mechanical Drying : Uses hot air dryers, tray dryers, or solar dryers
Temperature: 60–70°C
Time required: 24–48 hours Hygienic, fast, and uniform.

4. Polishing : To improve appearance and market value: Hand rubbing or drum polishing removes rough surface and scales. Polishing helps achieve a bright, smooth, and appealing product.

5. Colouring : For uniform colour, turmeric may be coated with turmeric powder or food grade colorants. This practice is common in commercial production.

6. Grading : Rhizomes are sorted based on: Size ,Color ,Purity ,Shape Higher grades fetch better prices.

7. Grinding (Optional): If turmeric powder is required: Dried rhizomes are ground into fine powder and Must be done in hygienic conditions to prevent contamination.



8. Packaging: Packed in airtight, moisture-proof bags to prevent humidity absorption. Export-quality turmeric uses double-layer packaging.

9. Storage: Stored in cool, dry, well-ventilated rooms. Moisture, pests, and sunlight should be avoided. Proper storage increases shelf life and maintains color and aroma.

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Turmeric standing crop



Turmeric rhizomes

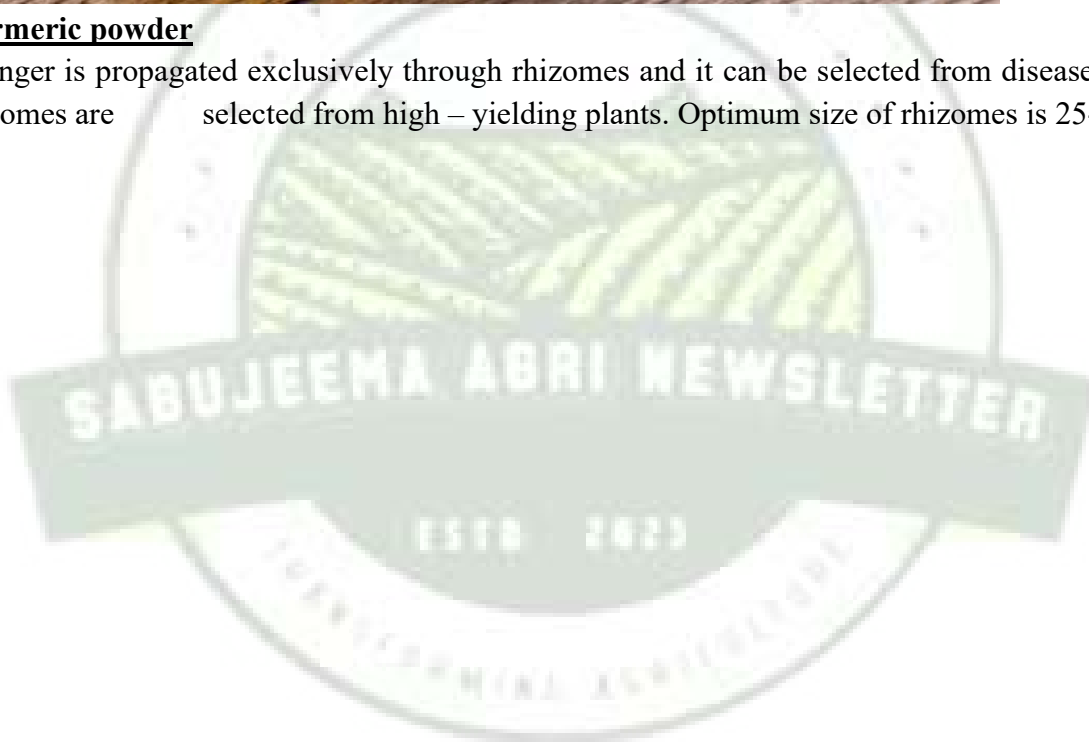


Turmeric mobile processing unit



Turmeric powder

Ginger is propagated exclusively through rhizomes and it can be selected from disease free rhizomes are selected from high – yielding plants. Optimum size of rhizomes is 25-30 g





Oil Palm Cultivation in Telangana: A Profitable Venture for Farmers

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INTRODUCTION

Telangana, with its diverse agro-climatic zones and irrigated areas, is emerging as a potential hub for oil palm cultivation in India. Traditionally known for crops like paddy, cotton, and horticultural produce, the state is now witnessing growing interest in **oil palm** as a commercial crop due to its high yield potential and economic returns.

Why Oil Palm?

Oil palm (*Elaeis guineensis*) is a tropical crop that produces oil-rich fruit. Palm oil is widely used in cooking, food processing, cosmetics, and biofuels. India imports a significant portion of its edible oil requirement, and promoting oil palm cultivation domestically can help reduce import dependency while improving farmer incomes.

Some advantages of oil palm cultivation include:

- **High income potential:** One hectare of mature oil palm can yield 3–5 tons of oil annually.
- **Long-term investment:** Oil palms start yielding economically from 3–4 years after planting and can produce for 25–30 years.
- **By-products utilization:** Apart from oil, oil palm residues like empty fruit bunches, palm kernel cake, and fronds can be used as organic manure, biofuel, or animal feed.

Climate and Soil Requirements

Oil palm thrives in areas with:

- Annual rainfall of 1500–2500 mm (supplemented by irrigation in dry areas like Telangana).



- Well-drained deep soils with a pH of 4.5–7.0.
- Minimum temperature of 22°C and maximum up to 32°C.

In Telangana, districts like **Khammam, Warangal, Nirmal, and Karimnagar** are being promoted for oil palm under irrigated conditions. Farmers with access to irrigation can achieve high yields even in regions with lower rainfall.

Planting and Crop Management

- **Land Preparation:** Clear the land and dig pits of 1 m³ size. Mix topsoil with organic compost.
- **Variety Selection:** High-yielding hybrids like **Giant Dura × Pisifera** are recommended.
- **Planting Density:** Typically, 143 palms per hectare (spacing of 9 m × 9 m).
- **Nutrient Management:** Balanced application of NPK fertilizers along with micronutrients ensures healthy growth and high yields.
- **Water Management:** Young palms require frequent irrigation, while mature palms can tolerate some moisture stress.
- **Pest and Disease Management:** Regular monitoring for red palm weevil, rhinoceros beetle, and fungal diseases is essential. Integrated Pest Management (IPM) is recommended.

Economic Returns

The financial viability of oil palm in Telangana is promising:

- Initial investment is higher than traditional crops due to cost of saplings, fertilizers, irrigation, and maintenance.
- Farmers can expect the first harvest in 3–4 years, with peak yields from 7–12 years.
- One hectare can produce 3–5 tons of crude palm oil annually, translating to substantial profits depending on market prices.



Government Support in Telangana

The Telangana government, in collaboration with the **National Mission on Oilseeds & Oil Palm (NMOOP)**, provides:

- Subsidies on planting material and irrigation systems.
- Technical training on nursery management, plantation, and harvesting.
- Assistance for forming farmer groups and linking with oil extraction units.

Conclusion

Oil palm cultivation presents a **viable and profitable option** for Telangana farmers seeking diversification and higher incomes. With proper management, access to irrigation, and government support, this crop can transform the agricultural landscape of the state while contributing to India's self-reliance in edible oils.



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Popular Article

Machine Learning Applications in Agriculture: Opportunities, Challenges, and Implications for Indian Farming Systems

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ABSTRACT

Machine learning (ML) is transforming Indian agriculture by enabling data-driven decision-making, predictive analytics, and smart automation. This paper examines ML applications in crop yield forecasting, pest and disease detection, precision irrigation, soil health monitoring, climate risk management, and smart farm automation. Drawing on Indian research studies, government initiatives, and field applications, the paper highlights both opportunities and challenges for ML adoption in India. Findings suggest ML can improve productivity, reduce input costs, and enhance sustainability, but success depends on data availability, farmer training, and digital infrastructure.

Keywords: Machine Learning, Smart Agriculture, Precision Farming, Artificial Intelligence, Crop Prediction, Climate Analytics.

1. Introduction

Agriculture in India is undergoing a digital transformation, driven by artificial intelligence, big data, and machine learning (Government of India, 2023; Ministry of Agriculture & Farmers' Welfare, 2022). With rising food demand and climate variability, traditional farming practices are often insufficient to maintain sustainability (Sharma & Singh, 2022).

Machine learning enables systems to learn from historical data, identify patterns, and make predictions without explicit programming. ML models in India process soil, weather, satellite



imagery, and crop records to generate actionable insights for farmers and policymakers (Kayastha, Behera, & Patnaik, 2024; Sahoo, Patnaik, & Behera, 2023).

The integration of ML into Indian agriculture allows proactive decision-making, improving crop management, reducing losses, and increasing efficiency (Behera, Sahoo, & Mahapatra, 2024). This paper explores applications, benefits, and challenges of ML in Indian agriculture.

2. Literature Review

Indian studies indicate that ML is effective in precision agriculture. Random Forests, Support Vector Machines, and deep learning models outperform traditional methods for crop yield prediction, pest detection, and irrigation management (Choudhary & Kumar, 2023; Behera, Sahoo, & Mahapatra, 2024).

CNNs have been successfully applied to detect diseases in rice, wheat, and vegetables in India (Mohanty, Panda, & Das, 2022). ML-assisted soil classification and nutrient assessment are improving fertilizer use efficiency (Jayalakshmi, Reddy, & Rao, 2022).

Government initiatives like the National Digital Agriculture Mission and AgriStack focus on integrating ML into Indian agriculture by creating a data-driven ecosystem that enhances productivity, transparency, and farmer welfare (Government of India, 2023; Ministry of Agriculture & Farmers' Welfare, 2022)

3. Methodology

This paper adopts a qualitative, secondary data-based approach. Sources analysed include:

- Peer-reviewed Indian journal articles on ML in agriculture
- Government reports on digital agriculture initiatives
- Case studies of ML-based agricultural applications in India
- Industry reports on AI-driven farm technologies in India

The analysis identifies key ML applications, benefits, challenges, and policy implications for Indian agriculture (Behera, Sahoo, & Mahapatra, 2024; Kayastha, Behera, & Patnaik, 2024).



4. Applications of Machine Learning in Agriculture

4.1 Crop Yield Prediction

ML models such as Random Forests, SVMs, and Artificial Neural Networks are used in India to predict crop yields using historical crop, soil, and weather data (Choudhary & Kumar, 2023; Kayastha, Behera, & Patnaik, 2024).

CNN-LSTM models with satellite imagery have been applied to rice and wheat in Odisha and Punjab, outperforming conventional statistical methods (Mohanty, Panda, & Das, 2022). These predictions allow farmers to optimize sowing, irrigation, and harvest schedules, while supporting policymakers in planning food supply (Behera, Sahoo, & Mahapatra, 2024).

4.2 Pest and Disease Detection

ML enables early detection of pests and diseases, reducing crop losses. CNN-based models analyse leaf images to detect diseases like leaf blight, rust, and wilt in rice and potatoes (Mohanty, Panda, & Das, 2022; Singh & Verma, 2022).

Mobile apps like “Plantix India” and ML-enabled extension services provide real-time diagnostics to farmers (Behera, Sahoo, & Mahapatra, 2024). Autonomous robots for pest detection and targeted pesticide application are being piloted at IIT Kharagpur and IIIT-Allahabad (Times of India, 2024; Times of India, 2025).



Fig 1: disease detection using plantix app

4.3 Precision Irrigation and Water Management

Water scarcity is a major challenge, particularly in Maharashtra and Rajasthan (Government of India, 2023). ML-assisted irrigation integrates soil moisture, weather, and crop growth data to optimize water use (Jayalakshmi, Reddy, & Rao, 2022).

Decision tree and neural network models calculate optimal irrigation schedules, reducing overwatering while improving



Fig 2: Precision Irrigation using IoT based ML irrigation system
Source: SDG investor platform



yields (Kayastha, Behera, & Patnaik, 2024). Pilot ICAR projects in Odisha implemented IoT-based ML irrigation systems for rice and wheat, achieving 25–30% water savings (Behera, Sahoo, & Mahapatra, 2024).

Predictive scheduling uses ML to forecast future water requirements based on growth stage, rainfall, and soil type, helping farmers make proactive decisions (Government of India, 2023; Kayastha, Behera, & Patnaik, 2024).

4.4 Soil Health Assessment

ML classifies soil types and predicts nutrient deficiencies using sensor and lab data (Sahoo, Patnaik, & Behera, 2023). Applications in Uttar Pradesh and Odisha have enabled site-specific fertilization, improved yields while reducing chemical overuse (Mohanty, Panda, & Das, 2022).

Algorithms recommend crop rotation, organic amendments, and input optimization based on historical soil and climate data, enhancing sustainability (Behera, Sahoo, & Mahapatra, 2024).

4.5 Climate Risk Analysis

ML integrates historical climate and crop data to forecast extreme events like droughts, floods, and heatwaves (Sharma & Singh, 2022). ML-based advisory platforms provide Indian farmers with crop-specific risk alerts and adaptation strategies, reducing vulnerability in rainfed regions (Government of India, 2023).

5. Smart Farming and Automation

ML is central to smart farming in India, combining IoT, drones, and robotics to automate operations (Behera, Sahoo, & Mahapatra, 2024; Sahoo, Patnaik, & Behera, 2023).

5.1 Autonomous Machinery

Autonomous tractors and robotic harvesters navigate fields using ML-based GPS and sensor data, performing sowing, ploughing, and harvesting efficiently (Choudhary & Kumar, 2023). Input wastage



Fig 3: Automated Ploughing Machinery
Source: INOX Solar



and labour costs are reduced.

5.2 Drone-Based Crop Monitoring

Drones with multispectral cameras capture field images. ML analyses these for nutrient deficiencies, water stress, and pest infestation, enabling targeted interventions (Singh & Verma, 2022; Kayastha, Behera, & Patnaik, 2024).



Fig 4: Drone Based crop monitoring
Source: Equinox Drones

5.3 AI-Based Weed and Pest Management

ML-powered smart sprayers apply herbicides only to weeds. Robotic pest detection systems reduce pesticide use while improving efficiency (Times of India, 2024).

5.4 Predictive Maintenance

ML monitors farm machinery to predict failures, reducing downtime and repair costs (Sahoo, Patnaik, & Behera, 2023).

5.5 Decision Support Systems

ML integrates data from sensors, drones, and weather stations to provide actionable recommendations to farmers through mobile apps or dashboards (Behera, Sahoo, & Mahapatra, 2024; Jayalakshmi, Reddy, & Rao, 2022).

6. Government Initiatives and Digital Agriculture Ecosystem

6.1 National Digital Agriculture Mission

Promotes AI and ML adoption in agriculture for real-time crop monitoring, predictive advisory services, and digital extension (Government of India, 2023).

6.2 AgriStack Framework

AgriStack links farmer IDs, land records, crop data, and input usage. ML applications support precision subsidies, crop insurance, and credit facilitation (Ministry of Agriculture & Farmers' Welfare, 2022).



7. Socio-Economic Impacts of Machine Learning in Agriculture

7.1 Productivity Enhancement

ML-driven precision farming optimizes input use and minimizes losses, increasing yields (Kayastha, Behera, & Patnaik, 2024).

7.2 Cost Reduction

Targeted irrigation, nutrient management, and pest control reduce production costs, improving profitability (Behera, Sahoo, & Mahapatra, 2024).

7.3 Farmer Empowerment

ML-based advisories enable informed decision-making, reducing dependency on intermediaries (Sahoo, Patnaik, & Behera, 2023).

8. Challenges and Limitations

Barriers to adoption in India include:

- Limited high-quality agricultural data (Behera, Sahoo, & Mahapatra, 2024)
- Digital divide and connectivity issues (Government of India, 2023)
- High cost of AI-powered machinery and sensors (Kayastha, Behera, & Patnaik, 2024)
- Lack of technical skills among farmers (Sahoo, Patnaik, & Behera, 2023)
- Data privacy and governance concerns (Ministry of Agriculture & Farmers' Welfare, 2022)

Addressing these is essential for inclusive ML adoption.

9. Conclusion and Policy Recommendations

ML can revolutionize Indian agriculture through data-driven decision-making, automation, and predictive analytics. Recommendations:

- Expand rural digital infrastructure
- Provide AI/ML training for farmers
- Encourage public-private partnerships in agri-tech



- Develop clear data governance policies
- Promote affordable AI-based farming solutions

With strategic implementation, ML can enhance productivity, reduce environmental impact, and empower farmers

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Popular Article

Data Analytics and the Transformation of Indian Agriculture: Opportunities, Challenges, and a Case Study from Odisha

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ABSTRACT

The integration of data analytics, artificial intelligence (AI), remote sensing, and digital technologies is fundamentally transforming agricultural practices in India. Traditionally, Indian agriculture has been largely experience-driven and observation-based, making it vulnerable to climate variability, market fluctuations, and resource inefficiencies. This paper examines the role of data analytics in reshaping agricultural decision-making in India, focusing on precision farming, climate risk management, market intelligence, and digital advisory systems. It also analyzes key government initiatives such as AgriStack and the National Digital Agriculture Mission. A detailed case study of Odisha highlights the practical implementation of digital agriculture through e-Chasa digital crop surveys, AI-based geospatial collaboration, and the Ama Krushi advisory platform. The study concludes that while data analytics offers significant potential for enhancing productivity, sustainability, and resilience in Indian agriculture, its success depends on digital inclusion, farmer capacity building, and robust data governance frameworks.

Keywords: Data Analytics, Digital Agriculture, Precision Farming, AgriStack, Odisha, e-Chasa, Ama Krushi, Artificial Intelligence, Remote Sensing.

1. Introduction

Agriculture remains a critical sector in India, contributing to food security, rural livelihoods, and economic stability. However, the sector faces multiple challenges, including climate



change, fragmented landholdings, declining soil fertility, water scarcity, and unpredictable market conditions. Traditionally, farming decisions in India have relied on experiential knowledge rather than systematic data analysis. While this indigenous knowledge is valuable, it is increasingly inadequate in the face of modern agricultural complexities.

The emergence of data analytics marks a shift from intuition-based to evidence-based farming. Data analytics involves collecting, processing, and analyzing large volumes of agricultural data using statistical and computational techniques to generate actionable insights. The integration of technologies such as IoT sensors, satellite imagery, machine learning, and mobile applications has enabled farmers and policymakers to make more informed decisions regarding crop selection, irrigation, fertilization, pest control, and market strategies (Kayastha et al., 2024).

This paper explores how data analytics is transforming Indian agriculture and evaluates its socio-economic, environmental, and governance implications, with a specific focus on Odisha as a case study.

2. Literature Review

Recent studies indicate that digital technologies and data analytics are playing an increasingly important role in modern agriculture. Kayastha et al. (2024) highlight the role of precision farming in optimizing resource use and enhancing sustainability. Their research suggests that data-driven decision-making can significantly reduce input costs while improving crop productivity.

Similarly, Precision Development (2025) emphasizes the importance of digital advisory platforms such as Ama Krushi in bridging the information gap between agricultural experts and farmers. These platforms leverage data analytics to provide localized, real-time agronomic recommendations, improving farmer resilience and productivity.

Government initiatives such as AgriStack and the National Digital Agriculture Mission aim to create a unified digital ecosystem for agriculture in India, integrating farmer data, land records, and crop information to streamline service delivery and policymaking (Government of Odisha, 2025).

Studies on Odisha's digital agriculture initiatives, including e-Chasa and AI-based collaborations with AMNEX Infotechnologies, demonstrate the practical benefits of integrating data analytics into agricultural governance and extension services (New Indian Express, 2024; 2025).



3. Methodology

This research adopts a qualitative, secondary data-based approach. Data sources include:

- Peer-reviewed academic literature on digital agriculture and data analytics
- Government reports and policy documents related to AgriStack and digital agriculture
- News articles and reports on Odisha’s digital agriculture initiatives
- Case study analysis of Odisha’s e-Chasa and Ama Krushi platforms

The Odisha case study was selected due to its leadership in digital crop surveys and data-driven agricultural governance.

4. Role of Data Analytics in Indian Agriculture

4.1 Precision Agriculture and Resource Optimization

Precision agriculture involves using data analytics to apply inputs such as water, fertilizers, and pesticides more efficiently. IoT-based soil sensors provide real-time data on soil moisture and nutrient levels, enabling farmers to optimize irrigation and fertilization schedules. This reduces resource wastage and minimizes environmental degradation (Kayastha et al., 2024).



Fig-1: Precision Agriculture
Source: The data Scientist

For example, data-driven drip irrigation systems adjust water supply based on soil conditions and weather forecasts, improving water-use efficiency in drought-prone regions.

4.2 Crop Monitoring and Yield Prediction

Remote sensing technologies such as satellite imagery and drones allow continuous monitoring of crop health. Vegetation indices like NDVI help detect early signs of stress due to pests, diseases, or nutrient deficiencies.

Machine learning models trained on historical agricultural data can predict crop yields with greater accuracy, enabling farmers to take



Fig-2: Yield Prediction using Remote sensing
Source: Geopad Agriculture



preventive measures before significant losses occur.

4.3 Climate Risk Management

Given India's dependence on monsoon rainfall, climate variability poses a serious risk to agriculture. Data analytics integrates weather data with predictive models to generate localized climate advisories. Farmers can use this information to adjust planting schedules, select resilient crop varieties, and implement adaptive farming practices.

5. Market Intelligence and Digital Advisory Systems

5.1 Market Price Forecasting

Data analytics has improved market transparency by analyzing price trends across APMC markets and e-NAM platforms. Predictive models help farmers determine the best time to sell their produce, reducing dependency on intermediaries and preventing distress selling.

5.2 Digital Advisory Platforms

Platforms such as Ama Krushi, Meghdoot, and Kisan Suvidha use data analytics to deliver personalized agricultural advisories via SMS, voice calls, and mobile applications. These services make expert agricultural knowledge accessible to remote and marginalized farmers (Precision Development, 2025)



6. Government Initiatives: AgriStack and Digital Agriculture Mission

AgriStack is a national digital framework that integrates farmer identities, land records, crop data, and input usage into a centralized system. This facilitates targeted delivery of subsidies, credit, and insurance to farmers.

The National Digital Agriculture Mission aims to create a farmer-centric digital ecosystem that enhances transparency, reduces bureaucratic inefficiencies, and supports real-time agricultural monitoring (Government of Odisha, 2025).

7. Case Study: Digital Agriculture in Odisha

7.1 e-Chasa Digital Crop Survey

Odisha implemented the e-Chasa platform to conduct geo-referenced digital crop surveys covering over three crore agricultural plots. Farmers and officials recorded crop data using mobile applications, improving accuracy and reducing manual errors.



This digital database supports crop insurance assessments, disaster management planning, and agricultural policy formulation (New Indian Express, 2024).

7.2 AI and Geospatial Collaboration with AMNEX

The Odisha government partnered with AMNEX Infotechnologies to integrate AI and geospatial analytics into agricultural planning. This collaboration enables real-time monitoring of cropping patterns, soil health, and water availability, supporting predictive analytics and efficient resource allocation (New Indian Express, 2025).

7.3 Ama Krushi (Krushi Samruddhi Helpline)

Ama Krushi provides data-driven advisory services to nearly 7.9 million farmers in Odisha. The platform delivers personalized recommendations via phone calls, SMS, and community outreach programs. Notably, one-third of its users are women farmers, highlighting its role in promoting gender inclusivity (Precision Development, 2025).

8. Socio-Economic Impacts of Data Analytics in Agriculture

8.1 Productivity and Cost Reduction

Data analytics enables precise input application, reducing production costs and increasing yields. Studies suggest that precision farming can reduce input costs by 10–20% while boosting productivity by 15–25%.

8.2 Farmer Empowerment

Access to real-time data and predictive insights empowers farmers to make informed decisions, reducing financial risks associated with crop failures and market volatility.

8.3 Gender Inclusivity

Voice-based digital advisory systems have improved access to agricultural information for women and less-literate farmers, promoting inclusive agricultural development.

9. Challenges and Limitations

Despite its potential, data-driven agriculture faces several barriers:

- Digital divide and limited smartphone access
- Poor internet connectivity in rural areas
- Lack of technical training for farmers
- Data privacy and governance concerns
- High cost of digital agricultural technologies

Addressing these challenges is essential for equitable digital transformation.



10. Conclusion and Policy Recommendations

Data analytics is reshaping Indian agriculture by enabling evidence-based decision-making, improving productivity, and enhancing resilience to climate risks. Odisha's digital agriculture initiatives demonstrate the practical benefits of integrating data analytics into governance and extension services.

To maximize impact, policymakers should:

- Expand rural digital infrastructure
- Promote digital literacy among farmers
- Encourage public-private partnerships
- Implement clear data governance policies
- Ensure inclusive digital platform design

With strategic investment and inclusive policies, data analytics can drive sustainable and resilient agricultural growth in India.

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Popular Article

AI and Digital Tools Are Transforming Small-Scale Agriculture in India

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ABSTRACT

At the moment, even modest agricultural producers equipped with simple mobile phones are utilizing AI to determine optimal times for planting, irrigation, and selling their crops. Digital farming is not a future concept; it is currently a reality. Digital agriculture is a term that describes the application of digital technologies and innovations in agricultural production systems, value chains, and food systems. . It encompasses various concepts, such as smart farming and precision agriculture, among others. These concepts refer to using data, sensors, machines, drones, and satellites to collect and analyze information on location, weather behavior, phytosanitary status, consumption, energy use, prices, and economic information. As agriculture enters a new digital era, even small farms are growing more resilient, sophisticated, and efficient. Climate change, rising production costs, and unpredictable market circumstances are making it more difficult for small-scale farmers to sustain their livelihoods. However, recent breakthroughs in artificial intelligence (AI) and digital technologies—such as mobile advisory apps, drones, sensors, and satellite-based monitoring—are revealing new opportunities for farmers across the world. These advancements enable them to make data-driven decisions about crop management, pest control, irrigation, and marketing, resulting in increased productivity and income. A simple smartphone can now access what formerly required costly equipment and specialized knowledge. AI and digital tools are transforming agriculture from a labour-intensive activity into a technology-enabled profession that supports rural economies and food security by bridging the information gap and providing farmers with fast and accurate insights. But the use of AI in agriculture also has its challenges. Disparities in access to technology, information, and skills— especially in developing nations—present enormous barriers to its



large-scale adoption. Moreover, the convergence of AI with other technologies, including biotechnology, precision agriculture, and robotics, and the assurance of its scalability and long-term sustainability are important areas for additional research. Bridging these disparities will be essential in unlocking the full potential of AI in ensuring global food security and sustainable agriculture.

Why Digital Tools Matter for Small Farms

1. Real-Time Farm Intelligence: The New Extension Worker

AI-powered advisories are rapidly transforming how farmers receive information. Platforms such as Kisan Sarathi, Krishi Network, Plantix, CropIn, Satyukt, and DeHaat are delivering location-specific, crop-specific recommendations directly to farmers' phones.

