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AUTHORS' DETAILS:

Vishal Gautam Bansode
Department of Veterinary Pharmacology and Toxicology, College of Veterinary Science & Animal Husbandry, Odisha University of Agriculture & Technology, Bhubaneswar-751003, Odisha

Himanshu Sekhar Rout
Department of Veterinary Pharmacology and Toxicology, College of Veterinary Science & Animal Husbandry, Odisha University of Agriculture & Technology, Bhubaneswar-751003, Odisha

Barsarani Sahoo
Department of Veterinary Pharmacology and Toxicology, College of Veterinary Science & Animal Husbandry, Odisha University of Agriculture & Technology, Bhubaneswar-751003, Odisha

Santwana Palai
Department of Veterinary Pharmacology and Toxicology, College of Veterinary Science & Animal Husbandry, Odisha University of Agriculture & Technology, Bhubaneswar-751003, Odisha

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HEPATOTOXICITY IN DOMESTIC ANIMALS

ABSTRACT

Liver is the main organ of metabolism which plays principal role in maintaining body's internal environment. It primarily affects the flow of nutrients and regulates the metabolism of lipids, proteins, and carbohydrates. Hepatotoxicity is seen in livestock due to liver damage which can be caused by virus, metabolic and genetic causes, biliary tract diseases, drug induced hepatotoxicity, immune disorders and vascular abnormalities. The main mechanisms are cellular necrosis, mitochondrial dysfunction and oxidative stress. The diagnosis can be done by with the help of common liver function tests such as SGOT, SGPT, Serum alkaline phosphates test, Serum total protein and albumin test, Serum total and direct bilirubin test, Urine bilirubin and Ultrasonography, FNAC and/or percutaneous liver. The common models to study hepatotoxicity in vitro are includes Isolated cells, Liver slices, Isolated organs, and in vivo are CCl_4 induced, thioacetamide induced, NSAID drugs induced, anticancer drugs induced, toxicity induced by antibiotic, bile duct and portal vein ligation, metal toxicated and genetic models. The in vivo models of hepatotoxicity include non-invasive model includes chemical, drug, radiation, metal or diet-induced hepatotoxicity and invasive model, genetic models., etc. As the liver is primary organs most frequently impacted by absorbed toxicants since it is the first organ to receive portal blood draining from the gastrointestinal system. Prevention of hepatotoxicity can be done by administration of polyphenols, herbals, supplementation of micronutrients, Dietary supplements like n-acetyl cysteine, alpha lipoic acid etc.

Keywords: CCl_4, thioacetamide, NSAID, herbals, alpha lipoic acid

INTRODUCTION

The liver is the largest glands of the body which functions as the hub for metabolism of xenobiotics and excretion of waste products in the body. Adult liver is the primary organ in charge of detoxifying and metabolizing a wide range of endogenous and exogenous substances. The liver structurally modifies regulatory hormones, foreign molecules, and exogenous and endogenous substances (such as medications) to reduce their biological activity or toxicity. This process, known as metabolic detoxification, promotes the intestinal and renal evacuation of potentially hazardous chemicals while reducing intestinal or renal tubular reabsorption. Standard metabolic clearance pathways process compounds such Alcohol, barbiturates, amphetamines, steroids, and hormones (such as estrogens, aldosterone, antidiuretic hormone, and testosterone) to avoid toxic accumulations. There are two types of reactions namely phase I and phase II which are mediated by enzymes which are produced majority by the liver cells. Phase I and Phase II Reactions: There are two primary stages to the liver's detoxification processes:

• Phase I: Involves hydrolysis, reduction, and oxidation processes to increase the reactivity of toxins and facilitate their conjugation in Phase II.

• Phase II: Conjugation reactions that bind chemicals (such as glutathione, sulphate, and glucuronic acid) to toxins, rendering them soluble in water for elimination by bile or urine. Function of Other Organs: In addition to the liver, the kidneys filter blood and remove waste materials that are soluble in water, and the lungs exhale volatile compounds.

There is a long history of using natural medicines to treat liver problems, and medicinal plants and their derivatives are being employed in one way or another for this purpose worldwide. Phytochemical analysis reveals that hepatoprotective plants contain diverse bioactive compounds including phenols, coumarins, lignans, essential oils, monoterpenes, carotinoids, glycosides, flavanoids, organic acids, lipids, alkaloids, and sxanthenes. Recent research has demonstrated that plant-based medications are generally safe, non-toxic, and even free of major adverse effects. Andrographis lineata, Andrographis paniculata are some of the hepatoprotective herbs (Ozougwu et el. 2017, Bhawna et al. 2009, Hassan et al.2024).

CAUSES OF HEPATOTOXCITY IN ANIMALS

There is different type of factors which hampers the work of normal functioning liver and produce liver disease.

1. **Virus:** Hepatotropic viruses are those viruses that primarily targets the liver and these viruses may lead to clinically significant liver disorders. Some viral infections or viruses commonly affect the liver, resulting in acute hepatitis, but in some persistent viral infections chronic hepatitis may develops and leads to liver fibrosis and cirrhosis. Viruses of human such as hepatitis A virus (HAV), HBV, HCV, HDV, HEV, HGV each of it can causes acute inflammation of liver and all this different type of viral hepatitis have a similar kind of pathology.

2. **Metabolic and genetic causes:** The liver's ability to operate can be impacted by a number of hereditary metabolic diseases, such as hemochromatosis, which relates to increased and improper absorption of dietary iron that causes deposits in liver. Wilson's disease is a disease which is related to copper metabolism ailment that is autosomal recessive, the condition causes the liver, brain, kidney, and other tissues to absorb and deposit excessive amounts of dietary copper.

3. **Biliary tract diseases:** Inflammation, scarring, and eventually cirrhosis can result from the liver's bile outflow restriction. It could be subsequent to surgical injury to the common bile duct, or it could be caused by a gallstone or tumour. Primary malignant hepatocytic tumours of the liver and biliary tract are extremely rare in affluent nations. 40 times as many secondary metastatic tumours occur as initial cancers.

4. **Drug induced hepatotoxicity:** Nearly every type of acute and chronic liver illness can be brought on by drugs, and some drugs can cause multiple hepatic reactions. Drug usage has traditionally been seen as a potential cause of liver disease, even if it is not a very common type of adverse drug reaction. Anti-tubercular medicines are among the many medications that cause hepatotoxicity. The first-line anti-tubercular medications, pyrazinamide, isoniazid, and rifampicin, have the potential to cause hepatotoxicity.

Anti-inflammatory Non-Steroidal Medications: Acetaminophen, nimesulide, diclofenac, and ibuprofen.

Antiretroviral medications: Ritonavir, Indinavir, Saquinavir, and Nelfinavir: deadly acute hepatitis caused by a number of anti-retrovirals. Reverse transcriptase inhibitors (NRTIs) that are nucleoside analogues include lamivudine (3TC), tenofovir, and zidovudine.

Medications that prevent hyperlipidemia: Pravastatin, lovastatin, and atorvastatin. *Anaesthetic agents*: Halothane, chloroform, isoflurane, enflurane, desflurane, and other (Pandit et al. 2012)

5. **Immune disorders :** *Autoantibodies and elevated immunoglobulin levels*: These are hallmarks of autoimmune illness, which can impact the hepatocyte or bile duct, autoimmune hepatitis

include primary sclerosis and primary biliary cirrhosis are the examples of these.

6. **Vascular abnormalities:** The blockage of the hepatic venous outflow system is the cause of the uncommon, diverse, and sometimes lethal blood-chiari syndrome. Portal venous system involvement is a frequent consequence that exacerbates the severity of the illness. Patients with BCS have a significantly higher prevalence of underlying thrombophilias (Patel et al. 2012).

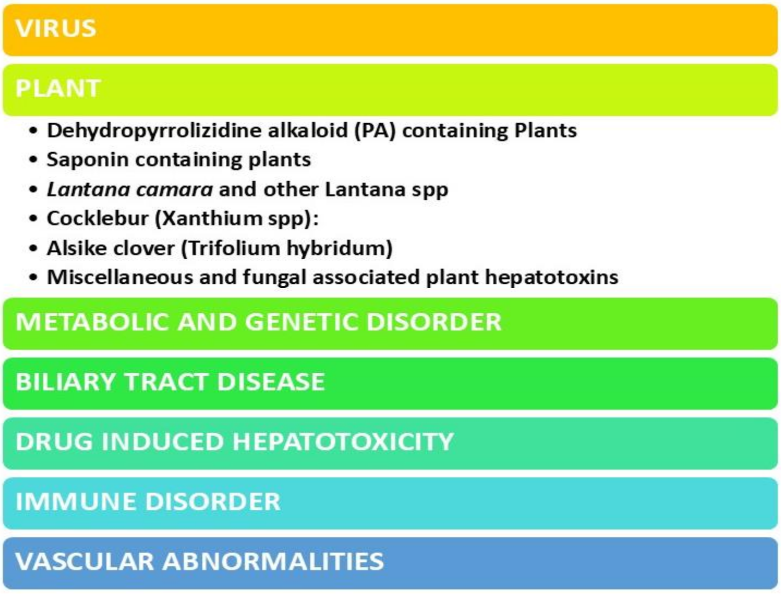

Figure 1 Causes of hepatotoxicity

DIAGNOSIS

Symptoms

Studies indicates that nearabout sixty percent of the liver disease patient shows some typical but not specific symptoms like generalised weakness, fatigue, and general malaise. Chronic liver illness is more likely to cause loss of appetite and ultimately weight loss, Loss of muscle mass in the arms and legs is also common. Patients with an enlarged liver or spleen frequently report experiencing abdominal pain, however this is usually brought on by the distension associated with ascites. Hepatobiliary disease also frequently causes abdominal pain, which is usually restricted to the right upper quadrant part of the abdomen. This is frequently a sign of a quick or severe liver enlargement. Acute hepatitis, hepatic abscess, or hepatic cancer can all cause associated tenderness. The most obvious symptom of liver illness is jaundice.

Sign of the liver disease

1. Skin signs: Increased melanin deposition causes hyperpigmentation, a frequent symptom of chronic liver disease.
2. Abdominal symptoms: Ascites, which can occur in both acute and chronic liver illness, is suggested by abdominal distension, particularly of the flanks.
3. Jaundice: This physical symptom, which is most readily apparent in the sclera, is thought to be indicative of liver illness.
4. Portal hypertension is brought on by increased hepatic resistance to portal flow as a result of cirrhosis.
5. Ascites: The buildup of fluid in the abdominal cavity is known as ascites.
6. Gynecomastia: Chronic liver illness is known to cause endocrine abnormalities (Patel et al. 2012).

COMMON LIVER FUNCTION AND DIAGNOSTIC TESTS

1. Serum glutamate oxaloacetate transaminase (SGOT) test: When the visceral organs of the body such as liver, kidney, heart, muscles and brain are gets injured, the SGOT enzyme is secreted, at 37°C and its typical serum levels can reach 46 IU/L. In patients having with acute hepatic necrosis, viral hepatitis, CCL_4 poisoining. SGOT is 10-200 times higher. Additionally, patients with intrahepatic cholestasis, posthepatic jaundice, alcoholism, and hepatic steatosis showed a 10-fold increase.

2. Serum glutamate pyruvate transaminase (SGPT) test: Damaged liver cells release the SGPT enzyme. At 37°C the normal serum SGPT levels is up to 49 IU/L. Patients with hepatic necrosis and viral hepatitis have extremely high SGPT levels. Additionally, it is 10–200 times greater in individuals with intrahepatic cholestasis and post-hepatic jaundice and less than 10 in those with alcoholic hepatitis, cirrhosis, and in malignancy.

3. Serum alkaline phosphates test: In response of some case of liver disorders such as liver damage, obstruction of bile flow, or some type of liver cancers, enzyme of the liver that is alkaline phosphates gets elevated. Bone disorders, hepatobiliary illnesses, and pregnancy are associated with elevated serum alkaline phosphatase levels, which range from 25 to 85 IU/dl. In cases of biliary system obstruction, the levels of alkaline phosphate may be increased in the range between three to ten than normal level; in cases of parenchymal liver disorders (hepatitis, cirrhosis, and metastatic liver disease), there is a small to moderate rise.

4. Serum total protein and albumin test: When regularly assessed, total protein falls within the normal range of 5.5 g/dl to 8 g/dl. Blood plasma protein levels are lowered in cases of severe liver injury. The liver typically produces between 3.5 and 5.0 g/dl of albumin. Serum albumin gets lowered in patients with chronic liver disease. Because in case of liver disorders hepatocytes are markedly gets destroyed and resulting in hypoalbuminemia, however hyperglobulinemia observed in cases of chronic inflammatory conditions like cirrhosis and chronic hepatitis.

5. Serum total and direct bilirubin test: The Total bilirubin ranges from 0.2-1.2 mg/dl. Bilirubin level rise in conditions including haemolysis, obstruction of bile duct (biliary excretion into the duodenum), and abnormalities in hepatic bilirubin uptake and conjugation, like Gilberts disease. If conjugated or direct bilirubin level is low and total bilirubin level is high, then hepatic cell or bile duct injury can be indicated.

6. Urine bilirubin: Presence of bilirubin in the urine is sign of hepatobiliary disease. Serum bilirubin levels are normal, but conjugated bilirubin can be detected in urine, for example, in the early stages of acute viral hepatitis.

7. Urobilinogen: Increase in the amount of urobilinogen in the urine is consider as sensitive indicator of hepatocellular dysfunction and in case of alcohol-related liver damage, liver malignancy, well-compensated cirrhosis it is a reliable indicator. As a viral hepatitis, it might appear early in the urine and cause a noticeable increase in haemolysis. Additionally, urobilinogen disappears from urine in cholestatic jaundice, but it may occasionally be present in gallstones.

8. Serum Lipid Profile Test: Up to 200 mg/dl of cholesterol is considered normal. Triglycerides (normal range >150 mg/dl) are elevated in the blood due to fatty liver deterioration.

9. Lactic dehydrogenase (LDH) test: Increased quantities of LDH are released into the bloodstream when tissues that hold it are destroyed. Additionally, liver illnesses, heart attacks, some forms of anaemia, excessive cell death, fractures, trauma, muscle injury, and shock all cause elevated LDH levels.

10. Ascorbic acid level in urine: It is used to screen the hepatoprotective drugs used for hepatotoxicity induced by CCl4 in rats Rats' urine excretion of ascorbic acid is reduced during CCl4-induced liver injury.

11. Superoxide dismutase (SOD): The enzyme superoxide dismutase transforms superoxide radicals into oxygen and hydrogen peroxide.

12.: It is an ancillary diagnostic test which can show dilated intrahepatic and extrahepatic canalicular trees due to cholestasis of various causes and space-occupying lesions (SOLs) in the liver which can be neoplasms or non-neoplastic cysts which can be further assigned for liver biopsies or FNAC.

13. FNAC and/or percutaneous liver biopsy: Percutaneous liver biopsy and the ancillary diagnostic test FNAC are used to analyse the microscopic alterations in liver morphology in a variety of hepatic disorders. Their primary indicators can be unknown-cause hepatocellular disease, possible chronic hepatitis cases, hepatomegaly with different causes or unknown-cause splenomegaly and fever (Gulati et al. 2018).

TREATMENT

Plant having hepatoprotective activity

Numerous plants with antioxidant qualities and the capacity to protect the liver can be found in nature. Numerous medicinal herbs are utilized to shield the liver against various illnesses and alcohol-related liver damage. Many plants are now grown as a result of consumer's growing knowledge of the amount, nutritional makeup, and health-promoting qualities of food. Herbal medicines are superior over synthetic drugs because they have minimal side effect, cost effective, minimum chances of drug resistance, and ecofriendly.

Some medicinal plants having hepatoprotective effect includes *Madhuca indica, Cajanus cajan, Aegle marmelos, Amomum sublatum, Cassia roxburghii etc.* These plants are well known for their hepatoprotective property because of their diverse phytochemical range including, polyphenols, flavonoids, terpenoids and other important phytoconstituents. This plant shows the potent antioxidant, anti-inflammatory and membrane stabilizing effects in mechanism of hepatoprotection. This plant also has been studied in laboratory animal models by inducing the hepatotoxicity and have found that on feeding crude extract of plants significantly reduced the hepatotoxicity markers such as SGPT, SGOT, serum bilirubin, alkaline phosphate, and other inflammatory markers. This suggests that these plants have strong hepatoprotective effect.

MODELS USED IN HEPATOTOXICITY STUDY:

In vitro models of hepatotoxicity

Isolated cells: Isolated cells are hepatocytes which is established as valid model for the toxicological studies, this model includes the all-animal hepatocytes including humans also. Source for hepatocytes may be included the biopsy sampling or whole animal liver, but study bile estimation and interactions between cells are the limitation of this model.

Liver slices: liver slice are made though using special précised cut liver and studied for the hepatotoxicity this beneficial to give intact lobular structure and give information about cellular toxicity.

Isolated organs: this is the closest model of in vivo study because this model contains the whole isolated and perfused liver. Used in the study of various toxicity like drugs and chemicals including alcohols, insecticides, metals, paracetamol, methacrylate, cyclosporine, thioacetamide etc.

In vivo models of hepatotoxicity:

This in vivo modelling for hepatotoxicity study are considered as best for the discovering new therapeutic agents. This animal models also mimic the human liver disorders. Which includes the non-invasive model, this models including the different chemical and drug induced intoxications like CCl_4, Aflatoxins, Thioacetamide, NSAID induced, Anticancer drugs, some antibiotics and some heavy metals like mercury. Non invasive model also includes the alcohol induced toxicity and feeding high fat diet, some animals developed as induction of hepatoxicity through radiations. Invasive animal models include Bile duct ligation, Portal vein ligation. Some genetic models have been developed for the study of hepatotoxicity.

PREVENTION

1. **Administration of Polyphenols**: More than 8,000 distinct chemicals are represented by polyphenols, which are frequently found in different parts of plant like leaves, fruits, vegetables, herbs, seeds, and other natural sources. Due to their potential to reduce early pro-inflammatory cytokines like (tumour necrosis factor-α and interleukin (IL)-1β), activate anti-inflammatoryIL-10 and inhibit lipopolysaccharide-induced activation of nuclear factor kappa B (NF-κB) in hepatocytes, polyphenols may be a promising candidate for preventing ethanol-induced liver injury through cyclic AMP-dependent regulation of alcohol metabolic enzymes.

2. **Herbals**:
   - Milk thistle (*Silybum marianum*): One of the most well-known herbal remedies for liver disorders is milk thistle (*Silybum marianum*). By inhibiting lipid peroxidation, depleting liver GSH, preventing genotoxicity, and promoting hepatogenesis, silymarin demonstrated antioxidant qualities and hepatoprotective potential.
   - Glycyrrhizin, the active ingredient derived from the aqueous extraction of the liquorice root (*Glycyrrhiza glabra*): it is found that in cases like human hepatitis, animal inducible hepatocarcinogenesis, and reducing the hepatotoxicity caused by titanium dioxide nanoparticles, Liquorice and its derivatives are beneficial in the treatment.

3. **Supplementation of micronutrients**:

- Vitamin B_{12}: In rats under the influence of dimethyl nitrosamine, vitamin B12 had a hepatoprotective effect. Additionally, vitamin B12 inhibits the genetic expression of heat-shock protein 47 and α-smooth muscle actin, two indicators of liver fibrosis.
- Vitamin C: In experimental animals with cholestatic liver damage, vitamin C can reduce hepatic apoptosis and necrosis.
- Zinc: Because of its structural and catalytic roles in a vast array of enzymes, zinc (Zn) is considered as an essential trace element with a variety of biological impacts. Additionally, zinc contains anti-inflammatory, antioxidant and anti-apoptotic qualities that suggest hepato-nephroprotective effects against hepatotoxicity caused by cadmium.

4. **Dietary supplements**:

- N-acetyl cysteine: NAC is derived from the sulphur-containing amino acid cysteine and acts as an intermediate in the conversion of cysteine to GSH, along with glycine and glutamic acid. When a dietary fitness supplement caused severe hepatic damage, NAC was successful in treating it.
- Alpha lipoic acid: Activation of HSCs driven by transforming growth factor (TGF) and platelet-derived growth factor are inhibited by the ALA. ALA also inhibits the production of reactive oxygen species (ROS), it protects against CCl4-induced hepatotoxicity and liver fibrosis. (Hamzawy et al. 2015)

Conclusion

Hepatotoxicity in domestic animals is a major concern in domestic animals. With the drugs used for treatment of various disease impacting liver health with their side effects there are other agents too like viral, genetic and metabolic causes etc. The signs and symptoms provide a clue for hepatoxicity. There are many preventive strategies for the occurrence of its incidence. This article will help veterinarians to put a check on domestic animals and take them into care and researchers for animal experimentation in development of novel hepatoprotective drugs.

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ETHANOL BLENDED PETROL: A NEW HORIZON FOR INDIAN AGRICULTURE

AUTHORS' DETAILS:

Ipsita Mishra
M.Sc. Scholar
(Agronomy)
OUAT, Bhubaneswar

India's call for green energy revolutionalizes the way we think about agriculture.For generations, the standard notion of Indian farming was in the bubble of abundant harvest followed by a glut in the local market, falling crop prices, and prolonged delays while farmers waited for processing units to clear their payments.Agricultural sector, despite being the backbone of the economy, suffered from chronic income volatility, seasonal cash flow bottlenecks, and heavy vulnerability to global market fluctuations.

Today, a steady shift is happening across domestic fuel stations. Every time an engine fills up with Ethanol Blended Petrol (EBP), a part of that money directly flows towards the agricultural economy. What began as an environmental policy designed to mitigate urban air pollution and lower the national oil import has evolved into a primary growth engine for India's agricultural sector.

The **Ethanol Blended Petrol (EBP) Programme** represents a structural re-designing of the agrarian economy. By converting surplus agricultural produce and crop residue into clean-burning fuel, India is creating a self-sustaining ecosystem of rural as well as environment betterment.

1. The Monetary facts and figures

The success of EBP could be determined by looking into for over a decade.In the past, India's ethanol blending efforts were modest, sabotaged by restrictive policies, limited crop residue availability, and inadequate distillery infrastructure.

The expansion accelerated dramatically following policy updates that prioritized domestic bioenergy production. The trajectory is reflected in national energy and agricultural data:

Fast Blending Rate Trajectory: National average ethanol blending in petrol surged from a meager **1.5% in 2013–14** to **10% in June 2022**, reached **14.6% in 2023–24**, and achieved the national benchmark of **20% (E20)**.

Bulk Procurement: Annual ethanol procurement by Public Sector Oil Marketing Companies (OMCs) expanded exponentially—growing from **38 crore litres in 2013–14** to over **1,200 crore litres**.

Infrastructure Development: Total domestic ethanol production capacity expanded nearly fivefold, growing from **421 crore litres in 2014** to approximately **2,000 crore litres**. This capacity is split across sugar-based distilleries and grain-based plants spread across rural industrial belts.

Direct Liquidity to Rural Communities: Cumulative procurement payments transferred directly to farmers and agricultural processing ecosystems have crossed **₹1.60 lakh crore**, providing much-needed liquidity to rural banks and households.

Foreign Exchange and Import Substitution: By substituting domestic bio-ethanol for imported fossil fuels, the programme has replaced over **310 lakh metric tonnes of crude oil imports**, saving India more than **₹1.90 lakh crore in foreign exchange**.

Environmental Dividends: On the environmental front, lifecycle carbon emissions have been reduced by approximately **930 lakh metric tonnes (93 million MT) of CO_2 equivalents**, contributing vastly to national decarbonization goals.

2.Diversification of Feedstock : Sugarcane, Rice, and Maize

Abandoning the single feedstock model is somewhat the reason for EBP's tremendous success.Previously **C-heavy molasses-** a low-yield,dark,liquid byproduct of raw sugar refining was the exlusive feedstock for bio-ethanol production in India. Heavy dependence on this single residual output restricted blending potential to 2% and made the distilleries disabled without bumper sugarcane production.