What AI now enables:

- Hyperlocal (1–5 km) weather alerts
- AI-based pest/disease diagnosis through simple photos
- Input advisories tailored to soil health reports
- Predictive warnings on nutrient deficiencies

A NITI Aayog assessment in 2024 showed that digital advisory users improved yields by 15–25% and reduced input costs by 8–22%.

2. Growing More with Less: Efficiency Becomes the Norm

With water scarcity, soil degradation, and climate stress rising, precision farming is no longer optional. According to market projections, precision farming adoption is expected to grow from 12% in 2020 to nearly 35% by 2025 among progressive farming clusters. Smartphone-based agriculture apps now reach 58–62% of Indian farmers, showing a major behavioural shift from traditional experience-based decisions to data-driven choices.

Efficiency outcomes:

- 18–30% reduction in fertilizers through site-specific nutrient management
- 20–40% savings in pesticides due to targeted spraying
- 12–20% reduction in irrigation water through AI-linked micro-irrigation scheduling

States like Telangana, Maharashtra, and Karnataka are already piloting precision farming zones to accelerate adoption.

3. AI Tackles Post-Harvest Losses:

India loses 5–16% of fruits and vegetables post-harvest (ICAR-CIPHET), largely due to Poor storage, Inadequate transport, Limited real-time market intelligence



Digital value-chain tools, including AI-based shelf-life prediction, smart cold-chain logistics, and real-time mandi price dashboards, are helping reduce losses considerably.

For example:

- AI-enabled cold storage optimisation reduces spoilage by 8–12%.
- Digital logistics matching cuts transport time by 15–20%.

This is crucial for states like Telangana, where horticultural produce is rapidly increasing and requires efficient storage and market linkage systems.

4. Better Price Discovery and Market Access

Farmers typically receive only 20–60% of the final consumer rupee due to weak bargaining power and fragmented markets (CACP).

Digital platforms—including e-NAM, DeHaat, Ninjacart, and various FPO-led e-commerce models help farmers to Access more buyers, Compare prices in real time, Sell produce beyond local mandis. Studies indicate that farmers using digital market platforms earn 10–25% higher prices than those selling through traditional intermediaries.

How AI is Transforming Key Farming Functions

AI-Based Pest and Disease Diagnosis

Apps like Plantix now offer over 90% accuracy in diagnosing crop diseases using a single image. Millions of farmers rely on these apps to avoid misdiagnosis, reduce pesticide misuse, and treat issues early.

Hyperlocal AI Weather Prediction

Traditional forecasts are too general. AI-driven micro-weather forecasting enables optimised sowing windows, irrigation scheduling, harvesting and spraying guidance, extreme weather alerts. This is particularly important as India experiences more frequent heatwaves, unseasonal rains, and dry spells.

Drone Services for Small Farmers

With government subsidies and FPO-led drone hiring centres, drones are entering small farms as shared assets and the drones can do precision spraying (reduces chemical use by 20–30%), crop health mapping, acreage estimation for insurance, monitoring plant growth. Custom Hiring Centres (CHCs) ensure affordability, with spraying services costing roughly ₹500–700 per acre.



AI in Water Management

India uses 80% of its available freshwater for agriculture—an unsustainable figure. AI-assisted micro-irrigation systems have demonstrated that 39–55% reduction in water use, 33–41% increase in yields. Sensors track soil moisture, crop evapotranspiration, and rainfall to guide irrigation intervals and quantities.

Impact on Rural Livelihoods

1. Higher, More Stable Incomes: Digital tools + precision inputs + market insights = consistently higher profits. Field studies show that farmers using AI-assisted decision systems achieve 50–110% higher profitability, especially in horticulture, cotton, and paddy.

2. Youth and Women Take the Lead: Digital agriculture reduces physical drudgery and opens new jobs as Drone pilots, AI field technicians, Data collectors, e-Commerce coordinators for FPOs. Young rural graduates and women's groups increasingly run these micro-enterprises.

3. Strengthened Farmer Producer Organisations: AI tools help FPOs manage Aggregation planning, Storage decisions, Demand forecasting Price negotiation with buyers. FPOs using digital platforms report 15–30% higher turnover.

Roadblocks to India's Digital Agriculture Transition

Despite rapid progress, several constraints remain:

1. Limited Digital Literacy: Many farmers struggle with App navigation, Language barriers, Misinterpretation of AI advisories

2. Patchy Internet Connectivity: Nearly 25% of Indian villages still have inconsistent mobile broadband coverage.

3. High Cost of Devices and Sensors: Smartphones have become more affordable, but IoT devices, weather stations, and drones remain costly without subsidies.

4. Weak Last-Mile Extension Systems: Traditional extension staff often lacks digital training, limiting technology dissemination.

Policy Pathways for Scaling Digital Agriculture

To accelerate adoption, India needs a strong enabling ecosystem:

1. Strengthen Digital Extension: Village-level AI Kiosks, run by trained rural youth, can support farmers with Diagnostic services, Digital soil testing, Weather-based advisories, Drone bookings



2. Subsidise Key Digital Infrastructure: Government support can reduce costs of IoT sensors, Drones, Micro-weather stations, Low-cost soil testing devices.

3. Empower FPOs as Digital Hubs: FPOs should receive AI-based price forecasting tools, E-commerce training, Storage planning algorithms.

4. Build AI-Ready Rural Infrastructure: This includes Robust rural broadband, Cold-chain networks, Digital payment systems, Farmer digital IDs (e.g., UPAg portal)

Conclusion: India's Future Harvests Will Be Data-Driven

AI is not a silver bullet, but a powerful companion to farmers. When combined with strong institutions, modern infrastructure, and supportive policies, AI can drive a new farmer-centric revolution one that is:

- Inclusive
- Climate-resilient
- Market-ready
- Economically empowering

India's next agricultural revolution may not start in a laboratory or a field—but in the vast, invisible networks of data and algorithms quietly empowering farmers every day.

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Popular Article

Digital Soil Mapping

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INTRODUCTION

SOIL (Soul of Infinite Life) is the great life-supporting system for human beings from the beginning of civilisation. A detailed study of soil is required for command area development, sustainable agriculture, watershed management, soil conservation, reclamation of degraded lands, etc. So, mapping (Conventional soil mapping) of soils through field investigation and laboratory studies provides a detailed description, identification and delineation of different kinds of soils that are spatially available.

By combining this traditional conventional soil mapping (field investigation and laboratory) with modern computer technologies like Geographic Information System (GIS), remote sensing, Machine Learning (ML) and Deep Learning (DL), we can produce high-resolution spatially interpolated soil inference systems that support decision makers, research workers, farmers, etc., called Digital Soil Mapping (DSM).

DSM or 'predictive soil mapping' or 'pedometric mapping' is the method of creating and populating spatial soil information by means of field and laboratory observations, geo-statistical models, machine learning and deep learning techniques. It produces detailed information about varying soil properties such as pH, soil moisture, Soil Organic carbon (SOC), Electrical Conductivity (EC), Cation Exchange Capacity (CEC) and nutrient details such as Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S) etc. with the help of spatially available environmental covariates like Digital Elevation Model (DEM), indices derived from satellite data and ancillary data (parent



material). DSM is an advanced technology for mapping soil properties or soil classes, secondary soil properties and soil functions or threats.

Principle of Digital Soil Mapping (DSM)

The underground principle of DSM is referred to as the ‘SCORPAN’ principle. Where SCORPAN is the modified form of soil forming factors ‘clorpt’.

$$S = f(S, C, O, R, P, A, N) + e$$

Where, S: Soil properties or prior knowledge or other properties of soil at a point

f: machine learning and deep learning models

C: climate and its models

O: organism, vegetation, fauna or human activities

R: topography, relief, landscape-related details

P: parent material and other related information

A: age and time factor

N: space, relative spatial information

e: auto-correlated random spatial variation

Thus, the equation states that soil(S) at an unsampled site is the random function of SCORPAN factors.

Environmental Covariates

Environmental Covariates are measurable environmental variables that represent the soil-forming factors (SCORPAN) and help explain the spatial variation of soil properties across a landscape. They are spatially continuous data layers derived from remote sensing, DEMs, climate models, geology, and land use maps, and are used as predictors in machine learning and geostatistical models for DSM. A list of available environmental covariates is given in Table 1.

Characteristics of Environmental Covariates

- Continuous spatial features
- Quantifiable and reproducible
- Derived from physically meaningful processes
- Scientifically linked to soil formation
- High-resolution and up to date
- Available over large regions
- Machine-learning friendly (numeric, raster, standardised)



Table 1. Environmental covariates

Parameter	Description
Organism (O)	
Satellite band data	Satellite band data represents reflectance captured in specific wavelength regions (visible, NIR, SWIR, thermal) by remote sensing sensors, highlighting unique surface characteristics. These raw spectral values act as key inputs in DSM for deriving indices and predicting soil properties.
Land Use & Land Cover	Land Use & Land Cover represents natural and human-made surface features, differentiating categories like forests, agriculture, water bodies, and urban areas.
Normalised Difference Vegetative Index (NDVI)	NDVI is a vegetation index that measures plant greenness and biomass by comparing the reflectance difference between the NIR and Red spectral bands. $NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$
Relief (R)	
Closed Depressions	Closed Depressions map low-lying DEM (Digital Elevation Model) areas where water accumulates due to the absence of natural outlets.
Convergence Index (CI)	CI quantifies terrain convergence or divergence in a DEM, indicating zones where water and materials accumulate (positive CI) or disperse (negative CI).
Elevation	Elevation is the vertical height of the terrain surface derived from DEMs using remote sensing methods like LiDAR, radar, or satellite imagery.
LS- Factor	LS-Factor combines slope length (L) and slope steepness (S) from the RUSLE model to estimate topographic influence on soil erosion.
Slope	Slope represents the rate of terrain inclination derived from DEMs, influencing runoff, erosion, drainage, and soil formation processes.
Hill shade	Hillshade simulates illumination on a DEM surface, highlighting terrain shadows and sunlight effects for visualising landform variations.
Aspect	Aspect indicates the compass direction a slope faces, affecting sunlight exposure, wind flow, and microclimatic conditions.
Curvature	Curvature describes whether terrain is convex, concave, or flat, helping interpret water flow, erosion risk, and deposition zones.
Climate (C)	



Mean Annual Rainfall	Total average precipitation received at a location over a year, calculated as the sum of monthly precipitation values across 12 months.
Mean Annual Temperature	Average temperature of a location over an entire year, typically calculated as the mean of monthly temperatures.
Parent material (P)	
Carbonate Difference Ratio	Particularly effective for identifying calcareous soils and determining the soil's buffering capacity, which influences nutrient availability and soil health. $\rho_{Red} - \rho_{Green} / \rho_{Red} + \rho_{Green}$
Clay Difference Ratio	Identify the degree of clay buildup or depletion, which can indicate soil formation processes like clay translocation, weathering intensity, or horizon development. $\rho_{SWIR(a)} - \rho_{SWIR(b)} / \rho_{SWIR(a)} + \rho_{SWIR(b)}$
Geomorphology	Information about the evolution of the Earth's surface during the geological period.
Iron Difference Ratio	Assess the difference in iron concentrations within soils or rocks. $\rho_{Red} - \rho_{SWIR(a)} / \rho_{Red} + \rho_{SWIR(b)}$
Lithology	Lithology describes the physical and chemical characteristics of rocks—such as mineral composition, texture, and structure—that influence soil parent material.
Physiography	Physiography characterises landscape features and terrain patterns shaped by geological, hydrological, and geomorphic processes that determine soil distribution.

DSM methods and techniques

DSM is carried out mainly in three methods, namely regression model, geostatistical techniques and machine learning. Whereas other methods involved deep learning, hybrid models, ensemble techniques, cloud-based DSM, Bayesian modelling, etc.

a. Regression models

Regression models quantify the relationship between soil properties (dependent variables) and environmental covariates (independent variables). When the relationship is linear, models like Linear Regression and Multiple Linear Regression are applied for spatial prediction. Advanced forms such as Geographically Weighted Regression (GWR) and non-linear regressions capture spatially varying or complex soil–environment interactions.



b. Geostatistical Techniques

Geostatistics relies on spatial autocorrelation, quantified through variogram models, to estimate soil variability. Interpolation methods such as Kriging, Co-kriging, and Regression Kriging predict soil properties at unsampled locations. These techniques also provide uncertainty estimation, making them powerful for spatially explicit soil modelling.

c. Machine Learning

Machine Learning models (like Random Forest, Support Vector Machines, Neural Networks) learn non-linear relationships from large spatial datasets. They integrate diverse inputs such as remote sensing, terrain attributes, climate data, and vegetation indices for robust soil prediction. Modern ML approaches, including Deep Learning, Ensemble Modelling, and Cloud Computing workflows, greatly enhance accuracy in DSM.



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Popular Article

Solar Panel Waste Management: Strategic Opportunities, Critical Challenges and Policy Frameworks

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ABSTRACT

Solar photovoltaic (PV) systems are expanding rapidly as a clean alternative to fossil fuels, but increasing end-of-life solar panels are creating a growing waste challenge. Without proper management, discarded panels can release hazardous substances such as lead and cadmium, while also wasting valuable materials like silicon, aluminium and glass. Effective waste management is therefore essential to preserve the environmental benefits of solar power. This article discusses the major challenges in recycling and disposal, including complex material separation, high processing costs and insufficient regulatory frameworks. It also highlights the potential of emerging recycling technologies and circular economy strategies such as improved design, reuse and material recovery to enhance sustainability throughout the solar lifecycle. Strong policies, expanded recycling infrastructure and increased producer responsibility will be critical to ensure responsible solar panel waste management in the future.

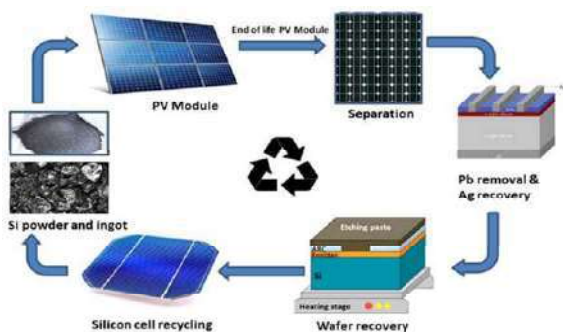
Key Words: *Circular Economy, Recycling Technologies, Solar Photovoltaic Waste, Sustainable Energy Systems*

Introduction

Solar photovoltaic (PV) technology has emerged as one of the fastest-growing renewable energy solutions in the 21st century, widely adopted across residential, commercial, industrial and agricultural sectors due to its ability to generate electricity without fuel combustion, air



pollution, or greenhouse gas emissions. However, solar panels have a limited operational lifespan, typically 25 to 30 years, leading to a rising volume of decommissioned PV modules as global installations continue to expand. The International Renewable Energy Agency (IRENA) estimates that global solar panel waste could exceed 78 million metric tons by 2050, making effective end-of-life management essential. Improper disposal of PV modules can result in environmental contamination from hazardous substances like lead, cadmium and



chemical polymers, while poor recovery also leads to the loss of valuable materials such as silicon, aluminum, copper and silver, causing unnecessary economic losses. Therefore, ensuring responsible handling, recycling and resource recovery is critical to maintaining the long-term sustainability of the solar industry, as the future success of renewable energy depends on both clean power generation and environmentally responsible waste management.

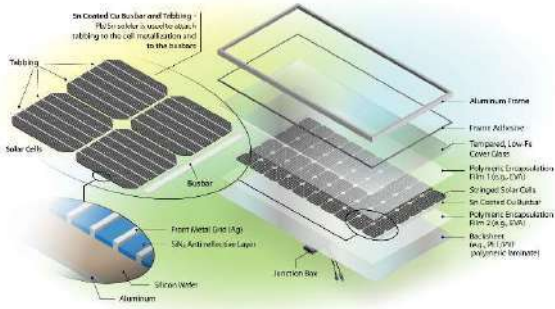
Composition and Sources of Solar Panel Waste

A solar panel is made of several strong, laminated layers designed to last 25-30 years under sunlight, heat and changing weather (IRENA, 2020). The main materials used in a typical crystalline silicon panel are shown in Table 1.

Table 1: Material Composition of Solar Panel

Component	Approx. %	Purpose
Glass	75-80%	Provides protection
Aluminum Frame	10%	Structural support
Silicon Cells	3-5%	Convert sunlight to electricity
Encapsulants & Polymers	5-7%	Protect cells from heat and moisture
Metals (Silver, Copper, etc.)	<1% each	Conduct electrical functions

Solar panel waste mainly comes from panels that reach the end of their 25-30 year life. Waste also occurs due to early failure, weather damage, transportation issues and upgrades to



newer technology (PV Cycle, 2021). Recycling is difficult because the layers are strongly bonded, making separation and recovery expensive and time-intensive.

Challenges in Solar Panel Waste Management

Solar panel waste management faces technical, financial and policy-related challenges that complicate large-scale recycling and sustainable disposal practices.

Technically, the layered structure of solar panels makes it difficult to mechanically separate materials without breaking or degrading components. Traditional recycling processes often recover only glass and aluminum, while high-value components like silicon and silver may be lost. Some panels, especially thin-film varieties, contain trace levels of toxic metals such as cadmium and lead, requiring specialized handling and disposal systems.

Economically, recycling remains costly due to transportation, labour and processing requirements. The market price of recovered materials is often insufficient to cover recycling expenses, discouraging investment and leading to underdeveloped recycling infrastructure in many regions. Transporting large volumes of solar waste to distant recycling facilities adds further cost and emissions.

Regulatory challenges also exist. While regions such as the European Union have implemented strong policy measures requiring manufacturers to manage panel disposal, most countries still lack dedicated laws governing PV waste. Limited public awareness further contributes to improper disposal practices, as consumers and installers may not be informed about environmentally responsible recycling methods.

Current and Emerging Recycling Technologies

Recycling technologies for solar panels continue to evolve, with research focusing on improving material recovery rates while reducing environmental impacts.

Traditional mechanical recycling involves shredding or milling panels to separate their components based on physical properties. Although cost-effective and widely used, this



method primarily recovers glass and aluminium, leaving much of the silicon and metal content underutilized.

Thermal and chemical processing techniques have been developed to improve material recovery. These methods use controlled heat or chemical agents to break down encapsulants and separate valuable internal layers. Such processes recover higher-purity silicon and precious metals but are energy-intensive and require specialized equipment.

Advanced research is exploring more innovative solutions, including low-heat chemical decomposition, solvent-based delamination and recycling-friendly panel designs. Some modern manufacturing approaches now focus on creating PV modules that are easier to disassemble at end-of-life, directly supporting the transition toward a more circular production system.

Regulatory Frameworks and Global Policy Direction

Among global regions, the European Union has taken the most structured approach, incorporating solar panels under the Waste Electrical and Electronic Equipment (WEEE) Directive. This legislation requires producers to take responsibility for the collection and recycling of PV waste, with targets aiming to recover at least 80% of panel material by weight.

In contrast, many countries in Asia, Africa and the Americas lack standardized policies for solar panel waste. While recycling initiatives are emerging, gaps in enforcement, infrastructure and funding remain significant barriers. International renewable energy organizations encourage the development of harmonized global standards that prioritize producer responsibility, lifecycle management and environmental protection.

Role of the Circular Economy in Sustainable Solar Development

The circular economy concept aims to maximize resource efficiency by designing products for longevity, reusability and recyclability. In the solar sector, this means designing modules that use fewer hazardous materials, implementing manufacturing processes that enable easier component separation and recovering valuable elements after use to reduce demand for newly mined materials.

Extending solar panel life through robust maintenance, using refurbished components and redirecting recovered metals and silicon back into manufacturing strengthens material security and reduces economic losses. A circular approach not only minimizes environmental burden but also reinforces industrial competitiveness and long-term sustainability.



Recommendations for Effective Solar Panel Waste Management

Addressing the growing challenge of PV waste requires coordinated action across the industry. Governments should establish clear policies governing the end-of-life responsibility of manufacturers and importers. Investments in recycling infrastructure are essential, especially in regions with rapidly increasing solar deployment. Research institutions and industries should collaborate to develop cost-effective, high-efficiency recycling technologies. Public education campaigns can ensure that installers, users and industries understand environmentally sound disposal procedures. Finally, circular production and design principles should be incorporated at the manufacturing stage to ensure that panels can be easily and economically recycled.

Conclusion

Solar photovoltaic energy remains central to the global transition toward a low-carbon future. However, the rapid expansion of solar installations makes post-consumer waste management an equally important aspect of technology deployment. Without advanced recycling strategies and strong policy frameworks, solar panels could shift from being a clean energy solution to a growing source of environmental burden.

Through thoughtful regulation, technological innovation, recycling infrastructure development and adherence to circular economy principles, the solar industry can ensure that photovoltaics remain sustainable across their entire life cycle. Properly managed solar waste represents not only an environmental responsibility but also an economic opportunity to reclaim valuable industrial materials and reinforce the future growth of renewable energy worldwide

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Impact of Climate Change on Plant– Soil–Water Interactions

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INTRODUCTION

Climate change is now recognized as one of the most significant environmental threats of the 21st century and its influence is deeply felt across the interconnected relationships among plants, soils and water. Climatic change is altering species distributions and simultaneously impacting interactions among organisms. Plant-soil-water interactions are under tremendous strain due to rising temperatures, changing rainfall patterns and an increase in extreme weather events. This is upsetting crop growth, long-term soil fertility and ecosystem balance. Plants depend on soil for essential nutrients and water, while soil health is shaped by plant roots, organic residues and microbial activity. Water, in turn, acts as the vital link that enables nutrient transport, root development and biochemical processes in the soil. Climate change is disrupting this sensitive balance by changing temperature, water availability and atmospheric conditions. As these disturbances grow more severe, it becomes ever more important to understand how plant soil water systems react to environmental stress. This knowledge is essential for creating adaptive measures that protect food production, enhance ecosystem resilience and encourage the sustainable use of natural resources.

Climate Change and Soil Water Deficits

Climate change significantly contributes to soil water deficits by altering the balance between rainfall, evaporation and plant water demand. Rising temperatures increase evaporation from the soil surface and transpiration from plant leaves, leading to faster depletion of moisture stored in the root zone. At the same time, shifts in rainfall patterns, such as delayed monsoons, shorter rainy seasons and more common droughts, decrease the natural recharging of soil moisture. Although heavy rainfall events are intense, they often lead to runoff instead of water soaking into the ground, leaving soils dry even during periods of heavy Precipitation. Consequently, crops face extended water shortages, root development is limited and soil microbial activity decreases. Over time, ongoing soil moisture shortages damage soil structure, lower nutrient availability and reduce the overall productivity of both agricultural and natural



ecosystems. Understanding and addressing these shortages is crucial for adapting farming methods and ensuring sustainable use of water and soil resources in a changing climate.

Climate Variables Affecting Plant–Soil–Water Dynamics

Rising Temperature

When temperatures rise, the soil dries out faster and plants lose water more quickly. The extra heat shortens the time crops have to grow, makes photosynthesis less effective and puts stress on the tiny organisms in the soil that help it stay healthy. All of this adds up to smaller harvests and shifts in how the soil works, including how it breaks down organic matter.

Changing Rainfall Patterns

Climate change is reshaping rainfall patterns across the world. Monsoons arrive late, dry spells drag on longer and sudden bursts of heavy rain leave little time for water to soak into the soil, causing more runoff. When droughts hit, crops struggle with limited water and when rain comes too hard and fast, it often washes away soil and nutrients. Together, these shifts make farming more difficult and threaten the health of the land.

Elevated CO₂ Levels

Rising levels of carbon dioxide in the atmosphere can give plants a boost, helping them photosynthesize more efficiently and use water more wisely. But this benefit only goes so far it often depends on whether the soil has enough nutrients and whether temperatures aren't too extreme. As plants grow larger and produce more biomass, they also need extra water and nutrients, which puts added pressure on the soil.

Extreme Weather Events

Climate change is causing floods, heatwaves, droughts, and storms to happen more often. These extreme events upset the balance of the soil, weaken plant roots, and change the way water flows through the land. Floods leave the ground soaked and deprived of oxygen, while droughts strip it of moisture, leaving it dry and fragile.

Soil Moisture Dynamics

Climate change is deeply affecting the way soil's function. Shifts in temperature and rainfall disrupt the balance of moisture, nutrients, and biological activity in the ground. Hotter conditions and unpredictable rains dry out the soil faster, making it harder for plants to grow, for nutrients to move and for microbes to thrive. Heavy downpours worsen erosion, washing away fertile topsoil and carrying sediments into rivers and reservoirs, which reduces both soil productivity and water quality. Meanwhile, nutrient cycling becomes unstable drought slows the breakdown of organic matter, heat speeds up mineralization and causes nitrogen losses, and excessive rain flushes nutrients out of the root zone. The tiny organisms that drive these processes also suffer under stress, leading to less diversity, weaker activity, and declining soil health overall.

Decreased Vegetation Development and Crop Output

Climate change imposes multiple stresses on plants, leading to reduced growth, weakened physiological functions and lower yields. Water scarcity, heat stress and nutrient deficiencies directly affect photosynthesis, flowering and fruit formation, with critical stages such as germination and grain filling being particularly vulnerable. Root crown development is also significantly altered, as drought encourages deeper rooting while waterlogging restricts root growth due to oxygen deficiency; under extreme stress, root strength declines, limiting the plant's ability to absorb water and nutrients. Although elevated CO₂ can temporarily enhance



water use efficiency, this benefit is offset by high temperatures and erratic rainfall, which force plants to close their stomata and reduce carbon intake, ultimately slowing growth. Moreover, warmer climates and increased humidity promote the proliferation of pests and diseases and plants already weakened by climate induced stress become more susceptible to infections, leading to greater crop losses and higher reliance on chemical control measures.

The impact on water resources

Climate change significantly affects water resources by reducing overall water availability, increasing competition among sectors and altering natural hydrological cycles. Declining rainfall and rising evaporation rates limit groundwater recharge and surface water supplies, reducing irrigation potential and intensifying pressure on agriculture. At the same time, domestic, industrial and agricultural demands grow, leading to increased competition for scarce water resources and making sustainable water management more challenging. Additionally, shifts in rainfall patterns, runoff, infiltration and evapotranspiration disrupt watershed processes, affecting soil water storage, reservoir levels, streamflow and groundwater recharge, ultimately threatening long-term water security for both ecosystems and human use.

Consequences for Ecosystems and Agriculture

Decrease in agricultural production caused by high temperatures and lack of water

1. Loss of soil nutrients and organic content
2. Greater likelihood of desertification and land deterioration
3. Decrease in biodiversity, including helpful soil organisms
4. Interference with natural ecosystem functions and equilibrium

Adaptation and Mitigation Strategies

To cope with the challenges of climate change, farmers are turning to climate-smart practices that make agriculture more resilient now a days. Growing crop varieties that can withstand heat and drought, along with using stress-resistant genotypes and diverse cropping systems, helps reduce risks to plants, soil, and water. Techniques like mulching, contour farming, terracing, vegetative barriers and cover crops protect the soil by holding moisture, cutting down erosion, and improving water infiltration. Modern irrigation methods—such as drip and sprinkler systems combined with careful scheduling based on soil and crop needs, ensure water is used efficiently without waste. Adding compost, manure, biochar, practicing reduced tillage, and adopting agroforestry enriches the soil with organic carbon, which strengthens its structure, boosts nutrient supply, and improves water retention for long-term health. On top of that, advanced tools like geo informatic system (GIS), remote sensing, and models such as RUSLE, Water erosion prediction project (WEPP) and Soil & Water Assessment Tool (SWAT) allow farmers and planners to assess erosion risks, predict climate impacts and design sustainable land and water management strategies.

Conclusion

Climate change is significantly altering the interactions between plants, soil and water, influencing factors such as soil moisture, nutrient cycles, plant growth and water availability. These changes pose risks to agricultural output, soil quality and ecosystem stability. Nevertheless, by implementing well-informed management approaches, utilizing advanced technologies and adopting climate-adaptive practices, it is feasible to lessen these effects and develop more sustainable systems. Enhancing the connections between plants, soil and water



is crucial for maintaining food security and ecological resilience in the face of a quickly changing climate.

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India's Blue Revolution: Transforming Fisheries and Aquaculture for Sustainable Growth

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INTRODUCTION

Fisheries and aquaculture play a pivotal role in India's economy, serving as crucial sources of food, nutrition, employment, and income. The sector directly employs around 14.5 million fishers and fish farmers, while an additional 13.5 million individuals are engaged in allied activities such as processing, feed production, and transportation, highlighting its extensive socioeconomic impact. In 2024–25, India's fish production reached a remarkable 195 lakh tonnes, reflecting a 104% increase compared to 2013–14, driven largely by the successful implementation of the Blue Revolution, which significantly expanded inland fisheries. The government's continued commitment is evident through initiatives such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY), with an allocation of ₹2,352 crore for 2024–25, and the recently launched Pradhan Mantri Matsya Kisan Samridhi Sah Yojana (PMMKSSY), with an investment of ₹6,000 crore, aimed at strengthening the fisheries value chain, enhancing livelihoods, and promoting sustainable development. These initiatives underscore the strategic importance of fisheries in ensuring food security, economic empowerment, and inclusive growth across the country (Anon, 2025; Sandeep, 2025).

Employment Generation

Aquaculture continues to play a crucial role in generating employment, particularly in rural and coastal regions where alternative livelihood options are limited. As a core component of the fisheries sector, it contributes substantially to the national economy by directly and indirectly providing jobs to over 14.5 million people, while an additional 13.5 million individuals are engaged in allied activities such as processing, feed production, and transportation, highlighting its extensive socioeconomic impact. When associated industries such as logistics and marketing are included, the total employment impact is estimated to reach nearly 28 million individuals. This diverse workforce comprising fish farmers, fishermen, hatchery workers, feed producers, processors, transporters, and marketers illustrates the sector's wide socioeconomic reach. The rapid expansion of aquaculture has also stimulated the development of ancillary industries, including cold chain logistics, input distribution, and processing units, thereby improving rural incomes and local economies. By fostering entrepreneurship, skill development, and women's participation, fisheries and aquaculture have



created a multiplier effect that strengthens community resilience and supports sustainable rural development.

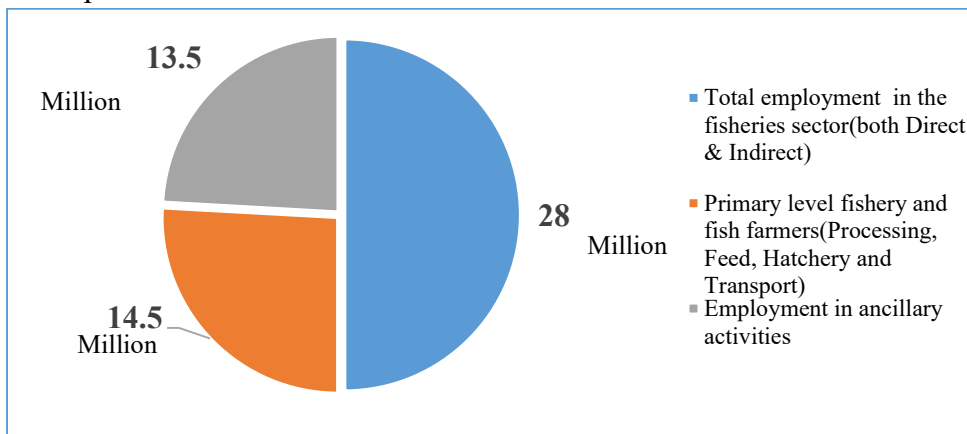


Fig.1. Overview of Employment in Indian Fisheries and Aquaculture

Export Performance and Global Integration

India’s fisheries and aquaculture sector plays a significant role in boosting export earnings and strengthening the country’s global trade presence. During the financial year 2023–24, India achieved a record seafood export of 17.82 lakh tonnes, earning approximately ₹60,524 crore. Although export volume rose by 2.67%, the overall export value experienced a slight decline due to international market fluctuations and changing global demand patterns. Frozen shrimp remained the leading export commodity, with the United States and China continuing as major import destinations. Efforts to diversify export markets, promote value-added seafood, and strengthen traceability and quality certification systems are helping India maintain its competitiveness in the global seafood trade (FAO, 2025; Anon, 2025a).

Blue Revolution: A Foundation for Sustainable Growth

The Blue Revolution, or global intensification of fisheries and aquaculture has its roots in countries like China, which accounts for a major share of global aquaculture production. In India, structured government support for fisheries expansion began with the establishment of Fish Farmers Development Agencies (FFDAs) in the early 1970s (1972–74 pilot projects). The Blue Revolution Program, as a national umbrella scheme for fisheries development, was formally launched during the 7th Five-Year Plan (1985–1990). Among Indian states, Kerala established its first FFDA in Palakkad district on 9 October 1976, marking an important milestone in institutional fisheries development. The program’s core objectives include: The Blue Revolution emphasizes enhancing fish production and productivity through sustainable utilization of inland and marine resources.

- Enhancing production and productivity of inland and marine fisheries;
- Promoting environmentally responsible aquaculture and ensuring biosecurity;
- Strengthening food and nutritional security;
- Doubling fishers’ and fish farmers’ incomes; and
- Encouraging inclusive growth among marginalized fishing communities.

Centrally Sponsored Scheme: Blue Revolution

The Blue Revolution marks a major policy initiative by the Government of India aimed at transforming and modernizing the fisheries sector through an integrated and sustainable



approach. To achieve this goal, the Ministry of Agriculture and Farmers Welfare, under the Department of Animal Husbandry, Dairying and Fisheries, restructured and consolidated all existing schemes into a single, comprehensive program titled “*Blue Revolution: Integrated Development and Management of Fisheries.*” This restructured umbrella scheme ensures focused development, efficient management, and optimal utilization of fisheries resources across the country. It encompasses a wide range of activities including inland fisheries, aquaculture, marine fisheries (with emphasis on deep-sea fishing), mariculture, and various initiatives undertaken by the National Fisheries Development Board (NFDB). The Centrally Sponsored Scheme on *Blue Revolution: Integrated Development and Management of Fisheries* was launched with a total Central outlay of ₹3,000 crore for a period of five years. It is designed to promote holistic growth of the fisheries sector through coordinated efforts across multiple components, which include:

- **National Fisheries Development Board (NFDB) and its Activities** – Supporting development programs, infrastructure creation, and technology dissemination.
- **Development of Inland Fisheries and Aquaculture** – Enhancing productivity and sustainability in inland water bodies and aquaculture systems.
- **Development of Marine Fisheries, Infrastructure, and Post-Harvest Operations** – Promoting deep-sea fishing, marine resource utilization, and value chain improvement.
- **Strengthening of Database and Geographical Information Systems (GIS)** – Improving data collection, analysis, and management for informed decision-making in the fisheries sector.
- **Institutional Arrangements for the Fisheries Sector** – Strengthening institutions and governance mechanisms to ensure effective implementation of fisheries policies and programs.
- **Monitoring, Control, and Surveillance (MCS) and Other Need-Based Interventions** – Ensuring responsible fishing practices and protection of marine ecosystems.
- **National Scheme for the Welfare of Fishers** – Focusing on social security, livelihood enhancement, and welfare measures for fishing communities.

Through this integrated approach, the Blue Revolution seeks to boost fish production and productivity, ensure environmental sustainability, and enhance the socio-economic well-being of fishers and aquaculture farmers across India. Today, the Blue Revolution has evolved into a comprehensive, forward-looking initiative integrating policy, technology, and sustainability to transform India’s fisheries into a globally competitive, environmentally resilient, and economically inclusive sector.

**Progress of the Blue Revolution in India (2020–2025):**

Fisheries Sector Achievements	
 Record Production India's fish production reached 195 lakh tonnes in 2024–25, a 104% rise since 2013–14. Inland fisheries grew by 1422%, making India the world's second-largest fish producer after China.	 Infrastructure Investments The government has approved over ₹21,274 crore for fisheries development projects, with more than ₹17,210 crore allocated for infrastructure such as harbors, cold storage, and fish markets.
 Financial Inclusion The Kisan Credit Card (KCC) scheme lending limit for fisheries and allied activities has been increased from ₹2 lakh to ₹5 lakh. As of June 2025, over 4.76 lakh KCCs	 Empowerment Initiatives Programs like Mission Shakti in Uttar Pradesh have empowered women in the fisheries sector. For example, Meera Singh from Jaunpur expanded her fish farming operation from 1 acre to 25 acres,

Technology, Sustainability and Future Outlook

The recent phase of India's Blue Revolution is increasingly emphasized technological innovation and sustainability. Adoption of recirculatory aquaculture systems (RAS), biofloc technology, cage culture, and integrated multi-trophic aquaculture (IMTA) has led to higher productivity while minimizing environmental impact. Furthermore, the government's focus on climate-resilient aquaculture, ecosystem-based management, and digital platforms for real-time monitoring and traceability reflects a shift toward precision aquaculture. Research institutions such as ICAR-CIFA, CMFRI, and NFDB are driving advancements in seed technology, feed innovation, and disease management to ensure long-term sectoral sustainability. Looking ahead, India aims to expand aquaculture area and productivity, diversify species, strengthen cold chain infrastructure, and enhance exports through value addition and certification. The integration of smart technologies, sustainable practices, and community-based management is expected to propel India toward becoming a global leader in sustainable fisheries and aquaculture.

Conclusion

The Blue Revolution in India has transitioned from its foundational phase to a dynamic, innovation-driven era characterized by rapid growth, modernization, and empowerment. Through focused policy interventions, technological adoption, and sustainable management practices, the sector has evolved into a major driver of food security, employment generation, and rural prosperity. With a clear trajectory toward sustainability, inclusiveness, and global competitiveness, India's fisheries and aquaculture sector stands as a model for other developing nations aspiring to balance economic growth with environmental stewardship.

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From Guts to Glory: How Fish's Gut Waste is Powering the Pharmaceutical Industry

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INTRODUCTION

India's marine fisheries, a cornerstone of food security and livelihoods, generate colossal quantities of processing waste, with viscera (guts) from species like tuna, mackerel, and sardines constituting a significant, underutilized, and environmentally challenging by-product. This article explores the innovative valorization of this biological waste into high-value pharmaceutical and nutraceutical compounds, advocating for a paradigm shift from "waste to wealth." Among key commercial species, tuna is identified as the most significant source of gutted visceral material due to its large size and obligatory at-sea evisceration, providing a consistent feedstock for bioprocessing. Fish viscera are biochemical reservoirs rich in bioactive compounds: the liver yields concentrated omega-3 fatty acids (EPA/DHA), used in prescription medications for cardiovascular health; the pancreas and stomach provide enzymes (trypsin, pepsin, collagenase) essential for digestive therapeutics and wound care; and hydrolyzed visceral proteins generate bioactive peptides with demonstrated antihypertensive and antioxidant potential. By implementing dedicated biorefineries within a circular blue economy framework, India can transform this waste stream into a sustainable source of pharmaceutical precursors, mitigating environmental pollution, enhancing the economic viability of the fishing industry, and contributing to domestic drug production. This synthesis underscores the urgent opportunity to leverage marine bio-resources fully, positioning fish processing waste as a vital raw material for the medicine of tomorrow.

Keywords: Fish Viscera, Biovalorization, Pharmaceutical Compounds, Tuna Waste, Bioactive Enzymes, Circular Blue Economy,

Introduction: The Ocean's Unseen Treasure

Picture the bustling docks of Kochi, Visakhapatnam, or Mumbai. Mountains of glistening tuna, mackerel, and sardines are unloaded, destined for our plates. However, in the flurry of filleting and packing, a staggering 50-60% of each fish—heads, guts, scales, and bones—is discarded as waste (A et al., 2022). This "by-catch" of the processing industry often ends up in landfills,



creating environmental havoc. What if we told you that this very waste, especially the slimy, often-ignored guts and viscera, holds the key to powerful medicines? This is not science fiction; it's the cutting edge of blue biotechnology, where fish waste is being transformed from an environmental problem into a pharmaceutical goldmine(Yusuf, 2013).

The Guttled Truth: Which Fish Leads the Way?

To turn waste into wealth, we first need to know where the raw material is. Among the major marine catches—tuna, mackerel, and sardines—the volume of gutted material depends on size, processing method, and end use.

- **Sardines:** Often consumed whole, especially in canned form (e.g., sardines in tomato sauce). When processed for canning, they are typically **eviscerated**. However, due to their small size, the total volume of viscera per fish is low, though collectively significant(Ferraro et al., 2013).
- **Mackerel (Indian & Rastrelliger):** A staple across India. For export, filleting, and certain premium products, mackerel are gutted. Their medium size yields a moderate amount of viscera.
- **Tuna (Yellowfin, Skipjack):** The **undisputed champion of gutted waste**. As a large, pelagic fish, tuna is almost always gutted at sea immediately after catch to preserve meat quality and prevent spoilage. A single tuna can yield kilograms of visceral material—liver, stomach, intestines, and pancreas(Yi-Li et al., 2025).

The Verdict: Tuna is the most significant source of fish gut waste in India by sheer volume and weight per fish. Its large-scale industrial processing for loins, steaks, and canned products makes its viscera the most abundant and consistent feedstock for value-added extraction(Ngmenlanaa, 2002).

The Alchemy of Viscera: From Fish Guts to Life-Saving Drugs

So, what's inside these discarded organs that's so precious? Fish viscera are biochemical powerhouses, rich in enzymes, oils, and bioactive peptides. Here's the transformational journey:

1. The Liver: A Trove of Omega-3s and Vitamin A

Tuna and mackerel livers are exceptionally rich in omega-3 fatty acids—Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA). These are not just health supplements.

- **Pharmaceutical Use:** Highly purified EPA/DHA concentrates are used in prescription medications for treating severe hypertriglyceridemia (high blood triglycerides), reducing the risk of cardiovascular events (Skulas-Ray et al., 2019). The liver is also a historical source of cod liver oil (vitamin A & D), though now more refined from various fish species.

2. The Stomach & Pancreas: Enzyme Factories

The digestive tract is a repository of potent enzymes like pepsin, trypsin, chymotrypsin, and collagenases.

- **Pharmaceutical Use:** These enzymes are extracted and purified for:
 - **Digestive Aids:** Treating pancreatic insufficiency.
 - **Wound Debridement:** Collagenase-based ointments (e.g., Santyl®) are used to clean dead tissue from wounds and burns(Das et al., 2018).
 - **Laboratory & Research:** Trypsin is indispensable in cell culture and bioprocessing(Zhao et al., 2015)



3. The Intestines & Rests: Bioactive Peptides

Through enzymatic hydrolysis, proteins from visceral mass can be broken down into short chains of amino acids called bioactive peptides.

- **Pharmaceutical Potential:** These peptides have demonstrated ACE-inhibitory (anti-hypertensive), antioxidant, and anti-cancer properties in laboratory studies, showing promise for future drug development (Baraiya et al., 2024).

The Indian Opportunity: Turning a Challenge into a Cure

India is among the world's top fish producers. The potential is enormous but underutilized. Currently, most fish waste is either dumped, used as low-value fertilizer, or converted to fishmeal. Establishing dedicated biorefineries near major fishing ports could revolutionize this.

The Vision: Imagine a facility where trucks carrying fish guts are not a nuisance, but a delivery of precious raw material. Through a series of clean, cold-chain processes:

1. **Livers** are diverted for omega-3 and vitamin extraction.
2. **Stomachs and pancreata** are processed for enzymatic extraction.
3. **Remaining tissue** undergoes hydrolysis to produce peptide-rich protein powders for nutraceuticals.

This circular blue economy model creates high-skilled jobs, reduces pollution, adds tremendous value to the fishing industry, and contributes to domestic pharmaceutical production.

Conclusion: A Sea Change in Perception

The story of India's fish waste is ready for a rewrite. The very parts we turn away from—the guts and viscera of fish like tuna—are reservoirs of compounds that can heal hearts, aid digestion, and clean wounds. It's time to see the "guts" of the operation not as waste, but as the brave, vital core of a new industry. By investing in research and sustainable extraction technologies, India can lead the way in transforming ocean waste into ocean wellness, proving that sometimes, the greatest value lies in what we dare not look at—and choosing to look closer.

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Sea Minerals in Soil and Plant Nutrition for Sustainable Agriculture

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ABSTRACT

The ability of sea minerals, which are obtained from seawater, seaweeds, and marine sediments, to improve soil health and plant nutrition is becoming more widely acknowledged. These minerals, which are abundant in macro- and micronutrients including calcium, magnesium, potassium, sulphur, boron, zinc, and iodine, enhance the fertility, structure, and microbiological activity of soil. Bioactive substances, including auxins, cytokinins, and gibberellins that promote root growth and improve nutrient absorption, are also added by seaweed-based formulations. Improved mineral density, longer produce shelf life, and 15–20% improvements in tomato and brinjal crop yields have all been shown in field experiments conducted in coastal India, including Tamil Nadu and Kerala. The buffering capacity of soil is enhanced by the silicates and calcium carbonate found in marine sediments from corals and calcareous algae. Sea minerals assist in solving issues of nutrient depletion, soil degradation, and climate resilience by providing a sustainable and environmentally friendly substitute for synthetic fertilizers. In order to achieve long-term agricultural sustainability, this new paradigm incorporates resources from the ocean into regenerative farming systems.

Introduction

Modern agriculture faces a paradox; while intensive farming practices increase crop yields, they often deplete the soil of essential micronutrients, leading to a decline in soil health and nutritional quality of crops. This scenario has prompted renewed interest in alternative and sustainable nutrient sources. Among them, **sea minerals**, harvested from seawater, marine sediments, or seaweed, are game-changers since they are natural, eco-friendly, and highly effective. Rich in a wide range of macro and microelements, sea minerals have the potential to rejuvenate degraded soils, enhance plant metabolism, and improve crop resilience against biotic and abiotic stresses.

What Are Sea Minerals?

Oceans are home to naturally occurring inorganic compounds called sea minerals, which are abundant in macronutrients, micronutrients, and other healthy components. Millions of years of geological processes have condensed and purified these minerals into a special mixture of more than 90 different minerals, which makes them perfect plant fertilizer.



Phosphorus, nitrogen, and trace minerals are abundant in sea-based fertilizers, including kelp meal, fish bone meal, and fish emulsion. These healthy minerals can also be added to gardens by using ocean water for irrigation or by composting marine life.

Composition of Sea Minerals

Seawater contains over 90 elements, of which 70+ are vital trace elements for plant and microbial metabolism. Major constituents include sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), and sulphate (SO_4^{2-}), while minor and trace elements include boron (B), zinc (Zn), iron (Fe), manganese (Mn), cobalt (Co), molybdenum (Mo), selenium (Se), and iodine (I). (Menzel & Spaargaren, 2012).

Seaweed and Marine Sediments

Seaweeds are a bioavailable reservoir of sea minerals, accumulating essential nutrients in organic forms. Marine sediments, especially those from coral and calcareous algae, are rich in calcium carbonate, silicates, and trace elements (Thodhal *et al.*, 2019)

Role in improving soil health:

1. Nutrient Enrichment and Bioavailability

Sea minerals supply both macro and micronutrients in forms that are often more bioavailable due to ionic balance and synergistic interactions. For example, magnesium from sea minerals improves phosphate solubility in acidic soils, enhancing phosphorus uptake (Zhang *et al.*, 2010).

2. Microbial Activation

Marine-derived minerals can significantly influence soil microbiota. Elements like Zn, Mn, and Fe serve as cofactors in enzymatic processes of nitrogen fixation, organic matter decomposition, and phosphorus solubilization (Zhu *et al.*, 2018).

3. pH Buffering and Salinity Regulation

Calcareous marine deposits help neutralize acidic soils. Sea minerals, especially when diluted, can aid in managing soil sodicity and maintaining osmotic balance, reducing stress on crops (Liang *et al.*, 2014).

Role in Plant Nutrition

1. Macronutrient Support

- **Magnesium (Mg^{2+}):** It is a core element of chlorophyll, Mg enhances photosynthetic efficiency and carbohydrate transport.
- **Calcium (Ca^{2+}):** It is vital for cell wall development and signal transduction.
- **Potassium (K^+):** It regulates stomatal function, enzyme activation, and water relations.

2. Micronutrient Boost

- **Zinc (Zn):** It is involved in auxin metabolism and protein synthesis.
- **Iron (Fe):** It is essential for electron transport in photosynthesis.
- **Manganese (Mn):** It functions in the oxygen-evolving complex of Photosystem II.
- **Boron (B):** Boron is crucial for cell wall integrity and reproductive development.

The presence of a full suite of micronutrients, including trace rare earth elements like vanadium and strontium, contributes to overall crop vigour and yield stability (Turan *et al.*, 2011).

3. Plant Health and Stress Tolerance

Sea minerals can help in:



- **Abiotic stress tolerance:** Elements like Se and Si improve antioxidant defences and reduce oxidative damage under drought or salinity stress.
- **Pest and disease resistance:** A balanced mineral profile supports lignification and formation of phytoalexins (Broadley et al., 2012).
- **Presence of natural growth hormones:** Natural growth hormones found in seaweed, including as auxins, cytokinins, and gibberellins, promote the formation of roots. Plants with larger and more robust root systems are better equipped to obtain nutrients and water (Tuhy and Chojnacka, 2013).

Application Methods

1. Foliar Sprays

Diluted seawater or sea mineral concentrates are often applied as foliar sprays to rapidly correct micronutrient deficiencies. Care must be taken with salinity levels to avoid phytotoxicity.

2. Soil Amendment

Solid or liquid sea mineral formulations are used as base dressings. Seaweed composts or dried sea salt residue can be incorporated to enhance organic matter and microbial activity.

3. Seed Treatment and Hydroponics

Pre-soaking seeds in diluted sea mineral solutions can enhance germination and early seedling vigour. Sea mineral-based hydroponics is gaining popularity due to its comprehensive nutrient profile (Kim et al., 2014).



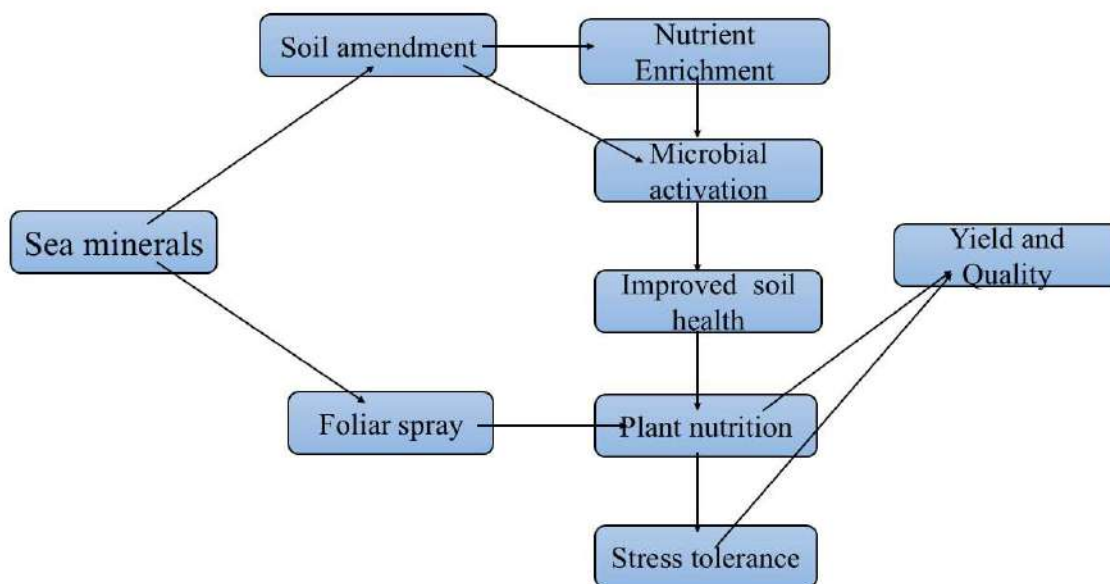


Fig 1: Flowchart of benefits from Sea Minerals in Agriculture

Case Studies and Field Applications

1. Japan and Korea

Rice fields amended with sea mineral solutions have shown improved tillering, grain filling, and resistance to fungal infections, attributed to improved silicon and selenium uptake (Nakamura et al., 2011).

2. India – Coastal Farming

In Tamil Nadu and Kerala, farmers using seaweed-based fertilizers observed increased tomato and brinjal yields by 15–20%, with enhanced fruit shelf-life and mineral density. (Devi and Paul, 2014).

3. Israel and the USA

Controlled studies in saline soils demonstrated that diluted seawater improved soil structure and maintained yields in salt-tolerant crops like barley and sorghum (Epstein, 2009).

Challenges and Considerations

1. Salinity Management

Undiluted or poorly formulated sea mineral applications may increase soil EC, causing osmotic stress. Best practices recommend 1:20 to 1:40 dilution ratios for most crops (Subbarao et al., 2003).

2. Standardization and Quality Control

Sea mineral content varies by source and season. Standardization for agricultural use requires consistent analysis and removal of undesirable elements like heavy metals or excess Na.

3. Economic and Logistical Constraints

Harvesting, desalting, and transporting sea minerals inland could be cost-intensive. Local sourcing, use of seaweed biomass, and integration with organic farming models can improve feasibility.