National Policy on Biofuels changed the framework of country's biofuel policy. By authorizing distilleries to process **direct sugarcane juice, B-heavy molasses, damaged food grains, surplus rice, and maize**, the supply chain created opportunities across multiple farming sector.

Sugarcane-Based Feedstocks: The Pillar

Sugarcane is the foundation of the bio-ethanol market , supplying approximately **one-third of total national ethanol procurement** (yielding over **238 crore litres** annually).

Direct Sugarcane Juice and Syrup: Diverting sugarcane juice directly to distilleries during peak crushing periods yields significantly higher ethanol per tonne than traditional molasses processing.

B-Heavy Molasses Utilization: Partial extraction of sugar leaves a sucrose-rich molasses that yields higher ethanol output while keeping sugar production calibrated.

Stabilizing the Sugar Sector: In surplus harvest years, excess sugar output historically flooded the market, driving sugar prices below production costs and forcing sugar mills into financial distress. Consequently, mills accrued massive arrears owed to sugarcane farmers. By diverting **4 to 5 million metric tonnes of excess sucrose** annually into ethanol production, the market supply of sugar remains balanced, mill cash flows stabilize, and farmers receive prompt payments for their crop yields.

Grain-Based Feedstocks: Broadening Geographic Inclusion

While sugarcane established the foundation, it requires substantial water resources, restricting its intensive cultivation to states like Uttar Pradesh, Maharashtra, Karnataka, and Tamil Nadu. To ensure inclusive growth across rain-fed and grain-producing regions, grain-based distillation was integrated into the national network. Grain-based feedstocks now account for roughly **two-thirds of total domestic ethanol supply** (over **480 crore litres**).

Maize (Corn) as a Strategic Crop: Maize has become one of the major contributors to the feedstock contributing to over 258 crore litres of ethanol production. Maize requires far less water than sugarcane and has a short growing period of 90 to 110 days. It helps farmers in states like Bihar, Madhya Pradesh, Rajasthan and Andhra Pradesh to grow two or three crops in a year on non-irrigated land and diversify their income streams.

Broken Rice and Damaged Grains: Broken rice grains produced during commercial milling operations and damaged food grains declared unfit for human consumption add more than 90 crore litres to the pool of ethanol. It provides a useful secondary market for grains that would otherwise rot in storage facilities or be sold at huge losses**.**

3. Second-Generation (2G) Bio-Ethanol: Turning Farm Waste into Energy

While First-Generation (1G) ethanol utilizes crop sugars and starches, the ultimate frontier of sustainable bio-ethanol lies in **Second-Generation (2G) Bio-refineries**. These advanced facilities process non-edible lignocellulosic biomass—such as paddy straw, wheat straw, bagasse, cotton stalks, and corn stover.

Supported by funding mechanisms like the **PM-JI-VAN (Pradhan Mantri JAIV-Etanol-Kharid ki Vatanavaran anukul Fasal Awashesh Nivarana) Yojana**, state-owned oil refining corporations have commercialized large-scale 2G bio-refineries:

Industrial Scale Deployment: Commercial 2G plants—such as Indian Oil Corporation's refinery in Panipat, Haryana, along with facilities in Bargarh (Odisha), Bathinda (Punjab), and Numaligarh

(Assam)—are designed with capacities ranging from **100 to 130 kilolitres per day (KLPD)**.

Mitigating Stubble Burning: In Northern India, particularly across Punjab, Haryana, and Western Uttar Pradesh, farmers face tight time windows between harvesting paddy and sowing wheat. Lacking cost-effective alternatives, many resort to open-field stubble burning, causing severe winter smog across the Indo-Gangetic Plain. 2G bio-refineries aggregate hundreds of thousands of tonnes of paddy straw annually, paying farmers and local baling aggregators for crop residues that were previously burned as waste.

Distillery Byproducts (DDGS): In addition to ethanol, grain-based distilleries produce **Distillers Dried Grains with Solubles (DDGS)** as a primary byproduct. Rich in protein and essential nutrients, DDGS is processed into high-grade animal feed for dairy cattle, poultry, and aquaculture, reducing livestock feed costs for farmers.

4. Social and Economic Implications and Safeguards: Based on the review of academic literature and economic impact studies, three key pillars form the crux of sustainable development: Protecting Food security Policy framework in this context is primarily focused on balancing fuel procurement with national food security, avoiding distortions in land-use pattern and preventing shortages in food-grain availability. Accordingly a well-defined hierarchy of feed-stocks for producing biofuels has been imposed: agricultural process wastes (bagasse, molasses, straws) spoiled and damaged food grains not fit for human consumption surplus stocks of food grains determined by central store agency after keeping in view of national buffer-norms dedicated non-food energy crops grown on degraded lands This prioritization ensures, that biofuel production would act as supplements to, not competitors to the food production. Empowering rural economy In addition to the income generated out of selling grains, employment opportunities to thousands of people through establishment of rural distillery units on a decentralised mode have opened avenues for skilled manpower in operations, technicians, supply-chain jobs in tier-2, tier-3 rural markets. An ecosystem of rural logistics based on procurement of biomass/ feedstocks/ distilled fuel between farm-processing plant and retail of fuel to oil companies is operational.

C. Vehicle and Engine Adaptation

As blending ratios shift toward higher levels like E20 and Flex-Fuel Vehicles (FFVs), automotive manufacturers have recalibrated engines, fuel lines, and injectors to resist material corrosion and maintain combustion efficiency. Various studies in the field of automobile has revealed the fact that,these blended fuel functions perfectly in the engines,delivering higher octane ratings and lower tailpipe greenhouse gas emissions.

Conclusion

The widespread popularity of India's Ethanol Blended Petrol Programme shows how synchronisation between energy policy and rural economics can yield national benefits. By forming a direct link between urban fuel demand and rural crop production—spanning sugarcane, rice, maize, and agricultural residues—the model transforms agricultural wastes into a gem for national energy security. As there are many paradigm shifting discoveries in the processing sectors and 2G bio-refineries are scaling up, Agriculture is becoming the lead player in food security as well as sustainability in the country.

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AUTHORS' DETAILS:

CHITRALEKHA DHRUW
Department of Entomology, Indira Gandhi Krishi Vishwavidyalaya, Raipur 492012 (C.G.), India.

RUPENDRA PATEL
Department of Entomology, Indira Gandhi Krishi Vishwavidyalaya, Raipur 492012 (C.G.), India.

ARTICLE ID: 03

MOLECULAR APPROACHES TO INSECT TAXONOMY

Abstract

Molecular taxonomy has transformed insect identification by overcoming the limitations of traditional morphology-based methods. This review discusses the evolution of molecular tools, particularly DNA barcoding, along with emerging approaches such as integrative taxonomy and cybertaxonomy. It highlights that combining molecular, morphological, and digital technologies provides more accurate species identification, improves accessibility, and strengthens biodiversity research and agricultural pest management.

Keywords: molecular taxonomy, DNA barcoding, cybertaxonomy, integrative taxonomy, insect systematics.

Introduction

Molecular taxonomy has revolutionized insect systematics by complementing traditional morphology-based identification with DNA-based techniques. This review outlines the evolution of molecular tools, from early methods such as allozyme analysis and DNA–DNA hybridization to modern DNA barcoding, while discussing their applications and limitations. It also highlights emerging approaches, including cybertaxonomy and integrative taxonomy, which combine molecular, morphological, and digital technologies to improve species identification, resolve cryptic taxa, and strengthen biodiversity research and agricultural pest management.

Molecular taxonomy

Molecular taxonomy is a method in systematics in which we use molecular tools for describing an organism. Some of the tools are described in this section.

Allozyme analysis

Allozymes are different forms of the same enzyme encoded by different alleles of a gene. Allozyme analysis has been used to study monophyly and paraphyly in various species such as *Phytobia spp*. (Nymen *et al.,* 2002). Genetic relationship among ten bug species belonging to tribe Rhodiniini were studied by Monteiro and coworkers (2002.). Sembene along with his associates (1998) compared eight loci in six system of enzymes of 17 samples of *Caryedon serratus*, groundnut seed beetle. All of them were fed on five different hosts- *Arachis hypogea*, *Bauhinia rufescence*, *Cassia seberiana*, *Tamarindus indica* and *Piliostigma reticulatum.* Study showed mean genetic diversity of 0.184. It was found that groundnut beetles fed of *P. reticulatum* and *Arachis hypogea* were genetically similar.

DNA/ DNA Hybridization

The technique of DNA-DNA hybridisation or DNA-DNA reassociation is predicated on a comparison of whole genomes. Teshima (1972) studied base sequence of five black flies' species by DNA-DNA hybridization. The species used by Teshima are *Simulium venustum, S. tuberosum, S. vittatum, Cnephia dacotensis* and *Prosimulium mutidentatum. S. venustum* and *S. tuberosum* were found closely related *S. vittatum* was more distant to these species, Minor homology was reported between *Prosimulium multidentatum* and members of other genera. Sohn and his coworkers (1975) conducted DNA-DNA hybridization to study phylogenetic relationship between six species of black flies.

Techniques currently used to provide molecular characters for insect taxonomy and systematic are as followed Cuticular hydrocarbons, Karyotypes, RFLP, (RAPD)DNA, AFLP, Microsatellites, Direct nucleotide sequencing, SNPs, ESTs and Microarray (Sperling and Roe, 2009). Both allozyme analysis and DNA-DNA hybridization are outdated, nowadays DNA barcoding is the trend.

DNA Barcoding

The technique of characterising species using one or a small number of conserved and standardised DNA regions, known as DNA barcoding, has emerged as a useful tool for species identification. DNA barcoding has been an invaluable tool for rapidly identifying species since its inception in 2003 and is utilised in conjunction with conventional classification. DNA barcoding finds its application in cryptic species identification (Shashank *et al.*, 2018), identification of immature life stages (Vivero *et al.*, 2017), rapid identification in quarantine (Madden *et al.*,2019), host-parasitoid interactions (Sow *et al.*, 2019), herbivore diet analysis (Kartzinel *et al.*,2015), disentangling food webs (Sow *et al.*,2020), understanding pollinator communities and their interactions using environmental DNA barcodes (Thomsen *et al.*, 2019), identification of species from different environments (Harper *et al.*, 2019) and in seasonal diversity shifts (Kirse *et al.*, 2021).

Identification of new species have been done by various scientists using DNA barcoding. A new species of *Conogethes* genera has been identified by Shashank *et al.*, (2018) in India. Similarly, a new species of *Asphondylia* on mango has been reported by Kolesik *et al.*, (2024).

Although the technique of DNA barcoding is a great tool for identification of already-sequenced organisms, and for involving students in research and hypothesis-testing, the use of the technique to discover new species is controver sial and has its critics (Collins and Cruickshank, 2013).

A curious case of minimalist revision

In 2021, Sharkey along with his coworkers described 403 new species in 11 subfamilies of Costa Rican Braconid wasps (Agathidinae, Braconinae, Cheloninae, Homolobinae, Hormiinae, Ichneutinae, Macrocentrinae, Orgilinae, Proteropinae, Rhysipolinae, Rogadinae), including host records for 219 species. Species delimitation is based primarily on DNA barcodes (COI gene), supported by rearing records (55%) and morphology for certain complexes. Each species entry included barcode Index Number (BIN) from BOLD, consensus COI barcode, images (lateral/dorsal) and holotype and locality details.

Numerous scientists have criticised the methodology of minimalist approach. Meier and his team (2021) reanalysed the minimalist species description by Sharkey *et al.,* 2021 and addressed the insufficiently informative diagnoses. Meier *et al.* (2021) indicated that the algorithm utilised by BOLD systems for categorising DNA barcodes is proprietary; hence, others are unable to replicate the findings or evaluate their validity. Furthermore, the outcomes are not consistent. When Meier *et al.* (2021) reanalysed the openly accessible information of Sharkey, *et al.* (2021), they discovered that the addition of additional data altered several of the barcode clusters. They believed that the minimalist method ran the risk of substituting a "superficial taxonomic impediment" (species are so badly and unreliably named that they would need to be redescribed before they can be used) for a "dark taxonomic impediment" (species have not been named). This is supported by Zamani *et al.*, 2022 who stated "DNA barcodes alone are not enough to describe any species".

Future of Molecular Taxonomy

After assessing all the above technique, we suggest a single methodology may not be enough to classify the insect species. Rise of new techniques are opening gates to the bright future of molecular taxonomy of insects.

Cybertaxonomy

Cybertaxonomy is the integration of digital and internet-based technologies into traditional taxonomy to accelerate species identification, classification, and information sharing while addressing the taxonomic impediment (Wheeler, 2008, 2010). Electronic journals such as *Zootaxa* and *ZooKeys*, together with open-access databases including Encyclopedia of Life, GBIF, GenBank, ZooBank, and MorphBank, have made taxonomic information more accessible and interactive. Digitization of museum collections through tools like SPECIFY® and Harvard's E-type initiative has further improved access to specimen data and type images. Interactive identification software such as Lucid Phoenix and Fact Sheet Fusion (FSF) provides multimedia-rich keys and standardized taxon factsheets, making species identification easier for both specialists and non-specialists. Their practical value was demonstrated through the Interactive Identification System for Platygastridae in Kerala's paddy ecosystems, which combined Lucid Phoenix, FSF, and advanced imaging to enhance biodiversity monitoring and agricultural pest management.

Rajmohana and Bijoy (2012) illustrated the practical application of these tools through a case study on parasitic Hymenoptera, specifically the family Platygastridae. These tiny wasps are important egg parasitoids of crop pests and play a significant role in agricultural ecosystems. However, their taxonomy has traditionally remained inaccessible to ecologists due to difficulties in identification. To address this, the authors developed an Interactive Identification System (IIS) for Platygastridae found in Kerala's paddy agroecosystems. Using Lucid Phoenix, FSF, and advanced imaging techniques, the system has been made available online through the Zoological Survey of India.

Favret (2014) also used cybertaxonomy to overcome taxonomic impedance in aphid taxonomy.

Integrative Taxonomy

Wang et al. (2015) resolved cryptic species in the leafhopper genus *Bundera* by integrating mitochondrial DNA (COI and 16S), hyperspectral imaging, and morphological traits. The combined approach confirmed seven distinct species, achieving high classification accuracy (91.3%) and demonstrating that no single method alone was sufficient for reliable species delimitation.

Rudoy et al. (2022) applied integrative taxonomy to the *Encyrtus sasakii* complex, combining morphometrics with molecular phylogenetics (COI and 28S). Their study revealed that the complex comprises three distinct cryptic species—*E. sasakii*, *E. eulecaniumiae*, and *E. rhodococcusiae*—and showed that integrating morphological and molecular evidence provides robust species delimitation and taxonomic validation.

Conclusion

Taxonomy has progressed from a purely morphology-based discipline to one enhanced by molecular tools and digital technologies. While DNA barcoding, integrative taxonomy, and cybertaxonomy have improved insect identification, their true strength lies in integration. Combining molecular markers, morphology, imaging, and digital platforms enables more accurate identification of cryptic species and immature stages, while improving accessibility through open databases and interactive tools. Future advances such as portable sequencing, artificial intelligence, and global cyberinfrastructures will further accelerate taxonomy, making it faster, more collaborative, and predictive. Through such integration, insect taxonomy can overcome the taxonomic impediment and better support biodiversity research, pest management, and conservation.

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At the Edge of Extinction: Critically Endangered Medicinal Plants of the Indian Himalayas

AUTHORS' DETAILS:

Rajni Devi
Agrotechnology Division, Council of Scientific and Industrial Research - Institute of Himalayan Bioresource Technology, Palampur - 176061 (Himachal Pradesh) India

Amit Rana
Agrotechnology Division, Council of Scientific and Industrial Research - Institute of Himalayan Bioresource Technology, Palampur - 176061 (Himachal Pradesh) India

Introduction

Hidden among the forests, alpine meadows, and rugged valleys of the Himalayas grows an extraordinary wealth of medicinal plants. From low-elevation subtropical forests to alpine slopes, this mountain landscape provides a mosaic of habitats where thousands of plant species have evolved and adapted over centuries. Many of these plants possess remarkable medicinal properties and have formed the foundation of traditional healing systems, serving generations of local communities with remedies for common ailments as well as complex diseases. Beyond their medicinal value, these plants are woven into the cultural traditions, livelihoods, and ecological fabric of the Himalayan region. Yet, despite their immense importance, many of these botanical treasures are becoming increasingly rare. Habitat degradation, unsustainable harvesting, and changing environmental conditions are driving several species towards decline, placing both Himalayan biodiversity and centuries of traditional knowledge at risk (Mehta et al. 2023).


Aquilaria malaccensis


Gentiana kurroo


Nardostachys jatamansi


Ormosia robusta


Aconitum chasmanthum


Gymnocladus assamicus


Saussurea costus


Lilium polyphyllum


Meizotropis pellita

(Photo source: IUCN Red List; Flowers of India)

Figure 1: Critically endangered medicinal plant species in the Indian Himalayan Region.

Why does it matter?

The Indian Himalayan Region (IHR) is one of the most important centers of plant diversity in India. Although India occupies only 2.4% of the world's land area, it harbors approximately 47,513 plant species, representing 11.4% of the world's flora, of which 23.8% are endemic. The IHR supports nearly 50% of India's flowering plant species, with about 30% of its flora being endemic (Khandekar and Srivastava 2014; Mehta et al. 2020). The region encompasses diverse biogeographical and climatic zones that support rich plant diversity and valuable plant genetic resources. These biological resources sustain essential ecosystem services, including the maintenance of ecological processes and natural resources, making the IHR vital for the ecological security of India.

Threatened medicinal plants

The Indian Himalayan Region supports a remarkable diversity of rare, endemic, and economically important plant species with medicinal value. Many of these, however, are under threat. Across the Himalayan states of Arunachal Pradesh, Assam, Himachal Pradesh, Jammu and Kashmir, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Uttarakhand, and West Bengal, the IUCN Red List currently classifies about 34 medicinal plant (human and veterinary medicine) species as threatened, comprising 9 Critically Endangered (CR), 13 Endangered (EN), and 12 Vulnerable (VU) species. The nine species falling under Critically Endangered group are presented in Figure 1. These nine span seven families: Fabaceae, Thymelaeaceae, Gentianaceae, Caprifoliaceae, Ranunculaceae, Asteraceae, and Liliaceae. They represent diverse life forms ranging from herbs and shrubs to trees and are valued for their bioactive compounds such as alkaloids, saponins, flavonoids and essential oils. Due to which, these plants face a high to extremely high risk of extinction in the wild due to overharvesting, habitat loss, and market demand. With market values ranging from ₹20 to ₹12,000 per kg, they remain under constant commercial pressure, making timely conservation efforts essential if they are not to be lost for good.

The nine critically endangered medicinal plant species, together with the main plant part used, their major bioactive constituents, and medicinal uses, are summarized in Table 1.

Table 1: Critically endangered species in the Indian Himalayan Region: Parts used, main constituents and uses.

S. No.	Species	Part used	Main constituent	Uses
1.	*Aquilaria malaccensis*	Resin	Agarospirol, jinkoh-eremol, 2-(2-phenylethyl) chromones, essential oil	sedative, digestive, antimicrobial, anti-inflammatory; used as a blood and heart tonic in traditional medicine
2.	*Gentiana kurroo*	Roots and rhizomes	Gentiopicrin (gentiopicroside), gentianin, gentiomarin	Expectorant, stomachic, carminative, anthelmintic; used for cough, stomach ache, and fever
3.	*Nardostachys jatamansi*	Roots and rhizomes	Jatamansone (valeranone), nardostachone, sesquiterpenes, sesquiterpenoids	Sedative, neuroprotective, memory enhancer, anti-inflammatory, antidiabetic; used for nervous and digestive disorders, cough, fever, and rheumatism
4.	*Ormosia robusta*	Bark	Flavonoids, tannins, phenolic compounds	Antioxidant, anti-inflammatory, antimicrobial, cytotoxic; bark used traditionally

S. No.	Species	Part used	Main constituent	Uses
				to treat jaundice
5.	*Aconitum chasmanthum*	Roots and tuber	Aconitine, pseudaconitine, atisine-type diterpenoid alkaloids	Analgesic, anti-inflammatory, antirheumatic; used in Ayurvedic and Homeopathic medicine
6.	*Gymnocladus assamicus*	Pods (mesocarp), bark	Saponins (pods), phenolics and flavonoids	Skin disorders and veterinary medicine; mesocarp used as a natural soap
7.	*Saussurea costus*	Roots	Costunolide, dehydrocostus lactone, sesquiterpene lactones, costus oil	Antiseptic, anti-asthmatic, antiulcer, anti-leprotic
8.	*Lilium polyphyllum*	Bulbs	Steroidal saponins, polysaccharides and alkaloids	expectorant, astringent, aphrodisiac, antipyretic and to treat general debility kidney disorders, fever, pain, and improves vitality and disease resistance
9.	*Meizotropis pellita*	Leaves	alcohols, aldehydes, carboxylic acids, halogenated compound	Antimicrobial and antioxidant
			s	

Why are they facing extinction?

- ✓ **Unsustainable harvesting:** Growing demand for herbal products has led to excessive and illegal collection, rapidly depleting wild populations.
- ✓ **Habitat loss and fragmentation:** Deforestation, agricultural expansion, infrastructure development, and urbanization continue to destroy and fragment natural habitats, leaving small, isolated populations.
- ✓ **Climate change:** Rising temperatures and changing rainfall patterns are shrinking suitable habitats and, together with overharvesting, accelerating species decline.
- ✓ **Slow growth and poor regeneration:** Many Himalayan medicinal plants grow slowly and regenerate poorly, making it difficult for wild populations to recover after harvesting or habitat disturbance.

Conservation efforts

- ✓ **Protect natural habitats:** Strengthen protected areas such as national parks, wildlife sanctuaries, forest reserves, and sacred groves to conserve medicinal plants in their natural habitats.
- ✓ **Promote sustainable harvesting:** Encourage selective collection and non-destructive harvesting practices to allow natural populations to regenerate.
- ✓ **Expand cultivation:** Cultivation on degraded, abandoned, and private lands, along with nursery development, botanical gardens, and micropropagation, can reduce pressure on wild populations.

- ✓ **Engage local communities:** Involve local communities in cultivation, traditional conservation practices, and sustainable resource management to ensure long-term conservation.
- ✓ **Strengthen policies:** Develop species-specific policies for the collection, trade, and sustainable utilization of medicinal plants based on their conservation status.

Conclusion

Himalayan medicinal plants are invaluable natural resources that support traditional healthcare, local livelihoods, and cultural heritage while serving as a rich source of bioactive compounds for future drug discovery. They also play an important role in maintaining biodiversity and ecosystem health. However, increasing pressures from overharvesting, habitat degradation, and climate change threaten not only these remarkable plant species but also the traditional knowledge associated with their use. Conserving these hidden healers requires an integrated approach that combines habitat protection, sustainable harvesting, cultivation and propagation, supportive policies, and the active participation and traditional knowledge of local communities. Through such coordinated efforts, these endangered medicinal plants can be safeguarded for future generations, ensuring the continued conservation of biodiversity, preservation of traditional healthcare practices, and sustainable use of their medicinal potential.

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AUTHORS' DETAILS:

Dr. T.Bharath
Senior Scientist& Head,
Krishi Vigyan Kendra, Bhadradri Kothagudem (PJTAU)

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Oil Palm Cultivation in Telangana: A Pathway to Farmer Prosperity and Edible Oil Self-Reliance

Introduction

Telangana is emerging as one of India's important oil palm-growing states, and the expansion of oil palm cultivation has the potential to transform the rural economy. With assured irrigation, suitable agro-climatic conditions, government support and growing demand for edible oil, oil palm can become an important crop for diversification and sustainable farm income. India is one of the world's largest consumers of edible oils and remains heavily dependent on imports. Recent data highlight the scale of this challenge: India's edible oil imports reached **1.48 million tonnes in July 2026**, while palm oil imports alone rose to about **731,000 tonnes**. Therefore, increasing domestic production of edible oils is not only an agricultural priority but also an economic necessity.