Future Prospects

The integration of sea minerals into agroecological models aligns with global sustainable agriculture goals. Their use supports:

- Soil regeneration
- Climate-resilient farming
- Biofortification of crops
- Reduction in synthetic fertilizer use

Research is expanding into nano-formulations of sea minerals, sea-mineral biofertilizers, and synergistic use with microbial inoculants, offering a promising frontier for next-generation agriculture.

Conclusion

Sea minerals represent a holistic nutrient source that can address multiple challenges in modern agriculture—from micronutrient deficiencies and soil degradation to enhancing plant resilience. When applied judiciously, they can play a pivotal role in sustainable crop production, especially in marginal and nutrient-exhausted soils. Further research and awareness can bring this ancient resource back into the heart of future farming systems.

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POST-HARVEST PROCESSING, STORAGE, AND UTILIZATION OF MORINGA (*Moringa oleifera*)

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ABSTRACT

Moringa (*Moringa oleifera*) is a highly valued multipurpose plant known for its exceptional nutritional, medicinal, and economic importance. This document highlights standardized methods for harvesting, processing, drying, storage, and utilization of various moringa plant parts including leaves, flowers, pods, seeds, resin, roots, and bark. Proper post-harvest handling practices are essential to retain bioactive compounds, color, and shelf life. Different drying techniques such as shade drying, solar drying, and hot air drying are discussed for quality preservation. The diverse food, medicinal, agricultural, and commercial applications of moringa are emphasized. Overall, moringa serves as a sustainable resource for nutrition, health promotion, and livelihood generation.

Introduction:

Moringa is widely recognized as a “miracle tree” due to its rich nutritional profile and broad range of applications. Almost every part of the plant including leaves, flowers, pods, seeds, resin, roots, and bark offers significant health and economic benefits. Proper harvesting and processing techniques play a crucial role in maintaining the quality and efficacy of moringa products. Post-harvest operations such as cleaning, drying, grinding, and packaging help extend shelf life and ensure safety. Traditional and modern drying methods are commonly adopted based on scale and resources. The growing demand for moringa-based products highlights the importance of standardized processing practices.

Moringa Leaf:

Harvesting:

Harvesting of moringa leaves should be carried out with care to ensure maximum quality, freshness, and nutritional value. Only young, tender, and healthy leaves should be selected, while mature, yellowing, or diseased leaves must be avoided as they negatively affect the final product quality. Harvesting is ideally done during the early morning or late afternoon hours, as these periods help retain higher moisture content, freshness, and nutrient density. Proper harvesting practices not only improve leaf quality but also enhance the shelf life and market value of moringa-based products.

**Cleaning:**

After harvesting, the leaves are manually stripped from the stems to separate the edible portions. The detached leaves should be washed thoroughly using clean, cold potable water to remove soil particles, dust, insects, and other contaminants. For improved hygiene and microbial safety, an optional mild salt water rinse using a 1% salt solution can be applied. After washing, excess water should be drained properly using a clean cloth or strainer to avoid moisture retention that may lead to microbial growth during drying.

Drying Methods:

Drying is a critical step in preserving moringa leaves and maintaining their nutritional and medicinal properties. Various drying methods are employed depending on available resources and desired product quality.

Shade Drying (Traditional & Economical):

Shade drying is a widely practiced and cost-effective method suitable for small-scale processing. Clean moringa leaves are spread evenly in thin layers on trays or mesh racks placed under shade. Direct sunlight should be avoided, as it degrades chlorophyll, vitamins, and bioactive compounds. The leaves are dried for about 3 to 5 days and turned periodically to ensure uniform drying. Drying is complete when the leaves become crisp and brittle.

Solar Dryer:

Solar drying offers a faster and more hygienic alternative to traditional shade drying. Leaves are placed in a solar dryer where controlled temperatures of around 40–50°C are maintained. This method reduces drying time to approximately 6–8 hours while preserving color, aroma, and nutritional quality.

Cabinet / Hot Air Dryer:

For commercial or large-scale operations, cabinet or hot air dryers are preferred. The dryer temperature is maintained between 50–55°C, and drying is completed within 4–6 hours. Leaves dried using this method are uniformly brittle and suitable for further processing.

Grinding:

Once the leaves are completely dried, they are ground into a fine powder using a mixer grinder or pulverizer. Proper drying prior to grinding is essential to avoid clumping and ensure smooth powder formation.

Sieving:

The ground moringa leaf powder is passed through a fine mesh sieve to obtain a uniform texture. This step removes coarse particles and enhances product consistency, making it suitable for food, medicinal, and commercial applications.

Packaging:

The processed moringa leaf powder should be packed immediately in airtight, moisture-proof containers or vacuum-sealed pouches to prevent exposure to air and humidity. Proper labeling with batch number and date of processing is essential for quality control and traceability. Packaged products should be stored in a cool, dry place away from direct sunlight.

Shelf Life:

When properly dried, processed, and stored, moringa leaf powder can retain its color, nutritional value, and bioactive properties for up to 12 months without significant deterioration.



Moringa Flower:

Fresh Storage:

For short-term storage, fresh moringa flowers can be kept in airtight containers or ziplock bags and refrigerated at temperatures between 4–6°C. Under these conditions, the flowers remain fresh for about 2 to 3 days. Moisture accumulation should be avoided to prevent fungal growth.

Drying (For Long-Term Use):

For long-term preservation, moringa flowers are shade-dried on clean cloths or mesh trays for 3–5 days under good airflow conditions without exposure to direct sunlight. Alternatively, a dehydrator can be used at 40–45°C for 4–6 hours. Once dried to a crisp texture, the flowers should be stored in airtight glass jars in a cool and dark environment.



Uses of Moringa Flower:

Culinary:

Moringa flowers are widely used in traditional cuisine and are commonly prepared in stir-fries, curries, and chutneys. They are valued for their high calcium content and antioxidant properties. Additionally, dried flowers are used in herbal teas that promote immunity and overall wellness.

Medicinal:

Moringa flowers act as a natural immune booster and possess strong anti-inflammatory and antioxidant properties. They are traditionally used in the treatment of urinary tract infections, colds, and respiratory ailments.

Nutritional Value:

Moringa flowers are rich sources of vitamin C, calcium, amino acids, and flavonoids. Dried moringa powder is particularly high in calcium and potassium and provides significant energy, minerals, and essential nutrients. Regular consumption, such as starting the day with a cup of moringa powder tea, supports a healthy lifestyle and strengthens immune function.

Moringa Honey Benefits:

Moringa honey is known for its high antioxidant content and rich nutritional profile. It helps boost immunity, supports digestive health, enhances energy levels, and promotes skin health due to its natural bioactive compounds.



Moringa Pod:

Harvesting:

Tender and immature moringa pods measuring about 45–60 cm in length should be selected for processing. Pods must be disease-free, undamaged, and preferably harvested during early morning hours to maintain freshness.

Washing:





Harvested pods are thoroughly washed in clean potable water to remove dirt, dust, and contaminants.

Cutting:

Pods are cut into uniform slices of 1–2 cm thickness to ensure even drying. In some cases, pods may also be split lengthwise.

Drying Methods:

Solar drying involves spreading pod slices on clean trays under direct sunlight while covering them with muslin cloth or nets to protect against insects. This method takes about 2–4 days depending on weather conditions. Alternatively, a food dehydrator or hot air oven maintained at 50–60°C can be used to dry pods within 6–8 hours until moisture content drops below 10%.

Cooling:

Dried pods should be allowed to cool completely before packaging to avoid moisture condensation.

Packaging:

The dried pod slices are packed in airtight or vacuum-sealed containers and stored in a cool, dry place away from sunlight.

Shelf Life:

Properly dried moringa pods can be safely stored for 6–12 months.

Moringa Seed:**Collection of Moringa Seeds**

Mature dry pods are collected once they turn brown and begin to split naturally, usually 90–100 days after flowering. Seeds are extracted manually, and damaged or immature seeds are discarded.

Drying & Storage:

Seeds are shade-dried for 3–5 days to reduce moisture content. They are stored in airtight containers under cool, dry, and dark conditions at temperatures of 15–20°C. With proper storage, seeds remain viable for up to 12 months. For long-term storage, moisture-proof packaging and silica gel sachets are recommended.

Uses of Moringa Seeds:

Moringa seeds are consumed as roasted snacks and are rich in protein, calcium, iron, and antioxidants. Crushed seeds are used for water purification as natural coagulants. Medicinally, they aid in controlling blood pressure, cholesterol, and detoxification. Seeds are also used for oil extraction, producing ben oil with a long shelf life. Agricultural uses include seed propagation and use of oil cake as organic fertilizer, while cosmetic applications include soaps, lotions, and skincare products.

Moringa Resin:**Collection of Moringa Resin (Gum):**

Moringa resin is naturally exuded from bark wounds during the dry season. Small incisions are made on mature branches, and hardened resin is collected carefully after a few days.

Cleaning & Drying:

Collected resin is cleaned to remove impurities and shade-dried until hard and brittle.



**Storage:**

Dried resin is stored in airtight containers with silica gel packets and kept in cool, dry conditions.

Uses:

Moringa resin is traditionally used for medicinal, binding, and emulsifying purposes and is widely utilized in Ayurveda.

Moringa Root and Bark:**Collection**

Mature plants aged 1–1.5 years are uprooted for root collection, cleaned, and optionally peeled. Bark is carefully stripped in small amounts from mature trees during the dry season.

Drying:

Roots and bark are sliced and shade-dried for 5–7 days or dehydrated at 40–50°C.

Storage:

Dried materials are stored in airtight containers in cool, dark places for 6–12 months.

Uses:

Moringa root contains horseradish-like compounds and is used cautiously as a digestive aid, antimicrobial remedy, and pain reliever. Bark is used traditionally for anti-inflammatory treatments, fever management, and blood purification.

Caution:

Moringa root and bark contain toxic compounds such as alkaloids and spirochin when consumed in high doses. Therefore, medicinal use should only be undertaken under expert guidance.

Conclusion:

Efficient harvesting, processing, and storage of moringa plant parts are vital to preserving their nutritional and medicinal value. Leaves, flowers, pods, seeds, resin, roots, and bark each require specific handling techniques to ensure product quality and safety. Adoption of appropriate drying methods significantly enhances shelf life while retaining bioactive compounds. Moringa products contribute to food security, healthcare, agriculture, and commercial industries. However, certain parts such as roots and bark must be used cautiously due to potential toxicity at high doses. Overall, moringa represents a sustainable, multifunctional crop with immense potential for health, nutrition, and economic development.





SUSTAINABLE APPROACHES TO FRUIT CULTIVATION: CONCEPTS AND MANAGEMENT STRATEGIES

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ABSTRACT

Sustainable fruit production has emerged as a vital strategy to address the challenges of climate change, resource scarcity, and increasing food demand. It represents a holistic farming approach that integrates environmental protection, economic viability, and social responsibility. By emphasizing efficient resource use, soil and water conservation, biodiversity enhancement, and integrated crop management, sustainable fruit farming ensures long-term productivity and ecosystem health. Practices such as integrated pest management, precision nutrient use, efficient irrigation, and canopy management reduce environmental impacts while maintaining fruit quality. This system also supports farmer livelihoods and worker welfare. Overall, sustainable fruit production is essential for ensuring food security while safeguarding natural resources for future generations.

Introduction

As global agriculture faces increasing pressure from climate change, resource depletion, and rising food demand, sustainable fruit production has become essential for long-term food security and environmental protection. Sustainable fruit farming is a holistic approach that integrates economic viability, environmental stewardship, and social responsibility. It emphasizes efficient use of natural resources, protection of ecosystems, and production of safe, high-quality fruits while ensuring the well-being of farmers, workers, and surrounding communities. Rather than being an optional alternative, sustainability is now a necessity for maintaining productivity and safeguarding natural resources for future generations.

Concept of Sustainability in Agriculture

Sustainability in agriculture represents a fundamental shift in food production systems. It is based on the principle of meeting present needs without compromising the ability of future generations to meet their own. In the context of fruit production, sustainability addresses major challenges such as soil degradation, declining water availability, biodiversity loss, and increased pest and disease pressure. As fruit crops are often resource-intensive and perennial in nature, adopting sustainable practices is especially important to ensure long-term orchard productivity and environmental balance.



Definition of Sustainable Fruit Production

Sustainable fruit production can be defined as a system that combines environmental care, economic efficiency, and social equity. It aims to deliver fruits that meet high standards of safety, quality, and nutrition while ensuring that farming practices remain environmentally sound, economically profitable, and socially acceptable. This system recognizes the interdependence between healthy ecosystems, productive farms, and stable rural livelihoods.

Four Pillars of Sustainable Fruit Production

Sustainable fruit production is built upon four foundational principles:

The Principle of Health	Ensuring food safety and nutritional quality
The Principle of Ecology	Protecting and enhancing natural ecosystems
The Principle of Fairness	Promoting equitable economic returns and working conditions
The Principle of Care	Demonstrating responsibility toward environmental and human welfare

Objectives of Sustainable Agriculture

The overarching objectives that guide sustainable fruit production include:

- ❖ Make best use of available resources
- ❖ Minimize dependency on non-renewable resources
- ❖ Produce sufficient high-quality and safe food
- ❖ Protect and enhance the environment and natural resources
- ❖ Protect the economic viability of farming operations
- ❖ Protect the health and safety of farm workers, local communities, and society

Benefits of Sustainable Fruit Production

- ❖ **Cost Reduction:** Sustainable practices minimize input through efficient resource use, significantly reducing operational expenses over time. By reducing dependency on chemical pesticides and optimizing water usage, farmers substantially lower production costs.
- ❖ **Long-term Soil Fertility:** Sustainable practices maintain and enhance soil health, ensuring that land remains productive for future generations. This protects the farmer's most valuable asset and eliminates costly rehabilitation efforts.
- ❖ **Environmental Stewardship:** Reduced soil erosion, improved water quality, and minimal pollution create healthier ecosystems that support productive agriculture and maintain the integrity of surrounding landscapes.
- ❖ **Market Premium:** Consumers increasingly demand sustainably produced fruits. Certification and transparent supply chains command premium prices, improving profit margins.

Challenges in Sustainable Fruit Production

Despite its benefits, sustainable fruit production faces several challenges. Water scarcity is one of the most critical constraints, requiring careful management to ensure efficient use while preventing contamination of water bodies. Soil degradation caused by erosion, nutrient imbalance, and organic matter loss threatens long-term productivity and must be addressed through regenerative practices. Pest and disease management remains complex, as producers must balance effective control with reduced chemical use. Biodiversity conservation is another



major challenge, as modern farming systems must preserve native vegetation and wildlife that provide essential ecosystem services.

Sustainable Farming System Approach

- ❖ Understand site history and previous land use, which may influence soil conditions and pest pressures
- ❖ Conduct comprehensive risk assessments evaluating water availability and quality, existing pest and disease pressure, and potential impacts on neighboring farms
- ❖ Check for contamination and pollution risks, implementing buffer zones where necessary
- ❖ Account for site-specific characteristics including topography, neighboring activities, and local ecological conditions

Selection of Planting Material

The selection of suitable planting material plays a crucial role in sustainability. Varieties and rootstocks adapted to local climatic and soil conditions, resistant to major pests and diseases, and aligned with market demands reduce input requirements and enhance productivity. Maintaining quality assurance and traceability of planting material further strengthens sustainability.

Integrated Crop Management Practices

Integrated crop management practices are central to maintaining soil health and productivity. Conservation-oriented cultivation methods such as minimal tillage help preserve soil structure, reduce erosion, and protect beneficial soil organisms. Maintaining continuous vegetative cover through cover crops, residue retention, and shade trees improves nutrient cycling, reduces nutrient leaching, and enhances soil organic matter. Crop rotation, where feasible, disrupts pest cycles, improves soil structure, and supports balanced nutrient use.

Nutrient Management for Sustainability

Nutrient management in sustainable fruit production is based on precise and balanced application of fertilizers according to crop demand. Soil and plant tissue analysis guide nutrient decisions, ensuring efficient use and minimizing losses to the environment. Incorporation of organic manures, compost, and crop residues builds soil organic matter and improves nutrient availability over time. Proper timing of nitrogen application and optimization of phosphorus and potassium use further enhance nutrient efficiency.

Integrated Pest Management (IPM)

Integrated Pest Management is a cornerstone of sustainable fruit farming. IPM prioritizes prevention through the use of resistant varieties, proper spacing, sanitation, and crop rotation. Biological control agents such as predators, parasitoids, and beneficial insects are encouraged through habitat management. Cultural and mechanical practices, including pruning, hand weeding, and removal of infested plant parts, reduce pest populations without chemical reliance. When chemical control is necessary, targeted and judicious use of low-impact pesticides based on monitoring and economic thresholds minimizes risks to human health and the environment.

Water Management in Fruit Orchards

Water management is increasingly critical in sustainable fruit production. Efficient irrigation systems, particularly drip irrigation, deliver water directly to the root zone, reducing evaporation and runoff while conserving water. Accurate assessment of crop water



requirements through soil moisture monitoring, rainfall records, and weather data allows precise irrigation scheduling. This data-driven approach improves fruit quality and yield while preserving limited water resources.

Canopy Management: Training and Pruning

Canopy management through appropriate planting density, training, and pruning significantly influences orchard sustainability. Optimal spacing ensures efficient use of sunlight, water, and nutrients while reducing disease pressure. Training and pruning shape tree architecture, improve air circulation, enhance spray penetration, and facilitate harvesting. In crops such as mango, pruning focuses on opening the canopy to allow better light and airflow, thereby improving pest and disease management and overall orchard health.

Soil Protection and Mulching

Soil protection practices such as mulching contribute greatly to sustainability. Organic mulches reduce evaporation, maintain soil moisture, control weeds, prevent erosion, and add organic matter to the soil. Over time, mulching improves soil structure, fertility, and biological activity, reducing the need for external inputs.

Harvesting Practices and Pest Reductio

Harvesting practices also play a role in pest management and sustainability. Timely harvesting and selective removal of infested or overripe fruits reduce pest breeding sites and lower infestation levels. Harvesting fruits at appropriate maturity stages can enhance resistance to pests and reduce post-harvest losses, decreasing dependence on chemical controls.

Economic Sustainability in Fruit Production

Economic sustainability in fruit production depends on maintaining safety, quality, and transparency throughout the production and supply chain. Consistent quality and documented sustainable practices build consumer trust and allow access to premium markets. Financial stability enables farmers to invest in improved technologies, infrastructure, and workforce development. Collective action through farmer groups and cooperatives strengthens market access and bargaining power, improving overall profitability.

Social Sustainability and Worker Welfare

Social sustainability focuses on the well-being of people involved in fruit production. Sustainable farms provide safe and healthy working conditions, adequate sanitation, access to clean water, medical care, and fair wages. Training and skill development empower workers to adopt sustainable practices effectively and create opportunities for professional growth. Respectful treatment and equitable employment practices contribute to stable and motivated workforces.

Environmental Sustainability and Biodiversity Conservation

Environmental sustainability remains central to sustainable fruit production. Farms that conserve and enhance biodiversity benefit from natural pest regulation, improved pollination, and greater ecosystem resilience. Protecting native vegetation, maintaining diverse landscapes, and encouraging beneficial organisms strengthen ecological balance. Waste reduction and recycling further support environmental goals through composting organic residues, reusing by-products, and minimizing off-farm waste disposal



Conclusion:

Sustainable fruit production is no longer an optional approach but a necessity for resilient and productive agricultural systems. By balancing ecological integrity, economic profitability, and social equity, it ensures long-term orchard productivity and environmental conservation. Adoption of practices such as integrated nutrient and pest management, efficient water use, soil protection, and biodiversity conservation reduces dependency on external inputs and minimizes environmental degradation. Economic and social sustainability further strengthen farming communities through improved market access and worker welfare. Despite challenges like water scarcity and pest pressure, sustainable strategies provide effective solutions. Ultimately, sustainable fruit production secures high-quality fruit supply while preserving natural resources for future generations.





Extension Strategies for Carbon Farming and Climate Mitigation

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INTRODUCTION

Climate change has emerged as one of the most critical global challenges affecting agriculture, ecosystems, and human livelihoods. Rising greenhouse gas concentrations in the atmosphere have led to increasing global temperatures, erratic rainfall patterns, and extreme weather events. Agriculture plays a dual role in this context: it is both a contributor to greenhouse gas emissions and a potential solution for climate change mitigation. Sustainable land management practices can significantly reduce emissions while enhancing carbon sequestration in soils and vegetation.

One of the most promising approaches to address this challenge is **carbon farming**, which refers to agricultural practices designed to capture and store atmospheric carbon dioxide in soil and plant biomass. Carbon farming practices not only contribute to climate mitigation but also improve soil fertility, water retention, and overall ecosystem health. However, the successful implementation of carbon farming largely depends on the effective dissemination of knowledge and technologies among farmers. Agricultural extension systems therefore play a crucial role in promoting climate-smart practices and encouraging farmers to adopt carbon farming strategies.

Extension strategies for carbon farming focus on educating farmers, facilitating technology transfer, strengthening community participation, and providing access to climate-related information and financial incentives. By integrating scientific knowledge with local farming practices, extension services can help farmers transition toward more sustainable and climate-resilient agricultural systems.

Concept of Carbon Farming

Carbon farming refers to a range of agricultural practices aimed at increasing the amount of carbon stored in soils and vegetation while reducing greenhouse gas emissions from farming activities. These practices are designed to improve soil organic matter and promote biological processes that enhance carbon sequestration.

Common carbon farming practices include conservation agriculture, agroforestry, cover cropping, crop rotation, integrated nutrient management, and improved grazing management. Such practices increase the storage of organic carbon in soils and reduce the release of carbon dioxide, methane, and nitrous oxide into the atmosphere.



In addition to environmental benefits, carbon farming also contributes to improved soil structure, enhanced nutrient cycling, and increased water-holding capacity. These improvements can lead to higher crop productivity and greater resilience to climate variability. For farmers, adopting carbon farming practices can therefore provide both ecological and economic benefits.

Role of Agricultural Extension in Carbon Farming

Agricultural extension services serve as a bridge between research institutions and farming communities. Extension professionals translate scientific knowledge into practical recommendations that farmers can implement in their fields. In the context of carbon farming, extension services help farmers understand the benefits of climate-smart agricultural practices and guide them in adopting appropriate techniques.

One of the primary roles of extension services is to raise awareness about the relationship between agricultural practices and climate change. Many farmers may not fully understand how soil management, crop choices, and livestock practices influence greenhouse gas emissions. Extension programs can provide training and demonstrations that illustrate the impact of sustainable practices on soil carbon storage and environmental health.

Extension services also support farmers in accessing new technologies and resources that facilitate carbon farming. This may include improved crop varieties, soil testing services, digital advisory tools, and climate information systems. By providing continuous guidance and support, extension agents help farmers integrate carbon farming practices into their existing production systems.

Participatory Extension Approaches

Participatory extension approaches are particularly effective in promoting carbon farming practices. These approaches involve farmers directly in the learning and decision-making process, encouraging them to experiment with new practices and evaluate their outcomes.

Group-based learning methods such as farmer field demonstrations, participatory research trials, and community workshops enable farmers to observe the benefits of carbon farming practices under local conditions. Through these activities, farmers gain practical experience and confidence in adopting new technologies.

Participatory approaches also encourage knowledge exchange among farmers. Experienced farmers who successfully implement carbon farming practices can share their experiences with others, thereby accelerating the diffusion of innovations within rural communities.

Capacity Building and Farmer Training

Training and capacity building are essential components of extension strategies for carbon farming. Farmers need to develop knowledge and skills related to soil health management, climate-resilient cropping systems, and sustainable land use practices.

Extension programs often organize training sessions, workshops, and field demonstrations to educate farmers about techniques such as conservation tillage, organic matter management, and agroforestry systems. These training activities help farmers understand how different practices influence soil carbon dynamics and greenhouse gas emissions.

Capacity-building initiatives may also include training on monitoring and measuring soil carbon levels. As carbon markets and climate finance mechanisms develop, farmers may have opportunities to receive financial incentives for carbon sequestration. Understanding how to



measure and report carbon storage can therefore become an important skill for farmers participating in such programs.

Use of Digital Extension Tools

Digital technologies are increasingly being used to support agricultural extension services in promoting carbon farming. Mobile applications, online advisory platforms, and remote sensing technologies can provide farmers with real-time information on soil health, weather conditions, and sustainable farming practices.

Digital extension tools can deliver customized recommendations based on location-specific data, helping farmers implement climate-smart practices more effectively. Satellite imagery and geographic information systems can also be used to monitor land use changes and estimate carbon sequestration potential in agricultural landscapes.

These technologies enable extension agencies to reach a larger number of farmers and provide continuous support even in remote areas. Digital platforms also facilitate knowledge sharing among farmers, researchers, and policymakers working on climate mitigation initiatives.

Policy Support and Incentive Mechanisms

Policy support is a critical factor in promoting carbon farming through extension services. Governments and development agencies can encourage farmers to adopt sustainable practices by providing financial incentives, subsidies, or technical assistance.

Carbon credit programs and climate finance initiatives are emerging mechanisms that reward farmers for adopting practices that reduce greenhouse gas emissions or increase carbon sequestration. Extension services play an important role in helping farmers understand these programs and participate in them effectively.

In addition, policy frameworks that support sustainable land management, soil conservation, and agroforestry can create favorable conditions for the widespread adoption of carbon farming practices. Collaboration between government agencies, research institutions, and extension organizations is essential for designing effective policies and implementation strategies.

Challenges in Promoting Carbon Farming

Despite its potential benefits, promoting carbon farming through extension systems faces several challenges. One major challenge is the limited awareness among farmers about the concept of carbon sequestration and its long-term benefits. Farmers often prioritize immediate economic returns, which may discourage them from adopting practices that provide benefits over a longer time horizon.

Another challenge is the complexity of measuring and verifying soil carbon sequestration. Accurate monitoring requires specialized tools and expertise, which may not always be available at the farm level. Extension systems need to develop simplified methods and training programs that enable farmers to participate in carbon farming initiatives effectively.

Resource constraints, including limited funding and insufficient extension personnel, may also limit the reach of extension programs. Strengthening institutional capacity and developing partnerships with private organizations and community groups can help address these challenges.

Future Prospects

The growing global emphasis on climate change mitigation presents new opportunities for integrating carbon farming into agricultural development strategies. Advances in soil science,



digital agriculture, and remote sensing technologies are improving our ability to measure and manage soil carbon more effectively.

Future extension strategies are likely to focus on integrating carbon farming with broader climate-smart agriculture programs that address productivity, adaptation, and mitigation simultaneously. Strengthening farmer organizations, promoting community-based resource management, and encouraging youth participation in climate-smart agriculture will also be important components of future initiatives.