Telangana: A Natural Opportunity for Oil Palm

Telangana has made oil palm expansion a flagship agricultural programme. The Telangana Oil Palm Mission states that the major objectives are to increase vegetable-oil availability, reduce dependence on imported edible oils and promote crop diversification. The state has already made substantial progress. According to the Telangana Socio Economic Outlook, oil palm cultivation reached about **2.03 lakh acres by 2023–24**, with 1,56,927 acres covered under the National Mission on Edible Oils–Oil Palm (NMEO-OP) during 2021–22 to 2023–24. The state has also planned further expansion, supported by assistance for plantation establishment, garden maintenance, intercropping and other interventions.

High Oil Yield and Long-Term Farm Income

Oil palm is particularly attractive because of its very high oil productivity per unit area. Government sources indicate that oil palm can produce several times more edible oil per hectare than traditional oilseed crops. Unlike seasonal crops, oil palm is a perennial plantation with a long economic life. With proper irrigation, nutrition, pest and disease management and timely harvesting, farmers can obtain regular income from Fresh Fruit Bunches (FFBs) over many years.

For farmers, this can mean:

- Better utilization of irrigated land
- Crop diversification beyond paddy, cotton and maize
- Regular income from FFB harvesting
- Scope for intercropping during the early years
- Greater opportunities for mechanization and value addition
- Creation of rural employment and allied enterprises

Reducing India's Edible Oil Import Burden

India's dependence on imported edible oil results in a substantial outflow of foreign exchange and exposes domestic prices to international market fluctuations. The Government of India launched NMEO-OP specifically to expand oil palm cultivation, increase domestic crude palm oil production and reduce the country's import burden. The mission has a financial outlay of **₹11,040 crore** and provides support for planting material, intercropping, maintenance, irrigation-related infrastructure, nurseries, training and harvesting equipment.

Consequently, every additional hectare brought under scientifically managed oil palm can contribute to strengthening domestic edible-oil availability. Telangana, with its expanding irrigation infrastructure and growing plantation base, can play a particularly important role in this national effort.

Boosting the Rural Economy

Oil palm is not merely a crop—it can become the foundation of a broader rural value chain. Expansion of plantations creates demand for nurseries, planting material, irrigation equipment, fertilizers, harvesting tools, transport, processing units, storage and marketing services. The Telangana government has reported that the oil palm programme can generate **farmer income, government revenue, rural employment and growth of ancillary small-scale industries**. Processing infrastructure is equally important. Establishing oil extraction and processing facilities close to production areas can reduce transportation costs, improve FFB handling and generate additional employment in rural regions.

Opportunity for Tribal and Rural Areas

Oil palm can also contribute to economic development in rural and tribal regions where suitable irrigated land is available.

Districts such as **Bhadradri Kothagudem, Khammam and other suitable areas** can benefit from integrated development involving farmers, processing industries, financial institutions, government departments and farmer organizations. However, oil palm should be promoted only in **suitable agro-climatic and water-available areas**. Long-term water availability, soil suitability, drainage and proximity to processing facilities must be carefully considered before plantation establishment.

Sustainable and Scientific Management is Essential

The expansion of oil palm should go hand in hand with responsible natural-resource management. Efficient drip irrigation, mulching, soil-test-based fertilizer application, recycling of organic residues, integrated nutrient management and proper drainage can improve resource-use efficiency. Farmers should also receive continuous technical guidance on plantation establishment, canopy management, nutrient management, pest and disease surveillance, harvesting and FFB quality. The objective should not simply be to increase acreage, but to establish **productive, profitable and sustainable oil palm plantations**.

Telangana Can Lead India's Edible Oil Mission

Government data already identify Telangana and Andhra Pradesh as major oil palm-growing states. Telangana's continuing expansion provides an opportunity to develop a strong oil palm ecosystem—from nursery production and plantation development to FFB collection, processing and marketing. If the expansion is implemented scientifically, oil palm can simultaneously support **farmer prosperity, rural employment, agro-processing, crop diversification and national edible-oil security**.

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AUTHORS' DETAILS:

Dr. T.Bharath
Senior Scientist& Head,
Krishi Vigyan Kendra, Bhadradri Kothagudem (PJTAU)

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Natural Farming for Healthy Soils, Higher Productivity and a Pollution-Free Future

Introduction

Agriculture is entering a new phase in which **soil health, productivity, profitability and environmental sustainability** must go together. Farmers are facing rising costs of fertilizers, pesticides, labour and irrigation, while excessive and imbalanced use of external inputs can contribute to declining soil organic matter, nutrient imbalance, water pollution and loss of beneficial soil organisms. **Natural farming** offers an important pathway towards more resilient and sustainable agriculture. It emphasizes locally available biological resources, recycling of farm biomass, minimum dependence on purchased external inputs, soil cover, biodiversity and ecological processes. Rather than treating soil simply as a medium for supplying nutrients, natural farming considers soil as a **living ecosystem**. The objective is not merely to reduce chemical inputs, but to develop a farming system that can maintain **healthy soils, stable crop yields, lower cultivation costs, better farm profitability and safer food production**.

Healthy Soil is the Foundation of Productive Agriculture

Soil health is one of the most important determinants of long-term agricultural productivity. A healthy soil has good structure, adequate organic matter, active microbial populations, balanced nutrients, better water-holding capacity and sufficient aeration.
Natural farming supports soil health through:

- Continuous addition and recycling of organic and biological resources.
- Retention of crop residues and biomass in the farming system.
- Use of farm-made biological preparations where locally appropriate.
- Soil mulching and maintenance of soil cover.
- Reduced unnecessary soil disturbance.
- Crop diversification and inclusion of legumes.
- Integration of livestock and other farm enterprises.
- Promotion of beneficial microorganisms and soil biodiversity.

These practices can gradually improve soil aggregation, biological activity, nutrient cycling and moisture conservation. However, improvements in soil organic matter and other soil-health indicators are generally **gradual and site-specific**, rather than immediate.

Natural Farming and Crop Productivity

Productivity is a major concern for farmers considering a transition to natural farming. Natural farming should therefore be promoted through **location-specific demonstrations, scientific validation and economic analysis**, rather than assuming that yields will automatically increase in every crop and soil.
Productivity depends on several factors:

Soil health + quality seed + timely sowing + moisture management + balanced plant nutrition + effective pest management + suitable crop varieties + good agronomic practices = sustainable productivity.

Natural farming can contribute to productivity by improving soil moisture retention, nutrient cycling and resilience to weather stresses. Crop diversification can also reduce production risks and provide alternative sources of income. In the initial transition period, farmers may experience variation in yield. Therefore, the success of natural farming should be assessed using **three indicators together: yield, net returns and resource-use efficiency**.

Lower Cost of Cultivation: A Major Opportunity

One of the strongest economic arguments for natural farming is the possibility of reducing expenditure on purchased external inputs.

A conventional crop budget may include expenditure on:

- Chemical fertilizers
- Pesticides and fungicides
- Herbicides
- Seed and planting material
- Irrigation
- Labour
- Machinery
- Transportation
- Other purchased inputs

Natural farming seeks to reduce dependence on several purchased inputs by increasing the use of **farm-generated biomass, crop residues, livestock resources and locally available biological materials**.

Illustrative Cost Comparison

The following is an **illustrative framework**, not a universal cost estimate. Actual values should be calculated from crop- and location-specific field data.

Component	Conventional farming	Natural farming approach
Fertilizer expenditure	High/variable	Potentially lower
Chemical pesticide expenditure	Moderate to high	Potentially lower through ecological pest management
Farm-made inputs	Usually limited	Greater use
Crop-residue recycling	Often limited	Strong emphasis
Soil-cover management	Variable	Important component
External input dependence	Higher	Potentially lower
Labour requirement	Crop/practice dependent	May increase for some practices
Total cultivation cost	Crop and region dependent	Potential to reduce
Net return	Depends on yield and market price	Depends on yield, cost and price premium

The correct economic indicator is not simply the **cost per acre**, but the **net return per acre**:

Net return = Gross return – Total cost of cultivation

Another useful indicator is the **benefit-cost ratio (B ratio)**:

B ratio = Gross return ÷ Total cost of cultivation

Farm-level demonstrations should record all costs, including labour used for preparation and application of farm-made inputs, so that the economic comparison is realistic.

Marketing: From Low-Cost Production to Better Farm Income

Reducing cultivation costs alone does not guarantee higher farmer income. **Marketing is equally important.** Natural farming can create opportunities for differentiated products when consumers are willing to pay for verified attributes such as safe production, traceability, ecological sustainability or organic/natural production methods.

Farmers should therefore focus on:

1. Collective marketing

Small farmers can form farmer groups, Farmer Producer Organisations (FPOs) or other collectives to aggregate produce, reduce transportation costs and improve bargaining power.

2. Grading and sorting

Clean, graded and properly packaged produce can obtain better market acceptance than ungraded produce.

3. Local and direct markets

Direct marketing through farmers' markets, institutional buyers, community-supported agriculture and local retail channels can reduce dependence on multiple intermediaries where suitable.

4. Value addition

Processing can increase the value of farm produce. Examples include:

- Pulses → cleaned and packaged dal
- Millets → flour and ready-to-cook products
- Turmeric → cleaned, dried and powdered turmeric
- Fruits → processed products
- Vegetables → graded and packaged produce

5. Traceability and credibility

Marketing claims should be supported by appropriate standards, certification or traceability mechanisms wherever required. Farmers should avoid making unsupported claims such as "chemical-free" or "100% pesticide-free" without an appropriate basis.

Soil Health and Pollution Control

Excessive and inefficient application of fertilizers and pesticides can contribute to environmental problems. Nutrient losses through runoff and leaching can affect water bodies, while pesticide misuse can affect beneficial organisms and ecological balance.

Natural farming emphasizes:

Right input + right quantity + right time + right place + biological alternatives wherever effective

The objective is to improve nutrient-use efficiency and reduce avoidable losses.

A healthy soil also acts as a **carbon and water reservoir**, helping agriculture become more resilient to droughts, intense rainfall and temperature variability.

Natural Farming and Climate Resilience

Climate variability is increasing production risks for farmers. Natural farming can contribute to resilience through:

- Improved soil moisture conservation
- Increased soil biological activity
- Crop diversification
- Integration of legumes
- Recycling of biomass
- Reduced dependence on purchased inputs
- Integration of crop and livestock enterprises
- Greater use of locally adapted resources

Diversified farms can also spread economic risk. If one crop suffers from drought, pest attack or market fluctuations, other enterprises may provide income.

A Whole-Farm Approach is More Powerful

Natural farming should not be viewed only as a replacement for chemical fertilizer and pesticides. It can be developed as a **whole-farm system**.

A diversified farm may integrate:

Crops + livestock + poultry + sheep/goat + fodder + horticulture + farm pond/fisheries + compost/biological recycling

For example, crop residues can be converted into livestock feed or compost; livestock manure can contribute to nutrient recycling; farm ponds can support water conservation and fisheries; and horticultural crops can diversify income. This creates a circular farm economy in which **waste from one enterprise becomes a resource for another**.

Measuring Success: Beyond Yield

The success of natural farming should be measured using a broader set of indicators.

Indicator	What should be measured?
Soil health	Organic carbon, pH, EC, available N-P-K and biological indicators
Productivity	Yield per acre/hectare
Cost	Total cost of cultivation
Profitability	Gross return and net return
Resource efficiency	Water, fertilizer and labour efficiency
Pest management	Pest incidence and control cost
Marketing	Sale price, market channel and value addition
Sustainability	Crop diversity, residue recycling and input dependence
Farmer welfare	Income stability and risk reduction

Suggested Data Collection for KVK Demonstrations

For scientific evaluation, KVKs and extension agencies can compare **Natural Farming vs Farmer Practice** using replicated or well-designed field demonstrations.