International collaboration and knowledge exchange can further enhance the effectiveness of extension strategies for carbon farming. By sharing successful experiences and best practices, countries can accelerate the adoption of sustainable agricultural systems that contribute to global climate mitigation efforts.

Conclusion

Carbon farming represents a promising approach for addressing climate change while improving the sustainability of agricultural systems. Through practices that enhance soil carbon sequestration and reduce greenhouse gas emissions, farmers can contribute to climate mitigation while improving soil health and productivity. Agricultural extension services play a crucial role in promoting these practices by providing training, facilitating technology transfer, and supporting farmer participation in climate initiatives. Effective extension strategies that combine participatory learning, digital tools, and policy support can accelerate the adoption of carbon farming practices and strengthen the resilience of farming communities in the face of climate change.

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Advances in Seed Priming Technologies for Climate Resilience

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ABSTRACT

Climate change is increasingly threatening global agricultural productivity through the intensification of abiotic stresses such as drought, salinity, extreme temperatures, and erratic rainfall patterns. These environmental constraints severely affect seed germination, seedling establishment, and early crop growth, ultimately reducing yield potential. Seed priming has emerged as a promising pre-sowing strategy to enhance germination efficiency, improve seedling vigor, and increase crop tolerance to environmental stresses. Recent advances in seed priming technologies including nanopriming, biopriming, nutripriming, and physical priming methods have expanded the potential of this technique in climate-resilient agriculture. Seed priming activates metabolic processes, improves antioxidant defense systems, and triggers stress-responsive gene expression prior to germination. This review highlights recent developments in seed priming technologies, the physiological and molecular mechanisms underlying priming-induced stress tolerance, and their applications in developing resilient agricultural systems under changing climatic conditions.

1. Introduction

Agriculture is increasingly vulnerable to climate change due to rising temperatures, prolonged droughts, increased soil salinity, and unpredictable rainfall patterns. These environmental stresses directly affect seed germination and early seedling establishment, which are among the most critical stages in the plant life cycle. Poor germination under stress conditions often leads to weak crop stands, reduced growth, and ultimately lower productivity.

Seed priming has gained recognition as a simple and effective seed enhancement technology capable of improving germination performance and seedling vigor under both optimal and adverse environmental conditions. Seed priming involves controlled hydration of seeds to initiate metabolic activities necessary for germination without allowing radicle emergence. After priming, seeds are re-dried to their original moisture level and can be stored or sown.

Primed seeds generally exhibit faster germination, synchronized seedling emergence, enhanced metabolic activity, and improved tolerance to environmental stresses. With increasing research efforts, seed priming has evolved from a simple hydration technique to a sophisticated technology incorporating microbial inoculants, nutrients, plant hormones, and nanomaterials. These innovations have significantly improved the effectiveness of seed priming in enhancing crop resilience to climate-induced stresses.



2. Concept and Mechanisms of Seed Priming

Seed priming initiates the early phases of germination by activating metabolic pathways involved in seed growth while preventing complete germination. During priming, water uptake by seeds triggers several physiological and biochemical processes such as enzyme activation, repair of cellular structures, synthesis of nucleic acids and proteins, and mobilization of stored food reserves.

One of the major benefits of priming is the enhancement of antioxidant defense mechanisms that protect cells from oxidative damage caused by reactive oxygen species. Primed seeds often exhibit higher activities of antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase. These enzymes help maintain cellular homeostasis during stress conditions.

Priming also improves membrane integrity, increases osmolyte accumulation, and enhances nutrient uptake efficiency. Additionally, it can induce stress memory in plants, enabling them to respond more effectively to subsequent environmental stresses. These physiological and biochemical adjustments contribute to improved germination, better seedling growth, and higher tolerance to environmental stresses.

3. Conventional Seed Priming Techniques

3.1 Hydropriming

Hydropriming is one of the simplest and most widely practiced seed priming techniques. In this method, seeds are soaked in water for a specific period and then dried before sowing. Hydropriming enhances germination speed and uniformity by initiating metabolic activities that prepare seeds for rapid germination once planted.

This method is particularly suitable for resource-poor farming systems because it requires minimal inputs and can be easily adopted by farmers. Hydropriming has shown significant improvements in germination and crop establishment in cereals, pulses, and oilseed crops.

3.2 Osmopriming

Osmopriming involves soaking seeds in solutions containing osmotic agents such as polyethylene glycol, mannitol, or other solutes. These compounds regulate water uptake, allowing seeds to hydrate slowly without initiating radicle emergence.

This controlled hydration process activates metabolic activities and enhances stress tolerance mechanisms in seeds. Osmopriming has been widely used to improve drought tolerance and seedling vigor in crops grown under water-limited environments.

3.3 Halopriming

Halopriming refers to the treatment of seeds with inorganic salt solutions such as potassium nitrate, sodium chloride, or calcium chloride. This method improves the ability of seeds to tolerate saline conditions by enhancing osmotic adjustment and regulating ion balance within plant cells.

Halopriming also stimulates enzymatic activities and improves the mobilization of stored nutrients during germination.

3.4 Hormonal Priming

Hormonal priming involves treating seeds with plant growth regulators such as gibberellins, salicylic acid, jasmonic acid, and abscisic acid. These hormones regulate physiological processes that control seed germination, growth, and stress responses.

Hormonal priming can enhance stress tolerance by activating signaling pathways that regulate antioxidant systems, osmotic balance, and gene expression associated with stress adaptation.



4. Emerging Seed Priming Technologies

4.1 Biopriming

Biopriming integrates seed priming with beneficial microorganisms such as plant growth-promoting rhizobacteria and fungal bioagents. During this process, microbial inoculants colonize the seed surface and establish beneficial associations with emerging seedlings.

These microorganisms enhance nutrient uptake, stimulate plant growth, and protect plants from pathogens. Biopriming also improves tolerance to environmental stresses by inducing systemic resistance and enhancing metabolic activities.

4.2 Nutripriming

Nutripriming involves soaking seeds in nutrient solutions containing essential macro- and micronutrients such as zinc, iron, selenium, and phosphorus. This method improves nutrient availability during early plant growth and enhances seedling vigor.

Nutripriming not only improves crop productivity but also contributes to biofortification by increasing the nutrient content of edible plant parts.

4.3 Nanopriming

Nanopriming is a recent innovation in seed technology that involves the use of nanoparticles as priming agents. Nanoparticles can enhance nutrient delivery, regulate oxidative stress, and activate signaling pathways that improve plant growth and stress tolerance.

Nanopriming has shown promising results in improving germination, root growth, and tolerance to drought, salinity, and temperature stress. The small size and high surface area of nanoparticles enable efficient interaction with seed tissues, making them effective carriers of nutrients and signaling molecules.

4.4 Plasma Priming

Plasma priming is an emerging physical method that utilizes cold plasma treatment to modify seed surface properties and stimulate physiological processes. Plasma treatment improves seed permeability, enhances water absorption, and accelerates germination.

This technique also improves seed sanitation by reducing microbial contamination on seed surfaces. Plasma priming is considered environmentally friendly because it does not require chemical inputs.

4.5 Electropriming and Magnetic Priming

Electropriming and magnetic field treatments are novel physical priming techniques that stimulate metabolic activities in seeds through electromagnetic fields. These methods have been reported to improve seed germination, enhance enzyme activities, and promote plant growth.

Such techniques offer promising possibilities for improving crop establishment under stress conditions without chemical inputs.

5. Role of Seed Priming in Climate-Resilient Agriculture

5.1 Enhancing Drought Tolerance

Seed priming improves root development, osmotic regulation, and water-use efficiency, enabling plants to survive under drought conditions.

5.2 Improving Salinity Tolerance

Primed seeds exhibit improved ion regulation and antioxidant defense mechanisms, which reduce the damaging effects of salt stress on plant cells.

5.3 Tolerance to Temperature Extremes



Seed priming enhances enzyme stability and membrane integrity, helping plants tolerate both high and low temperature stress.

5.4 Improved Crop Establishment

Faster and uniform germination ensures better crop stands, which is critical for achieving stable yields under unpredictable climatic conditions.

6. Challenges and Future Perspectives

Despite the promising benefits of seed priming, several challenges need to be addressed to ensure its widespread adoption. One major limitation is the reduced storage life of primed seeds, as metabolic activation during priming can accelerate seed ageing if storage conditions are not optimal.

Another challenge is the lack of standardized protocols for different crop species and environmental conditions. Further research is needed to optimize priming treatments and determine appropriate priming durations and concentrations.

Future research should focus on integrating seed priming with modern technologies such as genomics, proteomics, and metabolomics to better understand the molecular mechanisms underlying priming-induced stress tolerance. Advances in nanotechnology, artificial intelligence, and precision agriculture could further enhance the efficiency and scalability of seed priming technologies.

7. Conclusion

Seed priming has emerged as an effective seed enhancement technology capable of improving germination, seedling vigor, and stress tolerance in crops. Advances in priming techniques—including biopriming, nutripriming, nanopriming, and plasma priming—have significantly expanded the potential of this technology in climate-resilient agriculture. By improving crop establishment and enhancing tolerance to environmental stresses, seed priming can play a crucial role in sustaining agricultural productivity under changing climatic conditions. Continued research and technological innovation will further strengthen the role of seed priming as a key strategy for ensuring global food security in the face of climate change.

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Digital Extension Tools for Disseminating Millet Technologies

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INTRODUCTION

Millets are among the most resilient and nutritionally rich cereal crops cultivated in semi-arid and dryland regions of the world. In countries such as India, millets have traditionally been an integral part of farming systems due to their ability to tolerate drought, poor soil fertility, and adverse climatic conditions. Millets such as finger millet, pearl millet, foxtail millet, and little millet are important sources of essential nutrients including dietary fiber, proteins, minerals, and antioxidants. In recent years, the global recognition of millets has increased significantly, particularly after the declaration of the **International Year of Millets 2023**, which aimed to promote millet production and consumption worldwide.

Despite their nutritional and environmental advantages, millet cultivation has declined in several regions due to the expansion of major cereals such as rice and wheat, limited market demand, and insufficient dissemination of improved technologies. Traditional agricultural extension systems often face limitations such as inadequate manpower, limited reach in remote areas, and delayed information delivery. To overcome these challenges, digital extension tools are increasingly being used to disseminate millet production technologies to farmers in a timely and efficient manner.

Digital extension tools utilize modern information and communication technologies (ICTs) to deliver agricultural knowledge, advisories, and innovations directly to farmers. These tools include mobile applications, digital advisory platforms, satellite-based monitoring systems, and social media networks. By integrating digital technologies into agricultural extension services, it becomes possible to bridge the gap between research institutions and farmers while promoting the adoption of improved millet technologies.

Importance of Digital Extension in Millet Technology Dissemination

The adoption of improved millet technologies depends largely on effective knowledge transfer mechanisms. Farmers require timely information on improved varieties, seed treatment methods, nutrient management practices, pest and disease control strategies, and post-harvest processing techniques. Digital extension tools facilitate rapid dissemination of such information and allow farmers to access advisory services without the need for frequent physical interactions with extension personnel.

One of the key advantages of digital extension tools is their ability to deliver location-specific information. Weather-based advisories, soil nutrient recommendations, and pest alerts can be



tailored to specific regions using geospatial data and remote sensing technologies. This targeted approach helps farmers make informed decisions regarding crop management practices and improves the overall productivity of millet cultivation systems.

Digital tools also enable interactive communication between farmers, researchers, and extension agents. Through mobile platforms and online communities, farmers can share experiences, ask questions, and receive expert guidance on various aspects of millet production. Such interactive learning environments enhance knowledge exchange and encourage the adoption of innovative farming practices.

Mobile-Based Advisory Services

Mobile phones have become one of the most widely used communication tools in rural areas. Mobile-based advisory services are therefore among the most effective digital extension tools for disseminating millet technologies. Farmers receive information through text messages, voice calls, or smartphone applications that provide recommendations related to crop management.

In India, platforms such as Kisan Suvidha and IFFCO Kisan provide farmers with information on weather forecasts, market prices, pest management, and improved cultivation practices. These applications enable farmers to access advisory services in local languages, making them more accessible and user-friendly.

Another important platform is mKisan, which delivers crop-specific advisories to farmers through SMS and voice messages. Farmers cultivating millets can receive timely recommendations on seed selection, irrigation scheduling, nutrient management, and pest control measures. Such services help ensure that farmers adopt scientifically recommended practices for millet cultivation.

Digital Knowledge Platforms and Online Learning

Digital knowledge platforms provide comprehensive information on millet production technologies through online portals, e-learning modules, and multimedia resources. These platforms often include training videos, digital manuals, and interactive tools that help farmers and extension workers understand improved farming practices.

One of the key digital knowledge initiatives in India is Digital Agriculture Mission, which aims to integrate digital technologies into agricultural development programs. Through digital knowledge portals, farmers can access information on improved millet varieties, climate-resilient farming practices, and post-harvest processing technologies.

Research organizations and agricultural universities also play an important role in developing digital extension content. Institutions such as Indian Council of Agricultural Research regularly publish digital resources, videos, and advisory materials on millet cultivation. These resources help bridge the gap between scientific research and practical farming applications.

Use of Social Media and Communication Platforms

Social media platforms have become powerful tools for agricultural extension and knowledge sharing. Farmers increasingly use platforms such as WhatsApp and YouTube to access agricultural information and connect with experts. Extension agencies and agricultural institutions use these platforms to share educational videos, field demonstrations, and success stories related to millet cultivation.

WhatsApp groups created by extension officers often serve as interactive learning communities where farmers can share photographs of crop problems and receive instant recommendations



from experts. YouTube channels dedicated to agriculture provide step-by-step demonstrations of improved millet production practices such as seed treatment, intercropping, integrated pest management, and harvesting techniques.

The visual and interactive nature of social media content enhances farmers' understanding and encourages the adoption of improved technologies. In addition, social media allows rapid dissemination of information during emergencies such as pest outbreaks or extreme weather events.

Role of Remote Sensing and Geographic Information Systems

Remote sensing and geographic information systems (GIS) are increasingly being used in digital agricultural extension programs. Satellite imagery and drone-based monitoring systems help track crop growth, soil moisture levels, and weather patterns in millet-growing regions. These technologies enable extension agencies to provide early warnings about drought conditions, pest infestations, or nutrient deficiencies.

By integrating remote sensing data with digital advisory platforms, farmers can receive accurate and timely recommendations for crop management. For example, satellite-based monitoring can identify areas experiencing water stress and guide farmers on irrigation management practices. Such technologies contribute to improved productivity and resource efficiency in millet farming systems.

Digital Market Linkages for Millet Farmers

In addition to production technologies, digital extension tools also play an important role in improving market access for millet farmers. Online marketing platforms and digital marketplaces allow farmers to connect directly with buyers, processors, and consumers.

Platforms such as eNAM enable farmers to access real-time information on market prices and sell their produce across different markets. This improves price transparency and reduces the dependence on local intermediaries. Digital platforms also promote the development of value chains for millet-based products, thereby increasing the economic viability of millet cultivation.

Challenges in Implementing Digital Extension Tools

Despite the growing importance of digital extension tools, several challenges limit their effectiveness. Limited internet connectivity in remote rural areas can restrict access to digital platforms. Many smallholder farmers also face difficulties in using smartphone applications due to low levels of digital literacy. Language barriers and lack of locally relevant content may further reduce the adoption of digital advisory services.

Another challenge is the need for reliable and accurate information. Digital extension platforms must ensure that advisory messages are based on scientific research and adapted to local agro-climatic conditions. Collaboration between research institutions, extension agencies, and technology developers is therefore essential for the successful implementation of digital extension programs.

Future Prospects of Digital Extension in Millet Promotion

The future of digital extension in millet technology dissemination is closely linked to advancements in artificial intelligence, big data analytics, and smart farming technologies. AI-based advisory systems can analyze large datasets on weather patterns, soil conditions, and crop performance to provide highly personalized recommendations to farmers.



The integration of digital extension tools with precision agriculture technologies may further enhance the efficiency of millet production systems. Mobile-based diagnostic tools, image recognition technologies, and chatbot-based advisory services are expected to become increasingly important in supporting farmers.

Government initiatives promoting digital agriculture and millet cultivation are also expected to strengthen the role of digital extension in the coming years. Increased investments in rural internet infrastructure and farmer training programs will further expand the reach of digital advisory services.

Conclusion

Digital extension tools have emerged as powerful mechanisms for disseminating millet technologies to farmers in an efficient and scalable manner. Mobile-based advisory services, online knowledge platforms, social media networks, and remote sensing technologies are transforming traditional extension systems by providing real-time and location-specific information. These tools not only improve farmers' access to improved millet production technologies but also strengthen market linkages and promote sustainable agricultural practices. Although challenges related to connectivity, digital literacy, and content localization remain, continued technological advancements and policy support are expected to enhance the effectiveness of digital extension systems in promoting millet cultivation and improving the livelihoods of farmers.

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Farmer Field Schools as a Tool for Climate Resilience

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INTRODUCTION

Climate change has become one of the most pressing challenges facing global agriculture. Rising temperatures, irregular rainfall patterns, increased frequency of droughts and floods, and the emergence of new pests and diseases are significantly affecting agricultural productivity and food security. Farmers, particularly smallholders in developing countries, are among the most vulnerable groups to these climate-related risks. In countries such as India, where agriculture largely depends on monsoon rainfall and natural resources, the impacts of climate variability are increasingly evident.

To cope with these challenges, innovative extension approaches that strengthen farmers' adaptive capacity are required. One such participatory learning approach is the **Farmer Field School (FFS)**. Farmer Field Schools emphasize experiential learning, farmer participation, and collective problem-solving to help farmers understand agroecosystems and adopt sustainable farming practices. Over the years, FFS programs have been widely used to promote climate-resilient agriculture by enabling farmers to better understand climate risks and implement adaptive strategies in their farming systems.

Concept and Development of Farmer Field Schools

The Farmer Field School approach was originally developed in the late 1980s by the Food and Agriculture Organization to support farmers in managing pests through integrated pest management strategies. The first FFS programs were implemented in rice farming systems in Southeast Asia and gradually expanded to other crops and regions. The approach was designed to replace traditional top-down extension methods with participatory learning that empowers farmers to become active experimenters and decision-makers.

In a Farmer Field School, a group of farmers regularly meet throughout a cropping season to observe crop growth, analyze field conditions, and discuss management practices. Facilitated by trained extension workers or experts, these sessions involve hands-on field experiments, group discussions, and participatory analysis. Farmers learn by doing rather than simply receiving instructions, which improves their understanding of agricultural ecosystems and enhances their ability to adapt to changing environmental conditions.

Role of Farmer Field Schools in Climate Change Adaptation

Farmer Field Schools play an important role in helping farmers understand the impacts of climate change and develop strategies to cope with climate-related risks. Through regular field



observations and agroecosystem analysis, farmers gain knowledge about the interactions between crops, soil, water, climate, and pests. This holistic understanding enables them to make better management decisions in response to climate variability.

FFS programs often include training on climate-resilient agricultural practices such as drought-tolerant crop varieties, improved water management, soil conservation techniques, and integrated pest management. By testing these practices directly in the field, farmers can evaluate their effectiveness under local conditions before adopting them on a larger scale.

Another important aspect of FFS is the emphasis on collective learning and knowledge sharing. Farmers exchange experiences and discuss challenges related to climate variability, which helps them identify practical solutions. This collaborative approach strengthens community resilience and promotes the adoption of climate-smart agricultural practices.

Enhancing Knowledge and Decision-Making Capacity

One of the key strengths of Farmer Field Schools is their ability to enhance farmers' analytical and decision-making skills. Participants are trained to observe crop growth, identify pest and disease problems, assess soil conditions, and evaluate environmental factors affecting crop productivity. This process helps farmers develop a deeper understanding of the agricultural ecosystem and encourages them to experiment with different management practices.

Climate change often introduces uncertainty into farming systems, making it difficult for farmers to rely solely on traditional knowledge. Through FFS training, farmers learn to interpret weather patterns, monitor crop responses, and adapt their practices accordingly. This improved decision-making capacity is essential for managing risks associated with climate variability.

Promotion of Climate-Smart Agricultural Practices

Farmer Field Schools serve as effective platforms for promoting **climate-smart agriculture**, which aims to increase agricultural productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. FFS programs introduce farmers to various climate-resilient technologies and practices that can help mitigate the impacts of climate change.

For example, farmers may learn about conservation agriculture practices such as minimum tillage, crop residue management, and crop diversification. These practices improve soil health, enhance water retention, and reduce vulnerability to drought. FFS programs also promote integrated nutrient management, agroforestry systems, and efficient irrigation methods that contribute to sustainable land use.

By demonstrating these practices directly in farmers' fields, FFS programs increase farmers' confidence in adopting new technologies. The participatory nature of the learning process ensures that farmers understand not only how to implement these practices but also why they are beneficial under changing climatic conditions.

Strengthening Community Resilience

Climate change affects not only individual farms but also entire rural communities. Farmer Field Schools encourage collective action and strengthen social networks among farmers. Participants often work together to conduct field experiments, share resources, and address common challenges related to climate variability.

Community-based learning through FFS can also facilitate the development of local adaptation strategies. For example, farmers may collaborate to improve water management systems, establish community seed banks for climate-resilient crop varieties, or coordinate pest



management activities across multiple farms. Such collective efforts enhance the overall resilience of farming communities.

Integration with Extension and Development Programs

Farmer Field Schools are increasingly being integrated into national agricultural extension systems and rural development programs. Governments, research institutions, and development organizations use FFS as a platform to disseminate improved technologies and climate adaptation strategies.

In India, several agricultural development programs have adopted the FFS approach to promote sustainable farming practices and climate resilience. Extension agencies often collaborate with research organizations such as the Indian Council of Agricultural Research to develop training modules and demonstration programs for farmers. These initiatives help bridge the gap between scientific research and practical agricultural applications.

The FFS approach is also widely supported by international organizations and development agencies working to improve food security and climate resilience in vulnerable regions.

Challenges and Limitations

Despite its many benefits, the Farmer Field School approach faces several challenges. Implementing FFS programs requires trained facilitators, adequate funding, and continuous support from extension agencies. In some cases, the number of trained facilitators may be insufficient to reach large numbers of farmers.

Another limitation is the time commitment required from farmers. Since FFS programs involve regular meetings and field observations throughout the cropping season, some farmers may find it difficult to participate consistently. Additionally, the effectiveness of FFS programs can vary depending on the quality of facilitation and the level of farmer participation.

There is also a need to integrate modern technologies such as digital advisory tools and climate information services into FFS programs to enhance their impact and reach.

Future Prospects

The role of Farmer Field Schools in climate change adaptation is expected to grow in the coming years. As climate variability continues to affect agricultural production, participatory extension approaches that empower farmers with knowledge and skills will become increasingly important. Integrating FFS with digital extension tools, climate forecasting services, and precision agriculture technologies may further enhance the effectiveness of these programs.

In addition, expanding FFS programs to include topics such as climate risk management, sustainable water use, and diversified farming systems can help farmers develop comprehensive strategies for climate resilience. Strengthening partnerships between research institutions, extension agencies, and farming communities will also be essential for scaling up FFS initiatives.

Conclusion

Farmer Field Schools represent a powerful participatory extension approach that helps farmers adapt to the challenges posed by climate change. By promoting experiential learning, collective problem-solving, and knowledge sharing, FFS programs enhance farmers' understanding of agroecosystems and improve their capacity to implement climate-resilient agricultural practices. The approach not only strengthens individual farmers' adaptive capacity but also builds community resilience against climate-related risks. Although challenges related to



resources, training, and scalability remain, the continued development and integration of Farmer Field Schools into agricultural extension systems will play a crucial role in supporting sustainable and climate-resilient agriculture.

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Popular Article

Role of High Pressure Processing in Preserving Fluid Milk and Dairy Foods

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INTRODUCTION

Milk and dairy products are highly nutritious foods that contain essential nutrients such as proteins, fats, carbohydrates, vitamins, and minerals. However, these components also make milk highly susceptible to microbial spoilage and enzymatic degradation. Conventional preservation techniques such as pasteurization and ultra-high temperature (UHT) treatment are widely used to improve safety and extend shelf life. While these thermal processes are effective, they may negatively influence the sensory characteristics and nutritional quality of dairy products.

In recent years, **High Pressure Processing (HPP)** has emerged as a promising non-thermal food preservation technology. It offers the ability to inactivate microorganisms and certain enzymes while maintaining the natural characteristics of milk and dairy foods. HPP is increasingly gaining attention in the dairy industry for producing minimally processed, safe, and high-quality products.

2. Principle of High Pressure Processing

High Pressure Processing involves subjecting food to very high hydrostatic pressures ranging from **100 to 800 MPa**, usually for a few seconds to several minutes. The process is carried out in a pressure vessel filled with water or another pressure-transmitting fluid. The food product, typically pre-packaged in flexible packaging materials, is placed inside the vessel.

The process operates on two fundamental principles:

Pascal's Principle

Pressure applied to a fluid in a closed system is transmitted uniformly in all directions, ensuring that the entire product receives equal pressure.

Le Chatelier's Principle

Biochemical reactions that involve volume reduction are favored under high pressure, which affects microbial cells and protein structures.

The pressure disrupts cellular membranes, enzyme activity, and genetic material in microorganisms without significantly affecting covalent bonds in food molecules. Therefore, nutrients and flavor compounds remain largely intact.



3. Mechanism of Microbial Inactivation

High pressure damages microbial cells through several mechanisms:

- **Disruption of cell membranes**, leading to leakage of intracellular components
- **Denaturation of essential enzymes and proteins** required for metabolism
- **Interference with DNA replication and transcription**
- **Loss of ribosomal function and protein synthesis**

Vegetative cells of bacteria, yeasts, and molds are highly susceptible to pressures above **300 MPa**. However, bacterial spores are more resistant and may require combined treatments such as pressure-assisted thermal processing.

Common microorganisms inactivated in milk include:

- *Listeria monocytogenes*
- *Salmonella spp.*
- *Escherichia coli* O157:H7
- *Staphylococcus aureus*

4. Application of HPP in Fluid Milk Preservation

4.1 Shelf Life Extension

HPP-treated milk can achieve a shelf life of **2–4 weeks under refrigeration**, significantly longer than raw milk and comparable to pasteurized milk.

4.2 Retention of Fresh Flavor

Unlike heat treatments, HPP preserves the **natural taste and aroma** of milk, which is often described as “fresh-like.”

4.3 Improved Nutritional Quality

HPP causes minimal loss of:

- Heat-sensitive vitamins
- Essential amino acids
- Bioactive peptides

4.4 Protein Modification

High pressure alters the structure of **casein micelles and whey proteins**, improving functional properties such as:

- Emulsification
- Water holding capacity
- Gel formation

5. Effect of High Pressure Processing on Milk Components

5.1 Milk Proteins

Pressure treatment can cause partial denaturation of whey proteins and changes in casein micelles. These modifications can improve the texture and stability of dairy products.

5.2 Milk Fat

Milk fat globules are relatively stable under pressure. However, slight modifications in the fat globule membrane may occur, which can influence emulsification properties.

5.3 Lactose

Lactose remains chemically stable under high pressure, with no significant degradation.

5.4 Minerals

Calcium and phosphate equilibrium in milk may shift slightly due to pressure-induced changes in casein micelles.



6. Applications in Different Dairy Products

6.1 Cheese Production

High pressure treatment can be applied to cheese milk or finished cheese to:

- Improve microbial safety
- Accelerate ripening
- Enhance flavor development
- Modify cheese texture

HPP-treated cheeses often show improved **proteolysis and lipolysis**, leading to faster maturation.

6.2 Yogurt and Fermented Milk

Pressure-treated milk produces yogurt with:

- Higher viscosity
- Better gel strength
- Reduced syneresis (whey separation)

This reduces the need for stabilizers or thickeners.

6.3 Cream and Dairy Desserts

HPP improves the microbial stability of cream and dairy desserts while preserving flavor compounds.

6.4 Ice Cream Mix

Pressure treatment reduces microbial load in ice cream mix without affecting flavor compounds or freezing properties.

6.5 Whey-Based Beverages

High pressure improves the stability of whey proteins and enhances the nutritional value of whey beverages.

7. Advantages of High Pressure Processing in Dairy Industry

- Non-thermal preservation method
- Retention of natural flavor and aroma
- Improved nutritional quality
- Effective microbial inactivation
- Uniform pressure treatment
- Reduced need for chemical preservatives
- Ability to process packaged products, reducing contamination risk
- Environmentally friendly process

8. Limitations of High Pressure Processing

Despite its advantages, HPP has some limitations:

- **High capital investment** for equipment
- **Limited effectiveness against bacterial spores**
- Potential **protein structure changes** affecting texture
- Limited application in some solid dairy matrices
- Requirement of flexible packaging materials

9. Future Prospects

Research is focusing on improving the efficiency and economic feasibility of HPP in dairy processing. Emerging approaches include:

- **Pressure-assisted thermal sterilization (PATS)**



- Combination of HPP with **pulsed electric fields**
- Integration with **natural antimicrobial compounds**
- Application in **functional dairy foods**

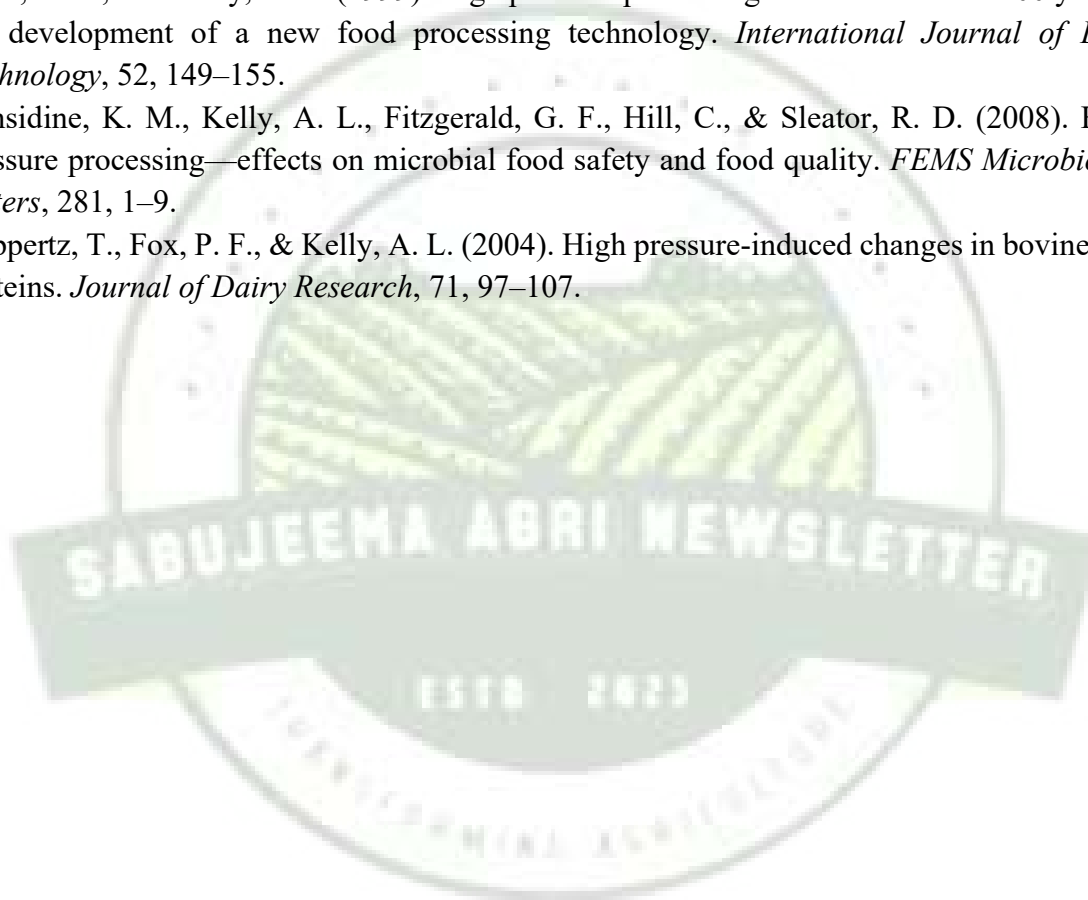
These developments will help expand the commercial use of HPP in the global dairy industry.

10. Conclusion

High Pressure Processing is a promising non-thermal preservation technology for fluid milk and dairy products. It effectively inactivates microorganisms while preserving the nutritional, sensory, and functional qualities of dairy foods. Although high equipment cost and spore resistance remain challenges, ongoing research and technological advancements are expected to increase the adoption of HPP in modern dairy processing systems.

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Nanotechnology Applications in Seed Coating and Treatment

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ABSTRACT

Seed quality and early plant establishment are crucial determinants of crop productivity and sustainability in modern agriculture. Conventional seed treatment methods often face limitations in terms of efficiency, environmental safety, and controlled delivery of active ingredients. Nanotechnology has emerged as a promising innovation in seed science, offering novel approaches for seed coating and treatment. Nanomaterials possess unique physicochemical properties such as high surface area, enhanced reactivity, and improved delivery mechanisms, making them suitable for targeted nutrient supply, disease protection, and stress tolerance. Nanoparticle-based seed treatments have demonstrated significant potential in improving germination, seedling vigor, nutrient uptake, and resistance to biotic and abiotic stresses. This article discusses the recent advances in nanotechnology applications in seed coating and treatment, the mechanisms through which nanoparticles influence plant growth, and the prospects and challenges associated with their agricultural use.

1. Introduction

Seed treatment plays a vital role in modern agriculture by protecting seeds from pathogens, enhancing germination, and improving early seedling establishment. Traditional seed treatment practices rely primarily on chemical fungicides, insecticides, and nutrient coatings. While these approaches have contributed significantly to crop protection, concerns about environmental pollution, chemical residues, and reduced efficiency have prompted researchers to explore alternative technologies.

Nanotechnology has emerged as a revolutionary field with applications in agriculture, particularly in seed technology. Nanoparticles typically range from 1 to 100 nanometers in size and exhibit unique chemical, physical, and biological properties. These characteristics allow nanoparticles to interact efficiently with biological systems, making them suitable carriers for nutrients, growth regulators, and plant protection agents.

In seed technology, nanotechnology is being explored for seed coating, seed priming, and seed treatment to improve germination, plant growth, and stress tolerance. The integration of nanomaterials into seed coatings enables controlled release of nutrients and agrochemicals, thereby enhancing the efficiency of seed treatments while reducing environmental impacts.



2. Concept of Nanotechnology in Seed Treatment

Nanotechnology in seed treatment involves the use of engineered nanoparticles or nanomaterials to enhance seed performance. These nanoparticles can be applied directly to seeds through coating, soaking, or encapsulation techniques. Due to their small size and high surface area, nanoparticles can easily penetrate seed coats and interact with cellular components, influencing physiological and biochemical processes.

Nanoparticles used in seed treatment may include metal nanoparticles such as silver, zinc oxide, titanium dioxide, and iron oxide, as well as carbon-based nanomaterials and polymeric nanoparticles. These materials can act as nutrient carriers, antimicrobial agents, or stimulators of plant growth.

Nanotechnology-based seed treatment improves seed hydration, enhances enzymatic activity, and stimulates metabolic pathways involved in germination and early plant development. The technology also allows for precise delivery of active ingredients in small quantities, reducing the need for excessive chemical applications.

3. Nanotechnology in Seed Coating

Seed coating is a technique in which seeds are covered with protective layers containing nutrients, pesticides, or biological agents. Nanotechnology has improved this process by enabling the development of nano-enabled seed coatings with enhanced functionality.

Nano-coated seeds can deliver nutrients in a controlled and sustained manner, ensuring availability during early seedling growth. Nanoparticles embedded in seed coatings can also protect seeds from soil-borne pathogens and pests.

For example, zinc oxide nanoparticles incorporated into seed coatings can improve seed germination and enhance zinc availability for plant growth. Similarly, silver nanoparticles possess antimicrobial properties that help protect seeds from fungal and bacterial infections. Nanoparticle-based coatings also improve the physical properties of seeds by enhancing seed flowability, durability, and resistance to mechanical damage during handling and sowing.

4. Nanopriming of Seeds

Nanopriming is an emerging seed enhancement technique in which seeds are treated with nanoparticle suspensions before sowing. During nanopriming, nanoparticles interact with seed tissues and stimulate metabolic activities that promote germination.

Nanoprimed seeds often show faster germination rates, improved seedling vigor, and enhanced tolerance to environmental stresses such as drought, salinity, and temperature fluctuations. Nanoparticles can regulate reactive oxygen species levels within seeds, thereby preventing oxidative damage and improving cellular stability.

In addition, nanopriming can enhance the activity of enzymes involved in seed metabolism, such as amylase and protease, which facilitate the mobilization of stored food reserves during germination.

5. Role of Nanoparticles in Enhancing Seed Performance

5.1 Improved Germination and Seedling Growth

Nanoparticles can stimulate physiological processes involved in seed germination by enhancing water absorption and enzyme activation. This leads to faster and more uniform germination, resulting in improved crop establishment.



5.2 Enhanced Nutrient Uptake

Nanoparticles can act as nano-fertilizers by providing essential nutrients in a highly available form. Their high surface area allows efficient interaction with plant tissues, improving nutrient absorption and utilization.

5.3 Protection Against Pathogens

Certain nanoparticles possess antimicrobial properties that help protect seeds from fungal and bacterial pathogens. This reduces seed-borne diseases and improves seedling survival.

5.4 Improved Stress Tolerance

Nanotechnology-based seed treatments can enhance plant tolerance to environmental stresses such as drought, salinity, and heavy metal toxicity. Nanoparticles stimulate antioxidant defense systems and improve osmotic regulation, enabling plants to cope with adverse conditions.

6. Environmental and Safety Considerations

Despite the promising potential of nanotechnology in seed treatment, concerns remain regarding the environmental and ecological impacts of nanoparticles. The long-term effects of nanoparticle accumulation in soil ecosystems and their potential toxicity to beneficial microorganisms require careful evaluation.

Proper risk assessment and regulatory guidelines are essential to ensure the safe application of nanotechnology in agriculture. Research should focus on developing biodegradable and environmentally friendly nanomaterials to minimize potential risks.

7. Future Prospects

Nanotechnology offers tremendous opportunities for advancing seed technology and improving agricultural sustainability. Future research should focus on designing multifunctional nanoparticles capable of delivering nutrients, growth regulators, and protective agents simultaneously.

Integration of nanotechnology with biotechnology, precision agriculture, and smart farming systems may further enhance the efficiency of seed treatments. Additionally, large-scale field studies are needed to validate laboratory findings and assess the economic feasibility of nano-enabled seed technologies.

8. Conclusion

Nanotechnology represents a transformative approach in seed coating and treatment, offering innovative solutions for improving seed quality, germination, and plant growth. Nanoparticle-based seed treatments enhance nutrient delivery, protect seeds from pathogens, and improve tolerance to environmental stresses. These advantages make nanotechnology a promising tool for sustainable agriculture and improved crop productivity. However, further research is required to address environmental concerns and develop safe and efficient nano-based agricultural technologies.

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Role of Reactive Oxygen Species in Seed Ageing and Viability Loss

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ABSTRACT

Seed ageing is a natural physiological process that occurs during storage and results in the gradual loss of seed viability and vigor. One of the major factors responsible for this deterioration is the accumulation of reactive oxygen species (ROS) within seed tissues. Reactive oxygen species, including superoxide radicals, hydrogen peroxide, and hydroxyl radicals, are generated during normal metabolic processes but can cause oxidative damage when their levels exceed the capacity of antioxidant defense systems. Excessive ROS leads to lipid peroxidation, protein degradation, nucleic acid damage, and membrane deterioration, ultimately reducing the germination potential of seeds. This article discusses the role of ROS in seed ageing, the mechanisms of oxidative damage, and the antioxidant systems that protect seeds from oxidative stress.

1. Introduction

Seed viability is a critical determinant of crop establishment and agricultural productivity. During storage, seeds gradually lose their ability to germinate and develop into healthy seedlings, a phenomenon commonly referred to as seed ageing. This process involves complex biochemical and physiological changes within the seed. Among the various factors contributing to seed deterioration, the accumulation of reactive oxygen species (ROS) has been identified as one of the most significant.

Reactive oxygen species are highly reactive molecules formed as by-products of aerobic metabolism. Under normal conditions, ROS levels are regulated by antioxidant defense systems. However, during prolonged storage or under unfavorable environmental conditions such as high temperature and humidity, the balance between ROS production and antioxidant protection is disrupted, leading to oxidative stress and cellular damage.

2. Generation of Reactive Oxygen Species in Seeds

ROS are produced in seeds mainly through metabolic activities associated with respiration and other cellular processes. The most common forms of ROS include superoxide radicals (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radicals ($\bullet OH$).

During seed storage, metabolic imbalance and environmental stress may increase the production of ROS. Since stored seeds have limited repair mechanisms and reduced metabolic activity, the accumulation of ROS becomes a major factor contributing to seed ageing.



3. Oxidative Damage Caused by ROS

3.1 Lipid Peroxidation

One of the primary effects of ROS accumulation is lipid peroxidation of cellular membranes. Polyunsaturated fatty acids present in membrane lipids are particularly susceptible to oxidation. Lipid peroxidation results in membrane destabilization, increased permeability, and leakage of cellular contents, which negatively affects seed germination.

3.2 Protein Oxidation

Reactive oxygen species can modify amino acids and damage proteins by altering their structure and function. Oxidative damage to enzymes reduces their catalytic activity, which interferes with metabolic processes essential for seed germination.

3.3 DNA and RNA Damage

ROS can also attack nucleic acids, causing strand breaks and base modifications in DNA and RNA molecules. Such damage affects gene expression and cellular repair mechanisms, ultimately reducing seed viability.

3.4 Membrane Integrity Loss

Cell membranes play a crucial role in maintaining cellular homeostasis. Oxidative damage to membrane components results in loss of membrane integrity and impaired cellular functions, contributing significantly to seed deterioration.

4. Antioxidant Defense Mechanisms in Seeds

Seeds possess antioxidant systems that help neutralize ROS and protect cellular components from oxidative damage. These defense systems include both enzymatic and non-enzymatic antioxidants.

4.1 Enzymatic Antioxidants

Important antioxidant enzymes include:

- Superoxide dismutase (SOD)
- Catalase (CAT)
- Peroxidase (POD)
- Ascorbate peroxidase (APX)

These enzymes detoxify ROS by converting them into less harmful molecules.

4.2 Non-Enzymatic Antioxidants

Non-enzymatic antioxidants such as ascorbic acid, glutathione, tocopherols, and carotenoids also contribute to ROS scavenging. These compounds help maintain cellular redox balance during seed storage.

5. Factors Influencing ROS Accumulation During Seed Storage

5.1 Temperature

High storage temperature accelerates metabolic reactions and ROS production, leading to faster seed ageing.

5.2 Moisture Content

Higher seed moisture content increases respiration and ROS generation, thereby promoting oxidative damage.

5.3 Oxygen Availability

Excess oxygen enhances oxidative reactions and contributes to ROS formation in stored seeds.



5.4 Storage Duration

Longer storage periods allow gradual accumulation of oxidative damage, ultimately reducing seed viability.

6. Strategies to Reduce ROS-Induced Seed Ageing

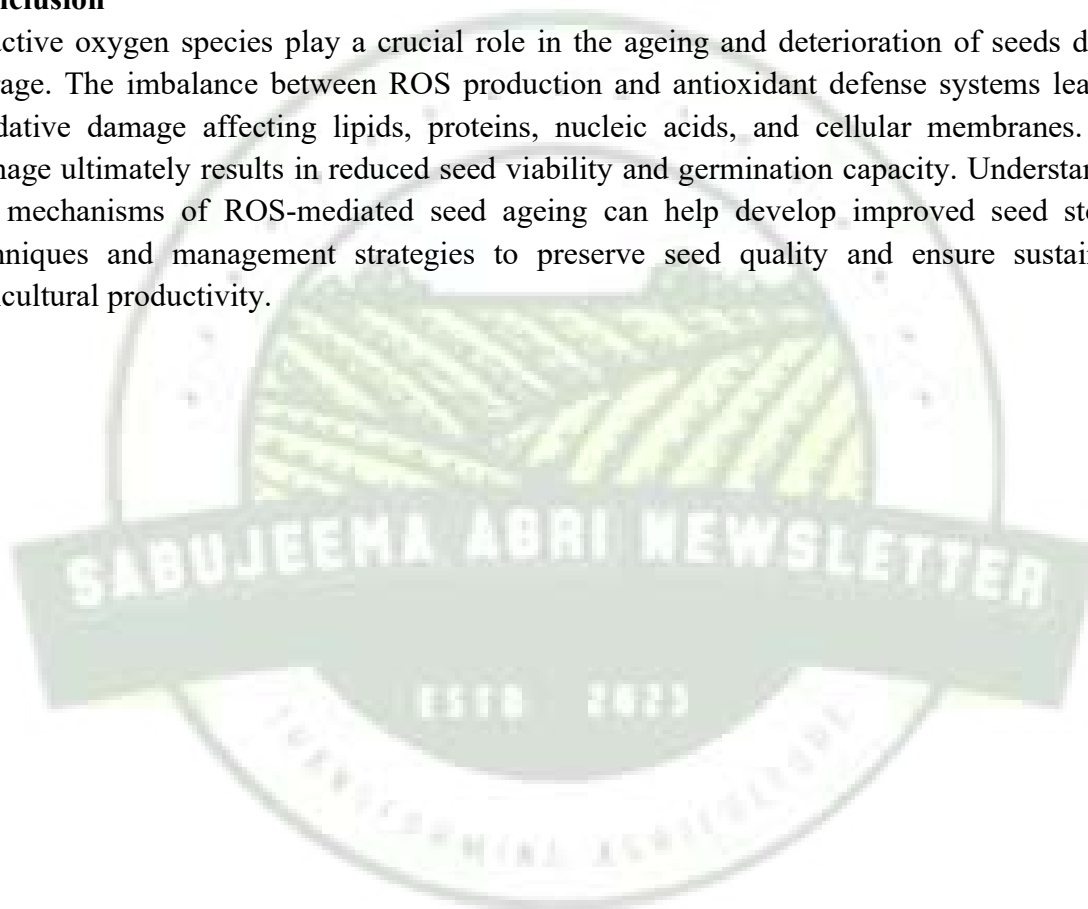
Several strategies can help minimize oxidative damage in stored seeds:

- Maintaining low moisture content in seeds
- Storing seeds at low temperatures
- Using airtight or vacuum storage containers
- Application of antioxidant treatments
- Adoption of advanced storage technologies such as cryopreservation

These methods help maintain seed viability and vigor for extended periods.

Conclusion

Reactive oxygen species play a crucial role in the ageing and deterioration of seeds during storage. The imbalance between ROS production and antioxidant defense systems leads to oxidative damage affecting lipids, proteins, nucleic acids, and cellular membranes. This damage ultimately results in reduced seed viability and germination capacity. Understanding the mechanisms of ROS-mediated seed ageing can help develop improved seed storage techniques and management strategies to preserve seed quality and ensure sustainable agricultural productivity.





Sensor-Based Robotic Solutions for Enhanced Dairy Farm Operations

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INTRODUCTION

The dairy sector has experienced remarkable technological transformation in recent decades as farmers seek to improve productivity, animal welfare, and farm profitability. Increasing herd sizes, rising labor costs, and the demand for higher milk quality have encouraged the adoption of automated technologies in dairy farming. Among these innovations, sensor-based robotic systems have emerged as one of the most significant advancements in modern dairy farm management. These technologies integrate sensors, robotics, data analytics, and intelligent software to automate various farm operations and provide real-time monitoring of animal health and productivity.

Traditional dairy farming relied heavily on manual labor for tasks such as milking, feeding, health monitoring, and barn management. However, manual observation can be time-consuming and sometimes inefficient, particularly in large herds where individual animal monitoring becomes difficult. Sensor-based robotic systems address these limitations by continuously collecting data on animal behavior, physiological conditions, and environmental parameters. This real-time information enables farmers to make informed decisions that enhance herd management, milk production, and overall farm efficiency.

Concept and Working Principle of Sensor-Based Robotic Systems

Sensor-based robotic solutions operate through the integration of sensing technologies, automated machinery, and digital data processing systems. Sensors installed on animals or within farm facilities continuously collect information related to animal health, movement, feeding behavior, milk production, and environmental conditions. These sensors transmit the collected data to a central processing unit or cloud-based management system where it is analyzed using algorithms and artificial intelligence tools.

The robotic components of the system perform automated tasks such as milking, feed distribution, manure removal, and barn cleaning. The integration of sensors with robotic devices allows machines to respond intelligently to the conditions detected by sensors. For instance, in robotic milking systems, sensors detect the position of a cow's teats and guide robotic arms to attach milking cups accurately. Similarly, feeding robots adjust feed distribution based on the nutritional requirements of individual animals.

Such systems operate continuously and provide farmers with detailed insights into the performance of each animal. By analyzing patterns in sensor data, farmers can identify



behavioral changes, detect diseases at early stages, and optimize feeding and breeding strategies.

Sensor Technologies Used in Dairy Farming

A wide range of sensors are used in modern dairy farms to monitor different aspects of animal health and farm operations. Activity and movement sensors are commonly attached to cow collars or legs and measure parameters such as walking patterns, rest periods, and physical activity levels. These sensors help detect estrus cycles, identify lameness, and monitor general animal behavior. Changes in activity patterns often serve as early indicators of health problems or reproductive status.

Milk quality sensors are another important component of sensor-based robotic systems. These sensors are integrated into automated milking machines and measure various parameters such as milk yield, temperature, electrical conductivity, fat content, and protein levels. Abnormal changes in milk conductivity can indicate the presence of mastitis, allowing farmers to take preventive measures before the disease spreads within the herd.

Physiological sensors are also widely used to monitor animal health. These sensors measure body temperature, heart rate, rumination activity, and other physiological parameters. Monitoring rumination behavior, for example, provides valuable information about digestive health and feed intake. A reduction in rumination may indicate metabolic disorders or digestive disturbances.

Environmental sensors installed in barns measure factors such as temperature, humidity, air quality, and ammonia concentration. Maintaining an optimal barn environment is essential for animal comfort and productivity. Poor ventilation or high ammonia levels can negatively affect animal health and milk production. Environmental sensors help farmers maintain suitable conditions by automatically controlling ventilation, cooling systems, and lighting.

Robotic Milking Systems and Their Impact

One of the most significant applications of sensor-based robotics in dairy farming is the Automatic Milking System (AMS), commonly known as robotic milking. These systems allow cows to enter the milking station voluntarily, where a robotic arm equipped with sensors identifies the cow and attaches the milking cups to the teats. Laser or camera sensors guide the robotic arm with high precision, ensuring efficient milking without causing discomfort to the animal.

Robotic milking systems collect extensive data during each milking session, including milk yield, milking duration, milk flow rate, and milk composition. This information helps farmers monitor the productivity and health of individual cows. Since cows can be milked multiple times a day based on their natural behavior, robotic milking systems often lead to increased milk yield and improved udder health.

Furthermore, automated cleaning and sanitation processes ensure high standards of hygiene during milking. The reduction in manual labor is another major advantage, as milking is one of the most labor-intensive tasks in dairy farming. Robotic milking systems allow farmers to focus on herd management and strategic decision-making rather than routine manual work.

Robotic Feeding and Nutrition Management

Proper nutrition is critical for maintaining animal health and maximizing milk production. Robotic feeding systems are designed to deliver precise quantities of feed to cows based on



their nutritional requirements. These systems use sensors to monitor feed consumption patterns and adjust feeding schedules accordingly.

In many modern dairy farms, feed-pushing robots move along the feeding alley and push feed closer to the cows, ensuring continuous access to fresh feed. This encourages consistent feed intake and reduces feed wastage. Some advanced systems can also mix different feed components automatically, ensuring balanced diets tailored to different groups of animals such as lactating cows, dry cows, and heifers.

By combining sensor data with feeding robots, farmers can monitor feed efficiency and identify animals with reduced appetite, which may indicate health problems. This integration contributes to improved feed management and enhanced productivity.

Robotic Manure Management and Barn Hygiene

Maintaining cleanliness in dairy barns is essential for preventing diseases and ensuring animal comfort. Robotic manure scrapers and automated cleaning machines are widely used in modern dairy farms to remove manure from barn floors. These robots operate at regular intervals throughout the day, keeping walking surfaces clean and reducing the risk of hoof infections and other health issues.

The use of automated manure management systems also improves air quality within barns by reducing the accumulation of ammonia and other harmful gases. This contributes to a healthier environment for both animals and farm workers.

Data Analytics and Precision Dairy Farming

Sensor-based robotic systems generate large amounts of data related to animal health, productivity, and environmental conditions. Advanced software platforms analyze this data to identify trends and patterns that can support better decision-making. The integration of sensors with precision livestock farming technologies allows farmers to monitor individual animals in large herds with high accuracy.

Artificial intelligence and machine learning algorithms are increasingly being used to analyze sensor data and predict potential health problems. For example, changes in activity levels, rumination patterns, and milk yield can be combined to predict diseases before clinical symptoms appear. Early detection enables timely treatment and reduces economic losses.