Soil Health Data

- Initial soil organic carbon
- pH and EC
- Available nitrogen
- Available phosphorus
- Available potassium
- Soil moisture
- Bulk density where feasible
- Earthworm/biological activity indicators
- Soil organic matter or related indicators

Crop Productivity Data

- Plant population
- Number of productive tillers/branches
- Pest and disease incidence
- Crop duration
- Grain/fruit/biomass yield
- Marketable yield
- Quality parameters

Economics

- Seed cost
- Fertilizer/input cost
- Plant protection cost
- Labour cost
- Machinery cost
- Irrigation cost
- Harvesting and transportation
- Total cost
- Gross returns
- Net returns
- B ratio

Marketing

- Quantity sold
- Farm-gate price
- Local market price
- Wholesale price
- Direct-market price
- Value-added product price
- Transportation and marketing cost
- Net realization to farmer

This type of data will provide stronger evidence than relying only on yield comparisons.

The Road Ahead

Natural farming should be promoted as a **science-based, farmer-centred and economically viable approach**. There is no single package that will work identically across all crops, soils and climatic regions. Practices must be adapted to local conditions and continuously evaluated. The transition should focus on **"lower cost + healthy soil + stable productivity + better market realization"**, rather than simply eliminating one category of agricultural inputs.

Krishi Vigyan Kendras, agricultural universities, research institutions, FPOs and farmer groups can play a crucial role by conducting demonstrations, collecting long-term soil-health data, comparing economics and developing local marketing models.

Conclusion

The future of agriculture depends on our ability to produce **more from healthy soils while using resources efficiently and protecting the environment**. Natural farming provides a promising framework for achieving this goal by emphasizing biological processes, farm-resource recycling, soil cover, biodiversity and reduced dependence on costly external inputs. Its real strength lies in connecting **soil health with productivity, productivity with profitability, and profitability with sustainability**.

The measure of successful natural farming should ultimately be simple:

Healthy soil + efficient resource use + profitable production + better market opportunities + reduced pollution = a resilient and sustainable farming future.

Natural farming is therefore not merely a farming technique; it is an opportunity to build a **healthier soil, a stronger farm economy and a pollution-conscious agricultural future**.

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METARHIZIUM ANISOPLIAE: THE GREEN GUARDIAN – A POWERFUL ECO-FRIENDLY BIOCONTROL FUNGUS FOR SUSTAINABLE AGRICULTURE

AUTHORS' DETAILS:

Dr. NITIN VASANTRAO PARJANE
Assistant Professor, Mahatma Phule Krishi Vidyapeeth, Vrindavan College of Agriculture, Gunjalwadi Pathar.

Dr. AVINASH SHIVAJI MAHALE
Assistant Professor, Mahatma Phule Krishi Vidyapeeth, Government College of Agriculture, Dhule.

Dr. NILESH SAHEBRAO DALE
Associate Professor, Mahatma Phule Krishi Vidyapeeth, College of Agriculture, Loni

INTRODUCTION

Metarhizium anisopliae is a naturally occurring entomopathogenic fungus widely recognized as one of the most effective biological control agents for sustainable agriculture (Lacey *et al*., 2015). Commonly known as the green muscardine fungus, it infects and kills a broad range of economically important insect pests, including white grubs, termites, caterpillars, weevils and beetles without causing harm to crops, humans, livestock or beneficial organisms (Zimmermann, 2007). Unlike chemical insecticides, *M. anisopliae* penetrates the insect body through its cuticle, multiplies within the host and ultimately causes death by producing insecticidal toxins and enzymes (Ortiz-Urquiza *et al*, 2013). Owing to its eco-friendly nature, broad host range and compatibility with Integrated Pest Management (IPM) and organic farming systems, *M. anisopliae* has gained worldwide importance as a safe and sustainable alternative to synthetic pesticides. Its widespread use not only helps reduce chemical pesticide residues and environmental pollution but also contributes to the conservation of biodiversity and the long-term health of agricultural ecosystems **(Dara, 2019)**

HISTORY

History of *M. anisopliae* (Chronological Events)

1879 - Elie Metchnikoff discovered *Metarhizium anisopliae* while studying the wheat cockchafer beetle (*Anisoplia austriaca*) infected with a green fungal disease.

1879 - 1880 Metchnikoff successfully isolated, cultured and experimentally demonstrated that the fungus could infect and kill healthy insects, establishing it as one of the first microbial agents for insect pest control.

Late 19th Century - The fungus became known as the causal organism of Green Muscardine disease because infected insects were covered with green spores after death.

Early 1900s - Scientists in Europe initiated studies on the biology, life cycle, host range and pathogenicity of *M. anisopliae.*

1920–1950 - Research confirmed that the fungus could infect a wide range of insect pests, including beetles, termites, grasshoppers, caterpillars, white grubs and weevils.

1950–1970 - Methods for laboratory cultivation and mass multiplication were developed using cereal grains and artificial culture media, enabling large-scale production.

1970–1990 - Commercial formulations of *Metarhizium anisopliae* were introduced for biological control of insect pests in agriculture, forestry and horticulture.

1990–2005 - The fungus became an important component of Integrated Pest Management (IPM) and organic farming programmes worldwide. Research also focused on improving spore production, shelf life and field efficacy.

2005–2015 - Molecular biology studies identified important virulence factors such as chitinase, protease, lipase and insecticidal dextruxin toxins, improving understanding of the infection process. (Zimmermann, 2007)

TAXONOMIC CLASSIFICATION

Rank	Classification
Kingdom	Fungi
Division	Ascomycota
Class	Sordariomycetes
Order	Hypocreales
Family	Clavicipitaceae
Genus	*Metarhizium*
Species	*Metarhizium anisopliae*

(Humber, 2012; Kepler *et al*., 2017)

MODE OF ACTION

Metarhizium anisopliae is an entomopathogenic fungus that controls insect pests by infecting them through direct contact. Unlike many bacterial insecticides, it does not need to be ingested by the insect. The fungal spores (conidia) adhere to the insect's body surface, germinate under favourable environmental conditions, penetrate the insect cuticle using specialized enzymes, multiply inside the insect's body and eventually kill the host. After the insect dies, the fungus produces green spores on the cadaver, which spread to infect other susceptible insects. This natural infection process makes *M. anisopliae* an effective and environmentally friendly biological control agent. (Ortiz-Urquizaet *et al*., 2013)

Step-wise Mode of Action

1. Attachment of Spores (Conidia)

The infective spores (conidia) of *M. anisopliae* come into contact with the insect body through soil, plant surfaces or direct application.
The spores adhere firmly to the insect's cuticle with the help of adhesive proteins and mucilage.

2. Germination of Spores

Under favourable conditions (25–30°C temperature and >70% relative humidity), the spores germinate and produce germ tubes. The germ tubes develop specialized structures called appressoria, which help the fungus firmly attach and penetrate the insect cuticle.

3. Penetration of the Insect Cuticle

The fungus penetrates the insect's cuticle through a combination of mechanical pressure and enzymatic degradation.
It secretes hydrolytic enzymes such as:
Chitinase – breaks down chitin in the insect cuticle.
Protease – digests cuticular proteins.
Lipase – degrades the lipid layer of the cuticle.
These enzymes weaken the cuticle, allowing the fungus to enter the insect body.

4. Colonization Inside the Insect

After entering the insect's body cavity, the fungus multiplies rapidly by producing fungal hyphae and blastospores. The fungus absorbs nutrients from the insect's tissues and spreads throughout the body.

5. Production of Toxins

During colonization, the fungus produces toxic secondary metabolites, mainly destruxins. These toxins suppress the insect's immune system, damage body tissues, cause paralysis, physiological disorders and accelerate insect death.

6. Death of the Insect

The combined effects of fungal growth, nutrient depletion and toxin production kill the insect within 4–10 days, depending on the insect species and environmental conditions.

7. Sporulation and Secondary Infection

Under humid conditions, white fungal growth appears on the dead insect, which later turns green due to abundant spore production. These green spores are dispersed by wind, rain, insects or soil movement and infect new insect hosts, continuing the disease cycle.
Destruxins - Toxic metabolites that suppress immunity, damage tissues and kill the insect. (Ortiz-Urquiza *et al*., 2013)

FLOW CHART MODE OF ACTION

Conidia
↓
Attachment
↓
Germination
↓
Appressorium Formation
↓
Cuticle Penetration
↓
Enzyme Secretion
↓
Colonization
↓
Destruxin Production
↓
Insect Death
↓
Green Sporulation
↓
Secondary Infection

MOST IMPORTANT PESTS CONTROLLED IN INDIAN AGRICULTURE

- ✓ White grubs (*Holotrichia* spp.)
- ✓ Termites (*Odontotermes* spp.)

- ✓ Tobacco caterpillar (*Spodoptera litura*)
- ✓ Fall armyworm (*Spodoptera frugiperda*)
- ✓ Cutworm (*Agrotis ipsilon*)
- ✓ American bollworm (*Helicoverpa armigera*)
- ✓ Pink bollworm (*Pectinophora gossypiella*)
- ✓ Banana pseudostem weevil (*Odoiporus longicollis*)
- ✓ Coconut rhinoceros beetle (*Oryctes rhinoceros*)
- ✓ Red palm weevil (*Rhynchophorus ferrugineus*)
- ✓ Coffee berry borer (*Hypothenemus hampei*)

WHY FARMERS PREFER METARHIZIUM ANISOPLIAE

- ✓ Chemical-free insect control
- ✓ Safe for pollinators
- ✓ Suitable for organic farming
- ✓ Reduces pesticide residues
- ✓ Long-lasting control
- ✓ Compatible with IPM
- ✓ Eco-friendly
- ✓ Cost-effective

METHODS OF APPLICATION OF METARHIZIUM ANISOPLIAE

Metarhizium anisopliae can be applied through **seed treatment, seedling root dip, soil application, and foliar spray** depending on the crop and target insect pest. The following are the commonly recommended methods and doses for agricultural use.

Method of Application	Recommended Dose	Purpose
Seed Treatment	**10 g/kg of seed**	Protects seeds and seedlings from soil-borne insect pests such as termites and white grubs.
Seedling Root Dip	**10–20 g/L of water** (dip roots for 20–30 minutes before transplanting)	Protects transplanted seedlings from soil insect pests.
Soil Application	**2.5–5.0 kg/ha** mixed with **50–100 kg well-decomposed FYM or compost**	Controls soil-dwelling pests such as white grubs, termites, and root-feeding insects.
Foliar Spray	**5–10 g/L of water** (or **2.5–5 kg/ha** depending on formulation)	Controls foliar insect pests such as caterpillars, weevils, and beetles. Spray during evening hours.
Pit/Basin Application (Fruit Crops)	**25–50 g per plant** mixed with compost or FYM	Controls root grubs and termites in orchards and plantation crops.

ENVIRONMENTAL CONDITIONS FOR BEST PERFORMANCE

Factor	Optimum
Temperature	25–30°C
Relative humidity	>70%
Soil moisture	Moderate
Sunlight	Avoid direct intense sunlight
Spray timing	Evening hours
Rain	Avoid spraying before rainfall

COMPARISON WITH CHEMICAL INSECTICIDES

Parameter	***Metarhizium anisopliae***	**Chemical insecticides**
Environmental safety	Excellent	Moderate to poor
Residue problem	No	Yes
Resistance development	Low	High
Beneficial insects	Safe	Often harmful
Organic farming	Suitable	Not suitable
Persistence	Moderate	Variable

ADVANTAGES OF METARHIZIUM ANISOPLIAE

- ✓ Broad-Spectrum Insect Control .
- ✓ Environmentally Safe
- ✓ Safe for Humans and Animals

- ✓ Compatible with Integrated Pest Management (IPM)
- ✓ Suitable for Organic Farming
- ✓ Reduces Chemical Pesticide Use
- ✓ Controls Soil-Dwelling Insect Pests
- ✓ Reduces Insecticide Resistance
- ✓ Long-Lasting Effect
- ✓ Self-Propagating Nature
- ✓ Conserves Beneficial Organisms
- ✓ Cost-Effective in the Long Term
- ✓ Supports Sustainable Agriculture
- ✓ Easy to Apply

(Lacey *et al*., 2015)

RECENT ADVANCES AND FUTURE PROSPECTS

- ✓ Recent advances in biotechnology and microbial pest management have considerably expanded the agricultural applications of *Metarhizium anisopliae*. Modern research has focused on developing improved formulations such as oil-based suspensions, wettable powders, granules and nano-formulations that enhance spore viability, prolong shelf life, and improve field persistence under adverse environmental conditions. These innovations have significantly increased the commercial potential and field efficacy of entomopathogenic fungi in sustainable crop protection.
- ✓ Another promising area of research is the integration of *M. anisopliae* with other biological control agents, including *Beauveria bassiana*, *Trichoderma* spp., entomopathogenic nematodes and botanical pesticides such as neem-based formulations. Such integrated biological approaches provide broader pest suppression, delay the development of insecticide resistance and reduce dependence on synthetic chemical pesticides within Integrated Pest Management (IPM) programmes
- ✓ Future research is expected to focus on strain improvement through molecular breeding, genome editing, precision fermentation technologies, climate-resilient isolates, drone-assisted application and smart formulations with enhanced persistence and targeted delivery. These innovations are likely to strengthen the role of *M. anisopliae* as one of the most important eco-friendly biocontrol agents for sustainable agriculture and integrated pest management worldwide

Culture of *M. anisopliae*

Spodoptera Frugiperda infected with *M. anisopliae*

CONCLUSION

M. anisopliae has emerged as one of the most reliable entomopathogenic fungi for sustainable insect pest management due to its broad host range, environmental safety, compatibility with Integrated Pest Management (IPM) and suitability for organic farming. Its unique mode of action, involving direct penetration of the insect cuticle and production of insecticidal metabolites, makes it an effective alternative to conventional chemical insecticides. Continuous advancements in formulation technology, molecular biology and application methods are further improving its field performance and commercial adoption. Promoting the use of *M. anisopliae* among farmers will not only reduce chemical pesticide dependence but also enhance biodiversity, soil health, environmental quality and long-term agricultural sustainability. With continued research and farmer awareness, this "Green Guardian" will continue to serve as a cornerstone of eco-friendly crop protection in the future.

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AUTHORS' DETAILS:

Sharad

Punjab Agricultural University, Ludhiana (Punjab)

Mandeep Singh

Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar (J&K)

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Major Insect Pests of Cotton and Their Integrated Management

A practical guide for farmers

Introduction

Cotton is one of India's most important cash crops, and few things hurt its yield more than insect pests. Broadly, two kinds of pests trouble the crop are sap-sucking insects, such as whitefly, thrips, and jassid, and boll-damaging insects, such as pink bollworm. Correctly identifying these pests and managing them through an Integrated Pest Management (IPM) approach is what allows farmers to bring in a good harvest, both in quantity and quality. This guide walks through the four major cotton pests are pink bollworm, whitefly, thrips, and jassid covering their scientific names, how they damage the crop, the symptoms to watch for, and practical management steps, explained in plain language.

1. Pink Bollworm

Scientific name: *Pectinophora gossypiella (Saunders)* **Family:** Gelechiidae **Order:** Lepidoptera

Nature of damage

Pink bollworm is considered the most destructive and economically damaging pest of cotton. It works mostly out of sight, hidden inside flowers and bolls. The female moth lays eggs on twigs, flower buds, and young bolls. Once the eggs hatch, the caterpillars bore straight into the bolls and feed on the seeds and lint, which causes a sharp drop in the amount, weight, and quality of cotton harvested. Since 2017, this pest has even developed resistance to Bt cotton, which has made it a serious threat all over again.

Symptoms

- Caterpillars glue the flower petals together, forming what's known as a **"rosette flower"** this is the single most distinctive sign of pink bollworm.
- Small round holes (pin-holes) appear on the surface of the boll, which later turn into exit holes.
- Bolls open or dry out prematurely, or rot from the inside.
- Tunnels form inside the seeds, and sometimes two seeds fuse into one large, deformed seed (double seeds).
- Affected lint loses its colour and shine, and seed germination ability drops.

Management

Cultural and mechanical control

- Don't store leftover cotton stalks or plant material after picking for use in the next sowing.
- Before sowing, fumigate the field to destroy dormant caterpillars (diapausing larvae).
- Clear out last season's stubble, fallen bolls, and crop residue so the pest doesn't carry over into the new season.
- Monitor the crop regularly start watching for this pest as soon as squaring (flower formation) begins.

Biological and pheromone-based control

- Once the crop is 45 days old, install 5-8 Gossyplure pheromone traps per acre to track moth activity.
- In standing crop (40-50 days old), mass trapping with pheromone traps (roughly 160 traps/acre) can catch up to 90% of the moths.
- Neem-based products (Azadirachtin 0.15% EC, or 1% neem extract) have proven effective in the early stages.

Chemical control

- Spray a recommended insecticide only once 10-20% of flowers/bolls show damage.
- Economic Threshold Level (ETL) spray when you find about **5 larvae per 100 bolls**, or 10% damaged bolls.
- Profenophos 50 EC (Curacron) - 500 mL/acre, Emamectin benzoate 5 SG (Proclaim) - 100 g/acre, Chlorantraniliprole 18.5 SC (Coragen) - 60 mL/acre

2. Whitefly

Scientific name: *Bemisia tabaci (Gennadius)* **Family:** Aleyrodidae **Order:** Hemiptera

Nature of damage

Both nymphs and adult whiteflies cling to the underside of leaves and pierce the plant to suck out its sap, which weakens the plant over time. They also excrete a sticky substance called honeydew, on which black sooty mould grows, blocking photosynthesis. On top of that, whitefly is the main carrier of Cotton Leaf Curl Virus (CLCuV), which poses a serious threat to cotton production in Punjab and northern India.

Symptoms

- Leaves curl upward, thicken, and drop earlier than they should.
- Swarms of tiny white, winged flies visible flying up from the underside of leaves.
- A sticky residue on the leaves, followed by a layer of black sooty mould.
- In severe infestations, plant growth stalls and both the quantity and quality of lint drop sharply.

Management

- Monitor regularly the Economic Threshold Level (ETL) is around **6 adult whiteflies per leaf**.
- Set up yellow sticky traps in the field to track whitefly numbers.
- Apply nitrogen fertilizer in balanced, recommended doses excess nitrogen makes infestations worse.
- Protect natural predators (ladybird beetles, green lacewings, and the parasitoids Encarsia and Eretmocerus), and avoid unnecessary spraying.
- Once the ETL is crossed, start with a spray of soluble neem extract (made from neem leaves/seeds).
- In case of heavy infestation, spray one of the recommended insecticides ETL 6 adults/leaf in upper canopy (check before 10 AM)- Diafenthiuron 50 WP (Polo) -200 g/acre, Flonicamid 50 WG (Ulala) -80 g/acre, Dinotefuran 20 SG (Osheen) - 60 g/acre

3. Thrips

Scientific name: *Thrips tabaci Lindeman / Thrips palmi Karny* **Family:** Thripidae **Order:** Thysanoptera

Nature of damage

Thrips are tiny, slender insects. Both nymphs and adults scrape the surface of leaves, new shoots (terminals), and other tender parts, then suck up the sap that oozes out. They're especially damaging to young crops, and in severe cases, plant growth stops altogether, which ultimately lowers yield.

Symptoms

- Leaves develop a wrinkled, silvery sheen from the scraping damage.
- Leaves curl upward, and the edges look scorched.
- Growth of new shoots and tender leaves stalls, leaving plants stunted.
- In severe attacks, leaves turn brownish/rust-coloured and yield drops noticeably.

Management

- Economic Threshold Level (ETL) about **8-10 thrips per leaf**.

- Use balanced nitrogen fertilization avoid heavy doses.
- Clear out alternate host plants and weeds from around the field.
- Spray a neem-based bio-pesticide in the early stages.
- According to recent research, spraying Simodis 10 DC (isocycloseram) at 240 ml per acre has proven effective against thrips.
- If needed, diafenthiuron 50 WP can be used at the 200 g/acre dose it works against both thrips and whitefly.

4. Jassid / Leafhopper

Scientific name: *Amrasca biguttula biguttula (Ishida)* | **Family:** Cicadellidae | **Order:** Hemiptera

Nature of damage

Both nymphs and adult jassids sit at an angle on the underside of leaves, sucking sap while also injecting a toxic substance into the plant. This destroys leaf cells and turns them yellow a process known as "hopper-burn."

Symptoms

- Leaf edges turn yellow first, then brownish-red.
- Leaves curl downward and take on a distorted, twisted shape.
- In severe infestations, leaves look completely scorched and fall off.
- Plant growth and flower/boll formation are affected, lowering yield.

Management

- Economic Threshold Level (ETL): when 50% of fully developed leaves show yellowing at the edges and downward curling.
- Choose hairy-leaf, jassid-tolerant cotton varieties these are naturally less susceptible.
- Treating seed with imidacloprid at 5 g per kg of seed before sowing helps control jassid in the early stages.
- Protect natural predators (lacewings and spiders), which prey on jassids.
- Once the ETL is crossed, spray of Thiamethoxam 25 WG (Actara) - 40 g/acre, Flonicamid 50 WG (Ulala) - 80 g/acre, Dinotefuran 20 SG (Osheen) - 60 g/acre

Conclusion

Managing these major cotton pests well comes down to identifying them correctly and taking a scientific, integrated approach choosing resistant varieties, following good cultural practices, using pheromone and sticky traps, protecting natural predators, and reaching for chemical insecticides only when they're genuinely needed. Keep monitoring your field regularly, and spray only once the Economic Threshold Level (ETL) has been crossed. Farmers are encouraged to confirm the correct dose and advice with their nearest Krishi Vigyan Kendra or agricultural extension expert before spraying any insecticide.

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AUTHORS' DETAILS:

[1]Chaudhari K.J.,
*[1]Satam S.B.,
[1]Pagarkar A.U.,
[1]Chogale N.D.,
[1]Dhamagaye H.B.,
[1]Sadawarte V.R.,
[1]Sawant A.N.,
[2]Bhatkar H.R., and
[1]Ghughuskar M.M.

[1]Marine Biological Research Station, Ratnagiri, M.S., India
[1]UNDP GCF-ECRICC Project, Mangrove-Forest Department, Ratnagiri, M.S., India

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STATUS OF SEAWEED CULTURE ON THE KONKAN COAST OF MAHARASHTRA

A brainstorming workshop titled "Seaweed Cultivation: Current Status and Future Prospects" was organized on March 24, 2026, under the aegis of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth jointly by the Fisheries Engineering Polytechnic, Ratnagiri; the Marine Biological Research Station, Zadgaon, Ratnagiri; and Jaljivika Ratnagiri (a UNDP-GCF project). A total of 67 beneficiaries attended the workshop. The participants primarily included researchers from Maharashtra and Goa; officials from the forest department; academicians, researchers, and various NGOs; as well as fish farmers, fisheries professionals, members of the fishing community, and students.

The workshop was inaugurated by dignitaries through the ceremonial lighting of a lamp. Distinguished guests present on this occasion included Dr. Anil Pawse, Associate Dean, College of Fisheries, Ratnagiri; Dr. K.J. Chaudhari; Dr. A.U. Pagarkar; Mr. H. Bhatkar, District Coordinator Associate for the UNDP, GCF, and ECIRCC projects; Mr. C. Damale, District Coordinator for Jaljivika, Ratnagiri; and Mr. M. Daphale, Forest Officer, Mangrove-Forest Department, Ratnagiri.

SESSION-I: Seaweed farming: present status and future prospects

Session-I, Topic-1: Present status of seaweed farming in India

Dr. K.J. Chaudhari, Senior Scientific Officer of Marine Biological Research Station, Ratnagiri, in his knowledge-sharing presentation on "Present Status of Seaweed Farming in India." They emphasized initiatives under PMMSY, Blue Economy Vision 2030, and NITI Aayog Seaweed Value Chain-2024 regarding promoting seaweed cultivation. He also spoke about the initiative of the Maharashtra government under the CMMSY to set up seaweed seed production centers to address the shortage of good quality planting material. The Raigad district showcased successful examples of livelihood diversification and restoration of marine ecosystems through community-based projects supported by organizations like DP World and different NGOs.