Mobile applications and cloud-based management systems allow farmers to access farm data remotely. Farmers can receive alerts about abnormal conditions, monitor herd performance, and adjust management practices from their smartphones or computers.

Benefits of Sensor-Based Robotic Solutions

The adoption of sensor-based robotic technologies provides numerous benefits for dairy farm operations. These systems significantly improve animal welfare by continuously monitoring health and behavior. Early detection of diseases reduces the need for antibiotics and prevents the spread of infections within the herd.

Automation also enhances labor efficiency by reducing the workload associated with repetitive tasks such as milking, feeding, and barn cleaning. This is particularly important in regions where skilled farm labor is limited or expensive. Improved monitoring and precise management of feed and environmental conditions lead to higher milk production and better milk quality.

In addition, the use of sensor-based technologies supports sustainable dairy farming by optimizing resource use and reducing environmental impacts. Efficient feed management



reduces feed wastage, while automated manure handling improves nutrient management and reduces greenhouse gas emissions.

Challenges and Limitations

Despite their many advantages, sensor-based robotic systems face several challenges that limit their widespread adoption. The high initial investment required for purchasing and installing robotic equipment is one of the main barriers, particularly for small-scale farmers. Maintenance and technical support are also important considerations, as these systems require specialized knowledge for operation and troubleshooting.

Data management is another challenge associated with precision dairy farming technologies. Large volumes of data generated by sensors must be properly analyzed and interpreted to provide meaningful insights. Farmers may require training to effectively use these digital tools and integrate them into farm management practices.

Furthermore, not all farming systems are equally suited for robotic technologies. Factors such as barn design, herd size, and farm infrastructure can influence the efficiency of robotic systems.

Future Perspectives

The future of dairy farming is likely to be increasingly driven by technological innovation. Advances in artificial intelligence, computer vision, and the Internet of Things are expected to further enhance the capabilities of sensor-based robotic systems. Autonomous robots capable of performing multiple farm tasks, such as monitoring animal health, distributing feed, and managing manure, are currently being developed.

Computer vision technologies using cameras and image analysis may allow continuous monitoring of animal behavior, body condition, and health status without the need for wearable sensors. Integration of genomic information with sensor data may also enable more precise breeding strategies and improved herd productivity.

As technology becomes more affordable and accessible, sensor-based robotic solutions are expected to play a crucial role in the development of smart dairy farms that combine efficiency, sustainability, and high animal welfare standards.

Conclusion

Sensor-based robotic technologies represent a major advancement in modern dairy farming. By integrating sensors, robotics, and data analytics, these systems provide continuous monitoring of animal health, automate labor-intensive tasks, and improve farm management efficiency. Applications such as robotic milking, automated feeding, and environmental monitoring have already demonstrated significant benefits in terms of milk production, animal welfare, and labor efficiency. Although challenges related to cost and technical complexity remain, ongoing technological developments are likely to make these systems more accessible in the future. The adoption of sensor-based robotic solutions will therefore play a critical role in shaping the future of sustainable and efficient dairy farming.

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Shatavari (*Asparagus racemosus*): The Queen of Herbs for Women's Health

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INTRODUCTION

Shatavari (*Asparagus racemosus*) is one of the most important medicinal plants in the Indian tradition of Ayurveda, where it is celebrated as the “Queen of Herbs,” particularly for women's health. For centuries, it has been used as a rejuvenating tonic to promote vitality, fertility, and longevity. Today, with increasing interest in natural and plant-based healthcare, shatavari is drawing renewed attention from scientists, healthcare practitioners, and health-conscious women seeking gentle, holistic support.

Botanically, *Asparagus racemosus* belongs to the family Asparagaceae and is a perennial climbing plant widely distributed in tropical and subtropical regions of India. It thrives in well-drained sandy loam to black soil and tolerates semi-arid conditions. The plant is characterized by its delicate, needle-like phylloclades (modified photosynthetic branches), small white flowers, and clusters of fleshy tuberous roots. These tuberous roots are the principal medicinal part and the source of its therapeutic value.



Freshly harvested shatavari roots

The name “Shatavari” is traditionally interpreted as “she who possesses a hundred husbands,” symbolizing vitality, fertility, and the capacity to nourish and sustain. In Ayurvedic classification, it is regarded as a Rasayana—a rejuvenator that supports tissue nourishment, immunity, and graceful aging. This traditional reputation is now being explored through modern phytochemical and pharmacological research. Chemically, Shatavari is rich in steroidal



saponins, especially Shatavarin IV, which is considered one of its major bioactive constituents. According to pharmacopoeial standards, the dried roots should contain not less than 0.1% Shatavarin IV on a dry weight basis. In addition to saponins, the plant contains alkaloids, flavonoids, dihydrophenanthrene derivatives, and essential oils. These compounds collectively contribute to its antioxidant, anti-inflammatory, immunomodulatory, and adaptogenic properties reported in scientific studies.

For women, Shatavari's importance extends through different stages of life. It is traditionally used to maintain regular menstrual cycles and to relieve dysmenorrhea (painful menstruation). Its phytoestrogen-like activity is believed to maintain hormonal balance, making it useful in cases of excessive menstrual bleeding and uterine weakness. In Ayurveda, it is also prescribed to support fertility and in cases of habitual miscarriage, reflecting its role in strengthening reproductive tissues. One of the most widely recognized uses of shatavari is galactagogue, a natural substance that promotes lactation. Nursing mothers have long relied on shatavari formulations to enhance breast milk production and support postpartum recovery. Its nourishing and cooling properties are considered beneficial in restoring strength after childbirth. During menopause, when hormonal fluctuations may lead to hot flashes, mood changes, fatigue, and anxiety, shatavari's adaptogenic action may help women cope with physical and emotional stress. By supporting endocrine balance and overall resilience, it offers a plant-based complementary approach for midlife wellness. Although primarily associated with women's health, Shatavari is not limited to female-specific applications. It has been used in male reproductive disorders such as oligospermia and benign prostatic hyperplasia, and in conditions like painful micturition. It also supports digestive health, helping in acidity, ulcers, indigestion, and inflammatory conditions of the gastrointestinal tract. As an adaptogen, it enhances the body's capacity to respond to stress and improves general stamina and immunity in both men and women.

From a pharmacognostic perspective, the roots are typically 5–15 cm long and about 2 cm thick. Fresh roots are smooth and silvery white externally, while dried roots develop longitudinal wrinkles. When powdered, the material appears light brown with a coarse texture. These identification features are important for quality control in herbal drug standardization.



Dried shatavari roots



Beyond its medicinal value, it possesses significant agricultural and economic potential as a high-value medicinal crop. With the growing demand for herbal medicines, nutraceuticals, and natural health products, its cultivation has gained increasing attention among farmers. The crop can be cultivated either as a sole crop or as an intercrop in orchards such as *Mangifera indica* (mango), *Anacardium occidentale* (cashew), and *Phyllanthus emblica* (amla), thereby enhancing land-use efficiency and farm income. Propagation is generally carried out through seeds or root divisions; seeds are usually raised in nursery beds during the early monsoon, and the seedlings are transplanted to the main field after about 45–60 days. The plant grows well in well-drained sandy loam to black soil under warm tropical conditions and requires moderate irrigation along with timely weeding for optimum establishment. The tuberous roots, which constitute the economically important part of the plant, are harvested 18–24 months after planting when the crop reaches maturity. After harvesting, the roots are thoroughly washed, cut into suitable pieces, and dried before being marketed for the preparation of herbal powders, capsules, tonics, and functional foods. Owing to its increasing market demand and relatively low input requirements, shatavari cultivation offers promising economic returns, with a cost–benefit ratio typically ranging from about 1:2 to 1:3, depending on yield, management practices, and prevailing market prices.



Shatavari seed for propagation

Shatavari seedlings in polybag

Shatavari plant ready for transplanting

Shatavari is more than a medicinal plant, it symbolizes strength, nourishment, and resilience rooted in nature. At a time when lifestyle stress, hormonal imbalances, and reproductive health concerns are increasingly common, shatavari offers a scientifically supported yet traditionally trusted botanical ally. By bridging ancient wisdom and modern research, it stands as a reminder that sustainable health solutions can emerge from well-documented traditional knowledge systems.



Copper Sulphate: The Blue Dust Balancing Algae and Aquatic Life

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ABSTRACT

For more than a century, copper sulphate, also referred to as bluestone or blue dust has been one of the most extensively utilized chemicals in freshwater aquaculture and water management. Its potent algacidal qualities enable it to effectively manage toxic algal blooms, enhance water clarity, and lessen pond and reservoir odour issues. Recent research, however, shows that although copper treatments offer temporary respite, they may also cause long-term ecological disruptions. These include changes in microbial diversity, oxygen depletion, nutrient imbalances, and the buildup of toxic residues in sediments. This article examines the effects of copper sulphate on the environment, aquaculture, safe dosage calculations, and its mechanism of action. Along with providing sustainable alternatives for controlling algae and preserving the health of aquatic ecosystems, it also highlights recent research demonstrating the legacy effects of copper use on cyanobacterial communities. This article, which is written in an approachable style, helps researchers, students, and regular water managers understand the connection between science and practice.

KEYWORDS

Copper sulphate, water alkalinity, algae control, parasite management, *Ichthyophthirius multifiliis*, toxicity, dosage guidelines, pond management, fish sensitivity, water hardness, copper toxicity, safe application, water chemistry, fish health.

INTRODUCTION

Have you ever noticed a pond emitting an unpleasant, earthy odour or turning a bright green? These are indicators of algal blooms, which are an overabundance of microscopic plants that feed on phosphorus and other nutrients. Copper sulphate has been the "go-to" remedy for cleaning up such waters for more than a century. Farmers and fisheries managers refer to it as "bluestone," a low-cost, quick-acting substance that eradicates numerous waterborne parasites and algae. However, the tale doesn't stop there. While copper treatments can rapidly suppress algal blooms, they may also cause subtle ecological changes, including shifts in microbial community structure and nutrient imbalances, which over time can degrade water quality and increase the risk of taste, odour, and toxin problems (Boyd et al.,2015).

WHAT IS COPPER SULPHATE AND HOW IT WORKS?

CuSO_4 , or copper sulphate, is a blue crystalline salt that dissolves easily in water. Copper ions damage algae's cell membranes and enzymes when they are put in a pond or reservoir. This stops them from photosynthesizing and eventually kills them. The University



of Florida's Extension Service says that the compound works best when it is applied in exact amounts that are based on the water's alkalinity, which is a measure of how well it can buffer itself. If the total alkalinity is 100 mg/L, for instance, you should only use about 1 ppm (part per million) of copper sulphate. Copper toxicity increases under low alkalinity conditions, making it more harmful to fish, and aquaculture guidelines indicate that species such as carp, koi, and trout are particularly sensitive to copper exposure (Wurts, 2002). Copper concentrations safe for one pond could be lethal in another, especially if the water's alkalinity is below 50 mg/L.

USE OF COPPER SULPHATE IN AQUACULTURE AND FISHERIES

In aquaculture, copper sulphate (CuSO₄) is a widely used chemical compound because of its effectiveness in maintaining water quality and controlling fish health problems. It serves two major purposes in pond and tank management:

- **Controlling Algae:** Algal blooms, especially those of green algae, can make the water in the pond look dirty or pea green. These blooms can keep sunlight from getting to deeper water layers. This makes it harder for submerged plants to photosynthesize and makes the water less oxygen-rich at night. Fish can get stressed out or even die if there isn't enough oxygen. Copper sulphate kills algae by messing with their cells, which clears the water. Using it regularly and carefully helps keep the water clear and the aquatic environment in balance.
- **Parasite treatment:** Copper sulphate is also a good way to get rid of parasites. It works against external protozoan parasites like *Ichthyophthirius multifiliis* ("Ich"), *Trichodina*, and *Chilodonella*, which often live on fish's skin and gills. These parasites can make you feel bad, make you cough up a lot of mucus, and make it hard to breathe. Copper sulphate kills parasites by breaking down their cell membranes and enzyme systems when used at the right concentration. It does not hurt fish. (Craig Watson et al.,2024)

Dosage for aquaculture

Copper sulphate has advantages, but it must be used carefully. If the substance is administered unevenly or in excess, it can quickly become poisonous. Before applying copper sulphate, experts advise completely diluting it with water and distributing it uniformly across the pond's surface. Uneven distribution can lead to "hot spots," which are regions with elevated copper concentrations that can harm fish tissues, kill planktonic creatures, and eliminate good bacteria that are necessary for the cycling of nutrients. Copper toxicity is also affected by water hardness, alkalinity, and pH; it is more harmful in soft, acidic water. The amount of copper sulphate required for effective treatment in aquaculture ponds largely depends on the total alkalinity of the water, and recommended dosage rates vary according to different alkalinity levels, as presented in Table 1 (Wurts, 2002).

Total alkalinity(mg/l)	Copper sulphate applied (Lb/acre foot)
Below 20	Copper sulphate should not be used
20	0.6
50	1.3



100	2.0
150	2.8
200	5.5
Above 200	Effectiveness of the copper sulphate is greatly reduced

Carp, grass carp, goldfish, koi, trout, and salmon are reported to be more sensitive to copper than other fish. It's risky to use copper sulphate in ponds containing these fish species; alternative treatments should be considered.

Environmental water quality impacts

Copper sulphate application in reservoir ecosystems is effective in the short term for controlling cyanobacteria (blue-green algae); however, its long-term use can alter microbial community structure and ecosystem stability. Following treatment, beneficial cyanobacteria may be replaced by other microbial groups such as Planctomycetota and Actinobacteriota, leading to microbial imbalance. These shifts can destabilize reservoir ecosystems and increase the risk of taste, odour, and toxin issues in drinking water. Additionally, rapid algal die-off results in decomposition that releases nutrients, particularly phosphorus, back into the water column, creating conditions favourable for subsequent algal blooms through internal nutrient loading. Prolonged use may also result in copper accumulation in sediments, posing potential risks to fish, snails, and other aquatic organisms (S.E. Watson et al., 2024).

Safe usage and best practices

When using copper sulphate, experts advise taking the following precautions:

- Prior to application, check the alkalinity of the water. If the alkalinity is less than 50 mg/L, do not use copper.
- Steer clear of treating dense blooms that cover more than 30% of a pond's surface because the abrupt die-off can kill fish and deplete oxygen
- Steer clear of overuse, as too much copper can build up in sediments and damage organisms that are not the intended target. Apply sparingly and uniformly, particularly in warm, low-oxygen environments
- Maintain dissolved oxygen levels by using aeration systems both during and after treatment. Steer clear of overuse, as too much copper can build up in sediments and damage organisms that are not the intended target

DISADVANTAGES OF USING COPPER SULPHATE IN AQUACULTURE

- Despite its efficiency in eliminating algae and parasites, the use of copper sulfate in aquaculture poses numerous downsides that deserve cautious evaluation. One significant issue is that free copper ions become more active and detrimental to fish in soft or low-alkalinity waters (below 20 mg/L as CaCO₃), which can cause gill damage, stress, and even death .
- Additionally, copper sulphate functions as a non-selective biocide, removing not only toxic algae but also advantageous plankton and microorganisms that are essential for pond biological balance and nutrient cycling .



- In addition to aquaculture, inappropriate use or dumping of copper sulphate can contaminate adjacent water bodies, endangering organisms that are not the intended target and perhaps making their way into the food chain, hence creating long-term dangers to human health and the environment.

LOOKING AHEAD: TOWARD ALGAE SUSTAINABLE MANAGEMENT

Copper sulphate continues to be used for controlling algal growth; however, it cannot be regarded as a permanent or sustainable remedy due to its limited effectiveness over time and its potential impacts on non-target aquatic organisms. As a result, water resource managers are increasingly focusing on environmentally safer approaches, including biological methods such as the use of beneficial microorganisms or algae-feeding fish, physical techniques like aeration and ultrasonic treatment to inhibit bloom development, and nutrient management practices aimed at reducing phosphorus inputs from agricultural runoff. The overall goal of these approaches is to maintain clean water bodies while safeguarding aquatic ecosystems and ensuring long-term environmental sustainability (Cooke et al., 2005).

CONCLUSION

Bluestone, also known as copper sulphate, has two sides in the water management industry. Although it provides quick respite from toxic algal blooms, it can subtly change the fragile ecology of reservoirs and ponds. This "blue dust" can continue to be a beneficial ally rather than an invisible danger to aquatic ecosystems if it is used responsibly and scientifically, guided by water chemistry and ecological awareness.

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Copper sulphate in crystal form



Ichthyophthirius multifiliis ("Ich")



Copper sulphate pollution





Bonsai- The Living Illusion

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ABSTRACT

A bonsai is one of the beautiful art form of plants that originated in China. The ultimate goal of growing a Bonsai is to create a miniaturized but realistic representation of nature in the form of a tree. Bonsai are not genetically dwarfed plants, in fact, any tree species can be used to grow one. “Bon” means a dish or thin bowl or “a modified vessel which has been divided or cut down from a deeper form” and “Sai” means a tree or other growing plant which is planted. “Bonsai” thus means or denotes “a tree which is planted in a shallow container”.

The art form thrived in Japan for hundreds of years and was categorized according to their growth habit and different types. In around 13th century, there grew a culture of Japanese collecting the forest trees that were dwarf by nature and by several training practices they trained the trees for pot culture and reduced them more in size and were beautifully designed. Whereas the naturally formed miniature trees plants was one of the first bonsai. In ancient India there are some references found that bonsai prepare from medicinal plants and called as “Waman Vruksha.”





In nature the old trees have more prominent rounded canopy as compared to young trees, and also have more drooping branches which makes them appear aged and elegant in looks and considered more desirable for bonsai.

Styles of Bonsai

There are more than 100 recognized styles in bonsai, but most experts consider five basic styles to be essential – formal upright, informal upright, slanting, cascade and semi-cascade. Another three styles also famous forest, root over rock and broom style. The Chicago Botanic Garden’s bonsai collection includes specimens in a range of 20 different styles.

			
Formal Style	Informal Style	Slanting Style	Cascade Style



			
Semi Cascade Style	Forest Style	Root Over Rock Style	Broom Style

Ideal Plants for Bonsai

Any significant plant can be prepared into a bonsai in the event that it can adjust to the shallow pots and limited development that bonsai require. Most bonsai are a hardy outdoor plant that needs a period of cold dormancy in the winter to thrive, but they should be protected from the harshest winter conditions.

Select a species of tree suitable for climate. The plants which offer special features such as small leaves, flowers, attractive bark, small foliage or seasonal fruits, cones and which have vigorous growing habits. Plants which give dense growth after every pinching and cutting.

Eg. Casurina Equisetifolia, Pine (Pinus), Ficus Varieties, Junipers, Tamarind, Chinese Orange, Bougainvillea, Chinese Elm - One of the most splendid elms, this east Asian native becomes a spectacular bonsai easily. Keep the plant in a spot that receives the sun in the morning and in the evening if possible. Chinese elm can tolerate the wide range of temperatures but doesn't like cold drafts. Longevity of this bonsai is 12 years. Styles: Broom, Informal upright, Cascade, Semi Cascade.

Tools for Bonsai

Bonsai requires very few tools. These tools, however, make certain jobs or tasks easier and quicker. Trimming shears or any scissors, Secateurs, Concave branch cutter, Wire cutter, Pliers, Root rake for removing soil from plants, Brush, Clamp for bending heavy trunk & branches, potting spatula and Poking stick.



Tools for Bonsai



Bonsai Containers

The selection of container is one of the most important considerations in bonsai trees. The container should be of proper depth and must be in proper proportion to the plant growth. It must look attractive and should be durable. The shape of the container can be round, oval or rectangular. For a single upright stem, an oval or round container will suit better while for the cascade style a rectangular container looks more artistic. An unglazed container is preferred as it allows aeration of the soil. The color of the container should be as natural as possible.



Pots for Bonsai

Propagation of Plants for Making Bonsai

By means of Seeds, Layering, Cuttings, Grafting, Buying from nursery and Collection from forests.

Ideal Time of Planting Bonsai

Generally, bonsai prepare or planted in February - March and July – August

Soil requirement

The soil mix used for bonsai should be of such a nature that it will not become waterlogged or sour and should not be rich in manures. Coarse, well drained medium which provide basic needs like water, oxygen and nutrition. The chemical reaction of the soil should be close to neutrality. Good soil mix will be made up of 2 parts of Loamy Soil or Coco-Peat, 1 and 1/2 parts coarse river sand, and 1 part leaf litter and crushed bricks or sand is ideal medium. Top layer must have sufficient humus. Conifer plants require more dry soil and fruit trees require soil with more humus.

Potting Method

Cover the drainage hole of the selected pot by the help of any plastic or steel wire mesh to prevent soil from draining out. Cover bottom of pot with thin layer of brick pieces of sizes 6 mm to 10 mm. Put some river sand on the brick pieces to cover the gaps between the brick pieces. Put some prepared soil on these brick pieces. Remove the plant from nursery container and with the help of root-rake or chop-stick remove 2/3rd portion of soil from the plant. Cut any tap thick or encircling roots of the plant. Now put the plant into the pot. If the pot is round or square, place it in centre. If it is rectangular or oval place the plant off the centre towards the rear on any side, left or right. Fill the container by the prepared soil. If the plant requires some support, tie a wire from outside the pot anchoring the trunk of the plant. Poke the soil with chop-stick to remove air pockets. Water the Bonsai by a fine nose shower. Keep this Bonsai in semi shade for 10 days and after this period bring it to full sunlight.

**Wiring**

Wiring is used for training the branches and trunk of bonsai to a desired shape. Two types of wire are used-copper or aluminum but mostly copper wire is used. While wiring branches, keep wire at 45o angle to branch for best results. Wire should be removed after a few months when it starts penetrating into the bark of plants.

Water requirement

As Bonsai grows on shallow containers, watering is an important aspect. During the summer months, watering three times a day is necessary. The compost should be filled in a container leaving about 2-3cm space from the brim to facilitate watering. One way of ensuring whether a plant needs watering is to tap the container with a wooden hammer on the sides. If a dull sound comes out, the plant should not be watered. But if there is a ringing tone, the plant needs watering.

Manure requirement

Manuring is needed for proper vegetative growth and to encourage flowering or fruiting. Generally, manuring is done twice a year, once during the spring and again during the rainy season. Too much manuring should be avoided as this may cause soft and sappy growth.

Repotting

The fast-growing plants need repotting every year, while the slow-growing plants may be repotted every 2-3 years. The plant is removed out of the pot gently with the earth ball and all drainage materials are removed. 1/3 of the old subsoil is removed. Soil stuck up between a few of the roots may be removed. Any root that is longer than what is accommodated in the container, is cut with a secateur. The plant is then placed in a position in the container and compost is filled in. The plant is immediately watered.

Training of Bonsai

Bottom 1/3rd part of plant should not have any branches. Middle 1/3rd part of plant should have bigger branches and top 1/3rd should have smaller branches than middle portion. So shape of the plant become triangular in shape. Every Bonsai should have one apex. Overall form of Bonsai must be triangular so that sunlight can reach each and every part of the plant. The lowest branches of a Bonsai must be the heaviest. Avoid branches coming directly towards the front. Always cut growing branches leaving two sets of leaves for compact growth of plants. Expose roots of plants on the surface of soil in radial direction. Every Bonsai must have one front and one back. Front of Bonsai is the side from which the plant looks most beautiful. Back branches are required for depth of a Bonsai. Allow branches to grow only in a horizontal direction. Trim branches which cross one other. Trim parallel growing branches.

Care & Maintenance

- Protect the plant from heavy winds and strong sunlight during summer.
- Keep Bonsai in neat and clean open area where it will get fresh air and full sunlight.
- Bonsai is outdoor plant which can be brought inside for one or two days for decoration purpose. If it is kept inside for long period it may die.
- In winter season don't give any water to Bonsai until and unless the soil becomes completely dry. But in summer season special care is required to water at least 2 times a day.
- Regularly pinch or prune the new leaf buds of Bonsai to maintain overall shape and maintain the vigour of the plant.



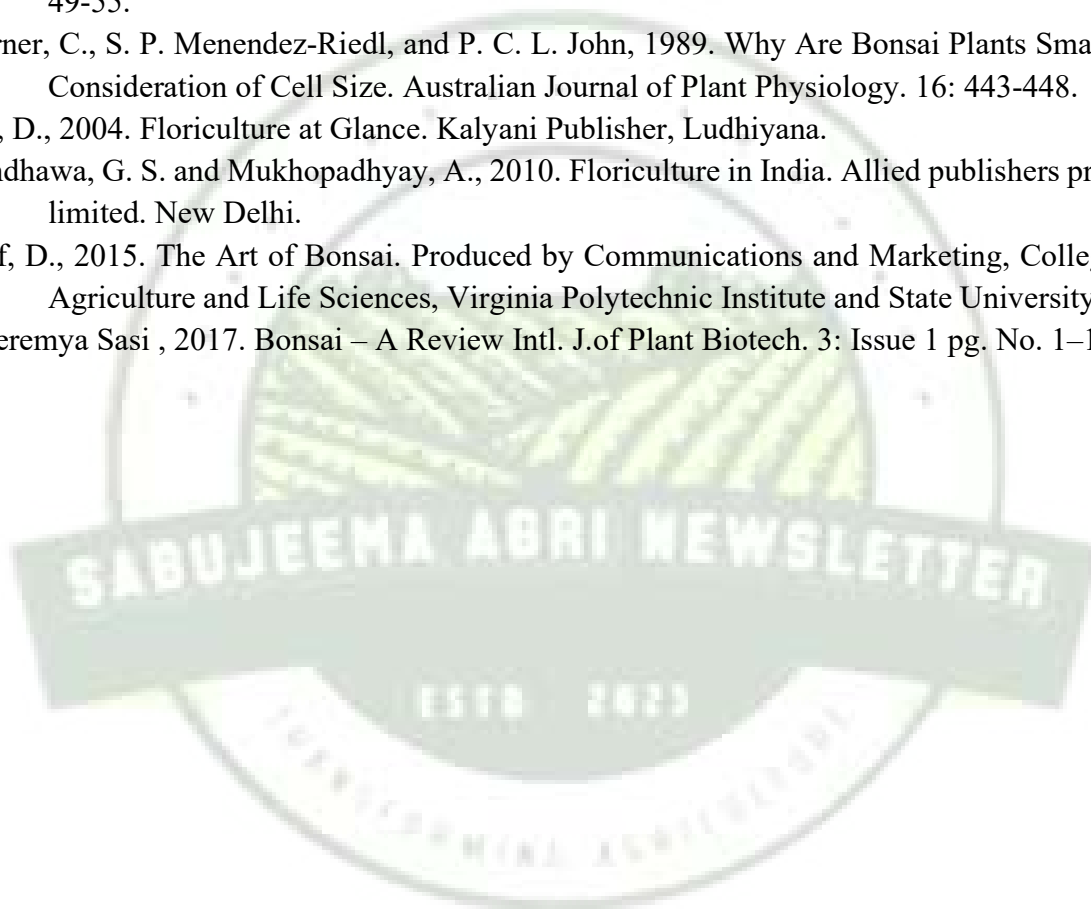
- Wash the leaves of Bonsai once a week.

Conclusion

Ultimately, bonsai is far more than just a tree in a pot; it is a living, breathing artwork that bridges the gap between humanity and nature. Through the patient and sometimes decades-long, process of training and shaping, we learn to accept the beauty of imperfection and the inevitability of change. In a world that often moves too fast, cultivating a bonsai invites us to slow down, find inner peace and cherish the quiet, unfolding beauty of nature in miniature.

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Assessing Drought Adaptation in Soybean: Morphological, Physiological and Yield-Based Indicators

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ABSTRACT

Soybean (*Glycine max* L. Merrill) is an important legume crop because of its considerable protein content (about 42%) and oil content (about 20%). However, drought stress greatly limits its productivity, especially during reproductive stages. As drought tolerance is a quantitative trait, its assessment requires an integrated approach to the analysis of its related morphological, physiological, and yield-related parameters under different moisture conditions. Important drought tolerance traits in soybean are root characteristics, plant height, leaf area, relative water content (RWC), canopy temperature depression (CTD), and chlorophyll retention. The yield-related drought indices, such as the Drought Susceptibility Index (DSI) and Drought Resistance Index (DRI), are useful in comparing genotypes and in the precise breeding of drought-tolerant and high-yielding soybean varieties.

Keywords: Drought stress, Drought tolerance, Morphological traits, Relative water content, Drought resistance index.

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is a self-pollinated legume ($2n = 40$) belonging to the family Fabaceae, subfamily Papilionoideae. Its origin is in northern and central China. Soybean is globally important due to its nutritional and industrial significance. Among the grain legumes, soybean seeds contain 42% protein and 20% oil content. Therefore, Soybean is a major source of plant protein and edible oil. Soybean is also enriched with the presence of essential amino acids such as lysine and tryptophan. These amino acids provide a competitive edge to soybean over other cereal grains. Due to its numerous uses in food, feed, and industrial sectors, soybean is also called the “Golden Bean” or the “Miracle Crop” of the Twentieth Century.



Despite its considerable economic importance, soybean productivity is adversely affected by a number of abiotic and biotic stresses. Among these stresses, Drought is a major constraint to soybean productivity. In fact, soybean yield in India is still stagnant for the last three decades because of recurring drought stress and environmental limitations. Drought stress may reduce soybean productivity by 40%. Its severity may result in yield loss of more than 80%. Terminal drought stress during the seed-filling stages (R4-R6) is the most detrimental because of the abortion of pods, shriveling of the seeds, and a consequent reduction in hundred-grain weight. Drought resistance in soybean is a complex quantitative trait controlled by many different parameters, including those related to morphology, physiology, and yield. As such, its evaluation entails a holistic approach considering both stressed and non-stressed conditions. Soybean root architecture, relative water content, canopy temperature depression, as well as drought indices like DSI and DRI, are collectively useful for the identification of genotypes for maintaining productivity under conditions of water deficit.

Drought

Drought is defined as an insufficient supply of moisture that causes a reduction in the production of plants. More specifically, drought is the difference between the water demand of a crop and the water supply. Drought is categorized into three main types:-

- 1. Meteorological Drought:** This is the most common form of drought, where there is an extended period of below-average rainfall.
- 2. Hydrological Drought:** This occurs when the water supply in sources such as groundwater, lakes, and reservoirs is below the statistical average. This can happen even when there is regular rainfall, provided the water demand is more than the water supply.
- 3. Agricultural Drought:** This is specifically defined as insufficient supply of water in the soil for the maximum growth of plants. This can be caused by insufficient rainfall, but it can also be caused by certain factors in the soil that prevent plants from accessing water.

Mechanisms of Drought Resistance

Drought resistance is an overarching term that describes the plant's ability to perform at an acceptable level when water is scarce. Drought resistance can be broken down into three sub-components, namely dehydration avoidance, dehydration tolerance, and drought escape.

- 1. Dehydration Avoidance:** The ability of the plant to retain a high level of tissue water content (i.e., water status) even when water stress is induced by the soil or the atmosphere. This is a primary mechanism observed in many crop species, where the plant can develop a root system that extends to reach water at greater depths, regulate water loss through the opening and closure of stomata, develop an epicuticular wax layer to prevent non-stomatal water loss, and osmotic adjustment to maintain turgidity in the cell.
- 2. Dehydration Tolerance:** The ability of the plant, or its parts, to perform when the water content in the tissues is low, i.e., dehydrated. This is the ability to maintain growth, fertility, and translocation even when the tissues in the plants are dehydrated. This should be evaluated by comparing the water status in different plants.
- 3. Drought Escape:** The ability of the plants to mature and produce grains before the onset of severe water stress that occurs during the dry season in the region where the plants are grown. This is the most important aspect of drought escape, where the plants will escape the severe water stress that would otherwise impair the plants' ability to produce grains.



Concept of Drought Characteristics Estimation

The concept of drought characteristics estimation refers to the systematic measurement and evaluation of traits that indicate a soybean plant's response to water deficit conditions, and these characteristics are categorized into different groups.

Morphological Indicators:

- **Leaf area:** The total leaf surface area of photo synthetically active leaves per plant or leaf area index per unit ground area, is an important parameter that plays a vital role in transpiration rate. Drought stress generally inhibits leaf area by accelerating senescence, thus affecting water use efficiency.
- **Leaf rolling:** Leaf rolling is a response to drought stress that leads to a loss of turgidity. This phenomenon reduces net radiation load on the leaf. Leaf rolling is one of the major symptoms of drought stress in cereals. In broad-leaved species such as soybean, leaf rolling or wilting with discoloration of leaves due to drought stress is observed.
- **Root length (primary root):** The root length refers to the length of a single axial root present in a taproot system, such as that found in soybeans. The axial root acts as a single root that explores deeper soil strata.
- **Root-to-shoot ratio:** The ratio represents the final weight of dry matter present in the root system divided by the final weight of dry matter present in the shoots. The ratio normally increases under drought stress as more biomass is allocated towards root development.
- **Root angle:** The root angle represents the geotropic growth angle. The change in root growth angles affects the depth of root penetration, thereby determining whether it becomes dehydrated.
- **Total root length (primary, secondary, and tertiary roots):** The total root length represents the sum of all root components. The total root length is positively related to root conductivity, which is essential for meeting transpiration demand.

Physiological Indicators:

1. Relative Water Content (RWC)

This acts as a standard and efficient measure of the water status of plants by measuring the leaf's water content relative to its water content at full turgor. RWC is better than measuring leaf water potential since, while the latter measures the physical status of the leaf, RWC measures the actual water content in the cells and incorporates osmotic adjustment.

$$RWC (\%) = \frac{(TW - DW)}{(FW - DW)} \times 100$$

Where, **FW** – Fresh Weight, **DW** – Dry Weight (after oven drying), **TW** – Turgid Weight (after rehydration to full turgor)

Maintaining high RWC during stressful periods is vital for continued growth and successful drought recovery. Plants that exhibit high osmotic adjustment potential will have high RWC and turgor at a given leaf water potential, thus delaying senescence and increasing productivity.

2. Canopy Temperature

Canopy temperature is defined as the average temperature of the leaves of the plant. Canopy temperature is normally measured using infrared thermometry. Canopy temperature acts as a measure of transpiration cooling. When plants have high water status and their stomata are



open, transpiration will cool the leaves. However, when the water status of the plant becomes low and the stomata shut, canopy temperature will rise.

$$\text{Canopy Temperature Depression (CTD)} = T_{air} - T_{canopy}$$

Low canopy temperatures are reliable indicators of yield under drought because they indicate avoidance of dehydration. This means that genotypes with low canopy temperatures are able to access deeper layers of moisture in the soil in order to support transpiration during a drought. High canopy temperatures are associated with drought susceptibility.

3. Chlorophyll Content

This refers to the amount of green pigment present in leaves necessary for capturing photosynthetic energy. Chlorophyll content is often a measure of stay-green phenotype, which is a mechanism to delay chlorophyll degradation under drought stress. Chlorophyll content is often measured indirectly via a SPAD chlorophyll content meter, which gives a reading that is highly correlated to actual leaf chlorophyll content.

Yield-Based Indices

1. Drought Susceptibility Index (S)

The Drought Susceptibility Index (S), developed by **Fischer and Maurer (1978)**, is used to quantify the relative drought tolerance of the genotype by comparing the reduction in yield due to drought stress with the non-stress conditions.

$$S = \frac{1 - \left(\frac{Ys}{Yn}\right)}{D}$$

Stress Intensity (D) is defined by:

$$D = 1 - \left(\frac{Ms}{Mn}\right)$$

Where, **Ys** = Yield of the genotype under stress conditions, **Yn** = Yield of the genotype under non-stress conditions, **Ms** = Mean yield of all the genotypes under stress conditions, **Mn** = Mean yield of all the genotypes under non-stress conditions.

Interpretation:

- (S < 1): Drought tolerant (less yield reduction than average)
- (S > 1): Drought susceptible (greater yield reduction than average)

It compares the relative loss in yield of a genotype under drought conditions relative to the average loss of other genotypes, taking into account the stress intensity (D) for comparison. It assists breeders in identifying genotypes that exhibit low loss in yield under drought conditions, showing tolerance to drought, based on actual data under drought and non-drought conditions.

Drought Resistance Index (DRI)

It is used for the evaluation of the relative performance of genotypes under drought conditions in relation to their yield potential and the mean of the experiment.

$$DRI = \frac{(Ys/Yn)}{(Ms/Mn)}$$

Where:

Ys = yield under stress, **Yn** = yield under non-stress, **Ms** = mean yield under stress, **Mn** = mean yield under non-stress

Interpretation:

- (DRI > 1) implies drought tolerance

- (DRI < 1) implies drought susceptibility

DRI compares the performance of genotypes under drought conditions with their yield potential and the experiment mean. It differentiates between drought-tolerant and non-drought-tolerant genotypes that have high yield potential.

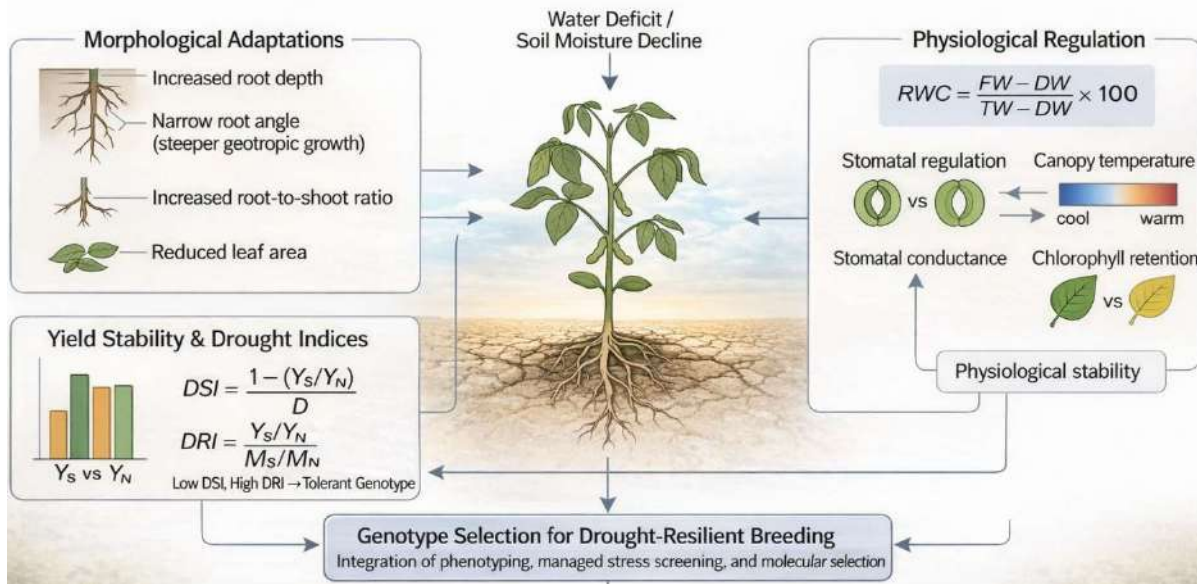


Figure 1. Integrated Systems-Level Framework of Drought Adaptation and Genotype Selection in Soybean

Applications:

1. Selection in Managed Stress Environments (MSE): Drought traits can be most reliably evaluated in managed stress environments such as rainout shelters, managed irrigation, and off-season nurseries. This deliberate application of drought stress can help to identify sensitive stages in the life cycle of the plant, such as flowering, podding, and seed filling.

2. Ideotype Breeding: Estimating drought traits for morphological and physiological characteristics can help to develop drought-tolerant ideotypes, i.e., the concept of breeding plants for particular environments. For plants growing in deeper soils with milder drought, root length density, and root depth can be improved, while for plants in shallow soils with severe drought, water extraction from the upper layers can be improved.

3. Marker-Assisted Selection (MAS): Field measurement of drought tolerance traits such as root depth, osmotic adjustment, etc., is difficult to carry out in the field. MAS can help in the rapid introduction of drought tolerance/avoidance traits associated with QTLs by the use of molecular markers in elite lines.

4. High-Throughput Phenotyping and Remote Sensing: Indirect methods of assessing drought traits, such as canopy temperature depression, and the use of infrared thermometry, etc., can also be used to estimate the water status of plants and transpiration efficiency. High-throughput phenotyping can help in the rapid evaluation of thousands of genotypes for drought stress.

Challenges and Limitations:

1. Field Heterogeneity: Differences in soil types, depths, fertility, and topography may result in experimental errors, irregular water supplies, or moisture availability that may be favorable



to certain genotypes. It becomes difficult to separate genotype and environment effects, which makes precision of selection less effective.

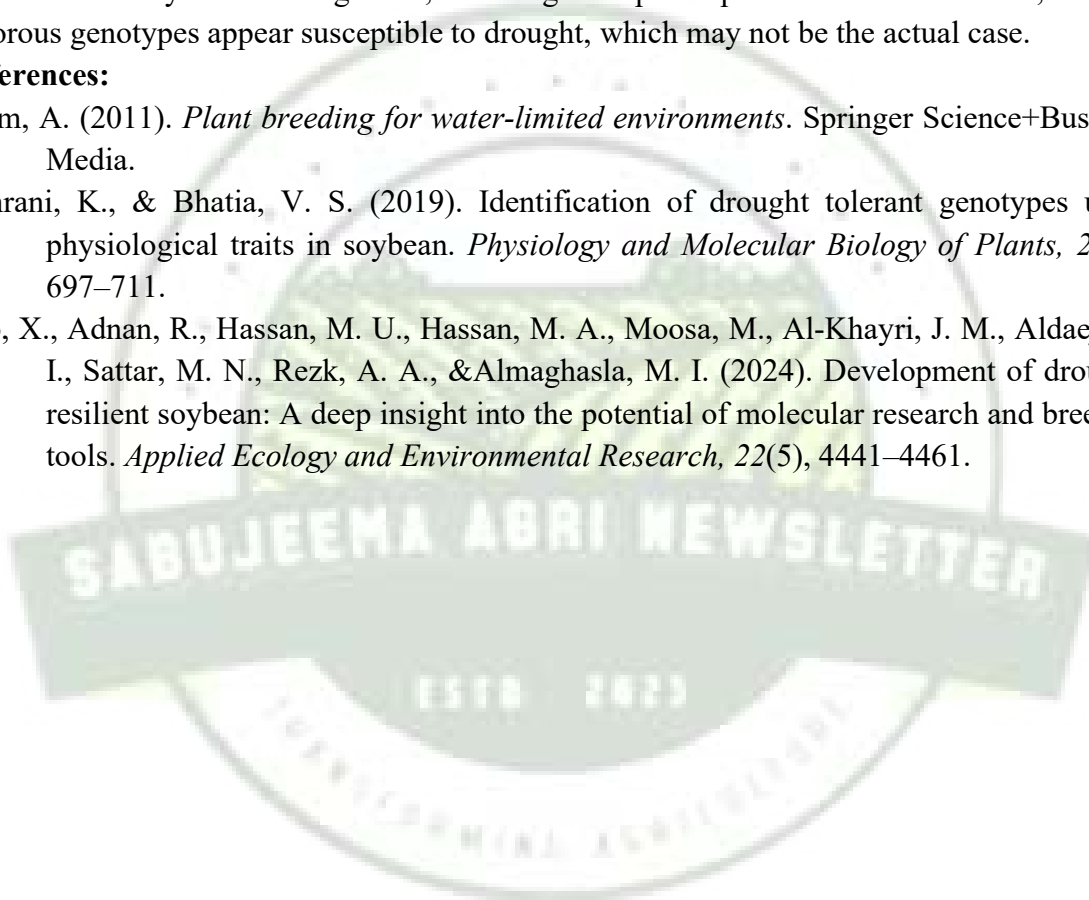
2. Genotype - Phenotype Gap: Drought resistance is environment-dependent. There is genotype x environment interaction that may obscure true potential of genotypes. For example, osmotic adjustment is evident under gradual stress but absent under abrupt stress, which makes it difficult to narrow down the genotype - phenotype gap.

3. Yield Trade-Offs (Crossover Interaction): Genotypes that perform best under optimal conditions may not perform well under severe drought stress. While drought may be survivable under reduced leaf area or transpiration, it may limit biomass productivity under favorable conditions.

4. Pot Experiment Artifacts: The pot method is commonly used, but it has its own limitations. Soil volume may limit root growth, resulting in rapid depletion of soil moisture, making vigorous genotypes appear susceptible to drought, which may not be the actual case.

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Artificial Intelligence–Driven Phenotyping in Sorghum: Transforming Climate-Resilient Crop Improvement

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is a vital cereal crop for food, fodder, and bioenergy, particularly in semi-arid and drought-prone regions. As climate change intensifies abiotic and biotic stresses, accelerating genetic improvement in sorghum has become essential. While genomic tools have advanced rapidly, phenotyping—the measurement of observable plant traits—remains a major bottleneck in breeding programs. Artificial Intelligence (AI)-driven phenotyping integrates imaging technologies, remote sensing, machine learning, and data analytics to enable rapid, accurate, and high-throughput trait evaluation. This article discusses the principles, tools, applications, benefits, challenges, and future prospects of AI-based phenotyping in sorghum breeding. The integration of AI into crop improvement programs holds immense promise for enhancing yield stability, stress tolerance, and climate resilience in sorghum.

Keywords: Sorghum, Artificial Intelligence, High-Throughput Phenotyping, Machine Learning, Climate Change, Precision Breeding

1. Introduction

Sorghum is the fifth most important cereal crop globally and is widely cultivated in Asia, Africa, and parts of the Americas. It is valued for its ability to withstand drought, high temperatures, and marginal soils where other cereals such as rice and wheat struggle to survive. In India, sorghum contributes significantly to dryland agriculture and livestock feeding systems. However, the agricultural landscape is changing rapidly. Rising temperatures, erratic rainfall, prolonged droughts, emerging pests, and new disease races are affecting sorghum productivity. Traditional breeding methods, though successful in the past, often require many years to release improved varieties. The need of the hour is faster, more precise, and data-driven crop improvement strategies. Artificial Intelligence (AI) has emerged as a powerful tool in agriculture. From yield prediction to disease diagnosis, AI is transforming how crops are



monitored and managed. In plant breeding, AI-driven phenotyping is addressing one of the biggest limitations: the slow and labor-intensive measurement of plant traits.

2. The Phenotyping Bottleneck in Sorghum Breeding

Plant breeding depends on two major pillars:

- **Genotyping** – understanding the genetic makeup
- **Phenotyping** – measuring observable traits

Over the last two decades, genotyping technologies have become faster and cheaper due to advances in molecular markers, genome sequencing, and bioinformatics. However, phenotyping has not progressed at the same pace. Measuring plant height, leaf area, biomass, disease severity, and yield components across thousands of breeding lines requires extensive manpower and time.

Manual phenotyping suffers from several limitations:

- Human error and subjective scoring
- Inconsistent measurements
- Environmental variability
- Limited scalability

This imbalance between fast genotyping and slow phenotyping is called the phenotyping bottleneck. AI-driven systems are designed to overcome this challenge.

3. What is AI-Driven Phenotyping?

AI-driven phenotyping refers to the automated measurement and analysis of plant traits using advanced computational techniques. It combines:

- Digital imaging systems
- Remote sensing Technologies
- Sensors and robotics
- Machine learning algorithms
- Big data analytics

Instead of manually measuring plants, high-resolution images and sensor data are captured using drones, ground platforms, or satellites. AI algorithms process this data to extract meaningful traits. For example:

- A drone captures images of a sorghum field.
- Software identifies individual plants.
- Machine learning models estimate plant height and canopy coverage.
- The system ranks genotypes based on performance.

This process is rapid, accurate, and non-destructive.

4. Technologies Enabling AI-Based Phenotyping

4.1 Unmanned Aerial Vehicles (UAVs)

Drones equipped with RGB, multispectral, and hyperspectral cameras can survey large sorghum fields within minutes. These platforms collect data on:

- Canopy structure
- Vegetation indices (e.g., NDVI)
- Leaf color intensity
- Stress symptoms

UAVs allow repeated measurements across growth stages, enabling dynamic monitoring. —



4.2 Multispectral and Hyper spectral Imaging

These sensors capture light beyond the visible spectrum. They detect subtle physiological changes before visible symptoms appear. For instance:

- Reduced chlorophyll content under nitrogen deficiency
- Early drought stress
- Disease infection zones

AI algorithms interpret spectral signatures to classify plant health status.

4.3 Thermal Imaging

Thermal cameras measure canopy temperature. During drought stress, plants with poor water uptake show higher temperatures. Cooler canopies indicate better transpiration efficiency and drought tolerance.

In sorghum breeding, thermal imaging is particularly useful for screening water-use efficiency and heat tolerance.

4.4 Ground-Based Phenotyping Platforms

These include tractor-mounted systems and robotic carts equipped with:

- LiDAR sensors
- High-resolution cameras
- Environmental sensors

They capture detailed plant architecture traits such as:

- Plant height
- Leaf angle
- Stem thickness
- Biomass estimation

4.5 Machine Learning and Deep Learning

Machine learning enables computers to learn from data patterns. Common algorithms used in crop phenotyping include:

- Random Forest
- Support Vector Machines
- Artificial Neural Networks
- Convolutional Neural Networks (CNNs)

Deep learning models automatically identify complex patterns in plant images, such as disease lesions or panicle morphology.

5. Key Traits in Sorghum Assessed Using AI

5.1 Plant Height and Architecture

AI-based image analysis calculates plant height and canopy structure accurately. These traits are linked to lodging resistance and biomass production.

5.2 Stay-Green Trait

The stay-green trait allows sorghum plants to retain green leaves during grain filling under drought stress. AI quantifies leaf greenness using vegetation indices and image colour analysis. This trait is crucial for yield stability in dry environments.

5.3 Biomass and Yield Estimation

Machine learning models correlate canopy area and plant volume with biomass accumulation. Yield prediction models combine environmental and phenotypic data to forecast grain production before harvest.



5.4 Disease Detection

AI models trained on leaf images can detect early symptoms of:

- Anthracnose
- Downy mildew
- Leaf blight

Early detection improves selection efficiency in breeding nurseries.

5.5 Nutrient Deficiency and Stress Indicators

Hyperspectral imaging identifies nutrient imbalances such as nitrogen deficiency. AI algorithms classify stress levels, enabling rapid screening of nutrient-use efficiency.

6. Role in Climate-Resilient Breeding Climate change is increasing the frequency of:

- Heat waves
- Drought periods
- Irregular rainfall
- Pest outbreaks

AI-driven phenotyping allows breeders to:

- Monitor stress progression over time
- Identify tolerant genotypes early
- Evaluate genotype × environment interactions
- Accelerate climate-resilient variety development

By integrating weather data and phenotypic observations, AI enhances predictive breeding strategies.

7. Integration with Genomics

The true power of AI phenotyping lies in its integration with genomic selection. When large phenotypic datasets are combined with molecular marker information, breeders can predict breeding values more accurately.

This integration:

- Increases selection accuracy
- Reduces breeding cycle duration
- Enhances genetic gain per year

Digital phenotyping platforms thus complement modern genomic tools. —

8. Benefits of AI-Based Phenotyping

1. High Throughput – Thousands of plots can be evaluated quickly.
2. Precision – Objective and consistent measurements.
3. Non-Destructive – Plants remain intact during assessment.
4. Cost Efficiency (Long-Term) – Reduced labor and repeated field visits.
5. Time Saving – Faster breeding decisions.
6. Data-Driven Selection – Improved accuracy in genotype ranking. —

9. Challenges and Limitations

Despite its potential, AI-driven phenotyping faces several challenges:

- High initial investment in sensors and drones
- Requirement of technical expertise
- Data storage and processing complexity
- Limited accessibility in small breeding programs
- Environmental variability affecting model accuracy



Moreover, AI models trained in one region may require recalibration before use in another agro-climatic zone.

10. Future Prospects

The future of sorghum improvement will increasingly depend on digital agriculture technologies. Some promising developments include:

- Real-time field monitoring systems
- AI-powered mobile diagnostic apps
- Edge computing for on-site data processing
- Integration with IoT-based soil and weather sensors
- Automated robotic breeding nurseries

As technology becomes more affordable, AI phenotyping may expand beyond research institutions to seed companies and progressive farmers.

In the long term, digital crop twins—virtual models of sorghum fields—may help simulate growth under different climate scenarios. —

11. Implications for Food and Nutritional Security

Sorghum is rich in fiber, antioxidants, and micronutrients. Improving its productivity through AI-assisted breeding supports:

- Food security in drought-prone regions
- Livestock feed supply
- Biofuel production
- Climate-smart agriculture

Faster development of stress-tolerant, high-yielding varieties will benefit millions of smallholder farmers.

12. Conclusion

Artificial Intelligence-driven phenotyping represents a transformative advancement in sorghum breeding. By addressing the long-standing phenotyping bottleneck, AI enhances speed, precision, and scalability in trait evaluation. Its integration with genomics and climate modeling strengthens efforts toward developing resilient, high-performing sorghum varieties. Although challenges related to cost, infrastructure, and expertise remain, continuous technological progress and institutional support are likely to expand adoption. AI-based phenotyping is not merely a technological upgrade it is a paradigm shift in crop improvement. For sorghum, a crop central to dryland agriculture, this innovation offers a promising pathway toward sustainable and climate-resilient food systems.

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