Topic-2: Optimization of seaweed culture: Comparative growth of marine species on Konkan coast.

Mr. Hussain Md. Shetranjiwala, National Institute of Oceanography (NIO), Goa, delivered a lecture on "Optimizing Seaweed Culture: Comparative Growth of Marine Species along the Konkan Coast. The experimental work was carried out in cultivation of Kappaphycus alvarezii, Gracilaria edulis and Gracilaria salicornia with monoline and tube-net techniques. Field data showed the monoline method was better in growth and operational efficiency. The speaker said that the choice of culture sites was of utmost importance and that the biomass production was greatly influenced by environmental factors such as seawater temperature, salinity, tides and water currents.

Some of the problems faced during cultivation such as bleaching in summer due to high temperature, loss of seed material due to strong waves and winds, damage to the cultivation structures, fouling by unwanted seaweeds and occasional lack of cooperation by local fishermen were discussed. There was low fish grazing but higher fish diversity on cultivation rafts, suggesting further ecological benefits of seaweed farming.

The speaker suggested to use a floating buoy and anchor system, correct orientation of the raft, seed fragments weighing 80-100 g, regular cleaning of the cultivation structures and constant monitoring with the involvement of local fishermen.

Remarks of Session I:

The session was very informative and practical, providing valuable insights into the real-world challenges and innovations in seaweed cultivation. It called for community-led, low-cost and sustainable approaches.

SESSION-II: Entrepreneurship and Livehood

Session-II, Topic-1: Sustainable seaweed farming in Sindhudurg: Paths for Livelihood & Coastal Resilience

Mrs. Puja Lute, Project Coordinator, Mangrove Foundation, Sindhudurg delivered a lecture on "Sustainable Seaweed Farming in Sindhudurg: Techniques for Livelihood and Coastal Resilience". The lecture highlighted the practical insights on implementation of seaweed farming for the coastal communities of Maharashtra as a nature-based solution. Seaweed farming in Sindhudurg dist. of Maharashtra state emerging as a critical nature based solution for coastal resilience and livelihood diversification . Institutes such as CSIR-CSMCRI are trying to shift fishers to sustainable aquaculture such as ventures like Achara (Malvan) and Hindale (Devgad) as stocks of wild fish dwindle.

They pointed out the increasing relevance of sustainable seaweed farming, especially of the Kappaphycus species, as a possible solution to the problem of declining wild fish stocks and climate vulnerability in the Sindhudurg region. Through proven techniques such as the Tube Net Method, Floating Bamboo Raft Method, and Monoline Method, local fishers and women's SHGs are being empowered with a low-investment, high-turnover livelihood option that yields substantial biomass (up to 5 times in 40 days and approximately 260 kg per raft in 45 days). At the end of this session Mrs. Prerana Hirve of Gadre Marine Exports, Ratnagiri, also recounted her experiences in marine seaweed farming.

Session II, Topic 2: Potential of seaweed from farming to high-value products

The second technical presentation was by Mr. Akshay Jadhav, Co-founder, Raftech Solutions Pvt. Ltd., Mumbai on "Unlocking the Potential of Seaweed: From Farming to High-Value Products" focused on the huge untapped potential of seaweed farming and value addition in India, particularly along the Maharashtra coast as a sustainable business for boosting the livelihoods of coastal people and the Blue Economy. Mr. Jadhav proposed a framework of collaborative farming to incorporate small scale fishers in organized seaweed farming systems by creating capacity building program. This was shown to be a viable tool for coastal communities to decrease market risks, enhance production efficiency, and establish sustainable income sources. They produced a range of value added products from seaweed, such as biostimulants, granules, fortified powders, and carrageenan. Humic and Fulvic acids along with polysaccharide and micronutrients added to the seaweed bio-stimulants were reported to enhance the crop productivity and to be a source of sustainable agriculture. The potential of carrageenan from red seaweeds for widespread use as a thickening and gelling agent in the food processing industry and other products demonstrated the expanding commercial opportunities in the seaweed value chain.

Mr. Jadhav said cultivation is limited to Kappaphycus species and still depends on traditional bamboo raft systems. They stressed the need for improved seedling preservation facilities and the development of location-specific cultivation technologies better suited to the state's coastal conditions.

Remark of Session-II

The discussions of session-II highlighted the high potential of seaweed farming to create a paradigm shift in the livelihoods of the coastal communities when supported by value addition, coordination of development, and market development. It was emphasized that efforts are needed to enhance seed production, create region-specific cultivation technology, enhance post-harvest infrastructure, and strengthen farmer–industry linkages to promote high-value seaweeds. In general, the session highlighted the importance of ensuring a sustainable and marketoriented seaweed value chain for achieving the goals of the Blue Economy in India.

SESSION-III: Innovation in Seaweed Farming

Session-III, Topic 1: Comparative account of *Kappaphycus* and other seaweed culture farming methods

Dr. Vaibhav Mantri, Chief Scientist, Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar, Gujarat presented on the status of seaweed diversity & production in the world and in India. It was noted that approximately 10,000 varieties of seaweed are reported worldwide, while around 1,000 varieties occur in India. The global seaweed production has reached about 36 million metric tons with an estimated value of 18 billion US dollars. By 1970, researchers had identified around 500 seaweed species. The technological advances in seaweed culture and processing began from 1940 to 1960, 1960 to 2000, and 2000 to the present. Special attention was given to agar production, which expanded significantly after World War-II. In India, seaweed utilization for agar production began around the 1940s using *Gracilaria edulis*.

In India, seaweed utilization for agar production began around the 1940s using *Gracilaria edulis*. They referred to major industries involved in seaweed processing. It was emphasized that seaweed-based MSMEs are expected to increase nearly tenfold, indicating major scope for enterprise development and employment generation in coastal regions. There was much concern with the technical side of seaweed farming. Different raft designs used in seaweed cultivation were described, i.e., triangular raft design, vertical raft design, and inclined raft design. Seedling production and nursery development were recognized as key elements for scaling up seaweed farming. Nursery production of seedlings can ensure a secure supply chain of feedstock. The need for nursery-based systems to facilitate commercial development was highlighted, as was the fact that one batch has the potential to produce 25,000 seeds.

Session-III, Topic 2: Technological Innovations in Seaweed Drying, Processing, and Value Addition

Dr. A.U. Pagarkar, Professor at the Marine Biological Research Station, Ratnagiri, delivered a detailed presentation on 'Technical Innovations in Processing and Value Addition of Marine Seaweeds.' They illustrated the different value-added products prepared from seaweed that are available at the Ratnagiri coast. Also given is an introduction of research on seaweed processing at the university as well as in India.

Remarks of Session-III:

Session-III focused on recent innovations, technological developments, and future prospects in seaweed farming, with emphasis on species diversity, cultivation systems, processing opportunities, seedling production, industrial applications, and policy support. Seaweed was identified as an emerging sector with great potential to generate livelihoods, develop coastal enterprises and diversify into value-added products.

Overall remark:

At the conclusion of the workshop, a discussion and Q&A session was organized where the participating beneficiaries posed various questions and sought guidance from the experts. In addition, the certificates were presented to the participants by the dignitaries who were present at the event. This workshop clearly added more to the perspective of considering marine seaweed farming as a viable and sustainable option for livelihood generation. The successful execution of this program was made possible through the special guidance of Dr. Sanjay Bhave, honorable vice-chancellor of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra; Dr. Rajesh Thokal, DEE; and Dr. Prashant Shahare, DoR, DBSKKV. Dr. Rakesh Jadhav, Prof. Nilesh Mirajkar, Prof. Rohit Burte, Mr. Sushil Kamble, Mr. Pankaj Sidam, and Mr. Sandesh Chavan put in exceptional effort. Ms. Srushti Surve, Ms. Samruddhi Sangare, Mrs. Piyusha Desai, Mr. Rohan Gurav, and Mr. Birje, all from Jaljivika, Ratnagiri, also made special efforts for the organization of the workshop.

Overall conclusion:

The brainstorming workshop on "Seaweed Cultivation: Current Status and Future Prospects" was an inclusive platform to understand the current status, technical challenges, livelihood opportunities, innovations, and future prospects of seaweed cultivation in India, especially along the Konkan coast. The sessions together highlighted the potential of seaweed farming as a major contributor to coastal livelihood diversification, women's and fisher empowerment, climate resilience, sustainable aquaculture, and development of India's Blue Economy. However, for successful expansion of the sector, reliable quality seed and nursery facilities, location-specific technologies for cultivation, appropriate farming structures, environmental monitoring, improved post-harvest handling, processing and value addition, and stronger linkages between farmers, industry, and research are needed. Discussions also pointed to the need to move away from traditional cultivation of limited species to diversification, technological innovation, and high-value products like carrageenan, agar, biostimulants, fortified products, powders and other industrial and agricultural applications. The workshop concluded that integrated, community-based, economically viable and environmentally sustainable approaches are essential to establish a robust seaweed value chain and unlock the immense potential of seaweed farming in Maharashtra and India, and such approaches need to be supported by research institutions, government agencies, industries, NGOs and coastal communities.

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AUTHORS' DETAILS:

Jayasuriya V.

Assistant Professor, Department of Soil Science and Agricultural Chemistry, Cardamom Research Station, Kerala Agricultural University, Pampadumpara P.O., Idukki, Kerala, India.

Dr. Nimisha Mathews

Assistant Professor (Horticulture) and Head, All India Coordinated Research Project on Spices (AICRPS), Cardamom Research Station, Kerala Agricultural University, Pampadumpara P.O., Idukki, Kerala, India.

Dr. Simi Asharaf

Assistant Professor, Department of Agricultural Extension Education, Cardamom Research Station, Kerala Agricultural University, Pampadumpara P.O., Idukki, Kerala, India.

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Correcting a common misconception: Dolomite application in cardamom plantations

Introduction

Cardamom (*Elettaria cardamomum* Maton), often called the "Queen of Spices," is one of Kerala's most valuable plantation crops. The crop thrives under cool, humid conditions and is predominantly cultivated in the high ranges of Idukki and adjoining districts. Maintaining healthy soil is one of the most important factors for achieving consistent yield and quality in cardamom plantations.

The soils of these high-rainfall regions are naturally acidic. Continuous rainfall gradually washes away basic cations such as calcium and magnesium from the soil, leading to increased acidity. Acidic soils reduce nutrient availability, restrict root growth, and increase the solubility of toxic elements such as aluminium. If left unmanaged, soil acidity can affect plant vigour, capsule production, and overall plantation productivity.

Figure 1. Liming in cardamom

To address this problem, soil acidity management has become an integral component of cardamom cultivation. Among the recommended practices, dolomite application plays an important role because it not only neutralizes excess soil acidity but also supplies calcium and magnesium, two essential plant nutrients. According to the Kerala Agricultural University (KAU) Package of Practices (2024), dolomite is recommended at 2 kg per plant per year, applied in two splits during May-June and September-October under conditions of adequate soil moisture. The recommendation further states that application may be discontinued once the surface soil pH stabilizes above 5.5.

A new practice emerging in some cardamom plantations

Agriculture is constantly evolving. Farmers readily adopt new ideas that promise improved efficiency, reduced labour, or higher yields. Today, information spreads rapidly through social media platforms, farmer discussion groups, local input dealers, and informal field demonstrations. While many of these innovations are useful, others become popular before they are scientifically evaluated.

During interactions with cardamom growers in Kerala, one such practice has been observed in some plantations. Instead of applying dolomite directly to the soil as recommended, some farmers mix agricultural lime or dolomite with sulphur in water and apply the mixture as a soil drench around the base of the plants. The belief is that dissolving the material in water allows it to act more quickly, penetrate deeper into the soil, and correct acidity more effectively than conventional application.

At first glance, this practice may appear logical. Water is commonly used to dissolve fertilizers and micronutrients for fertigation or foliar spraying. It is therefore understandable why some growers assume that dolomite or agricultural lime can also be applied in the same manner. However, the chemistry of liming materials is fundamentally different from that of highly soluble fertilizers.

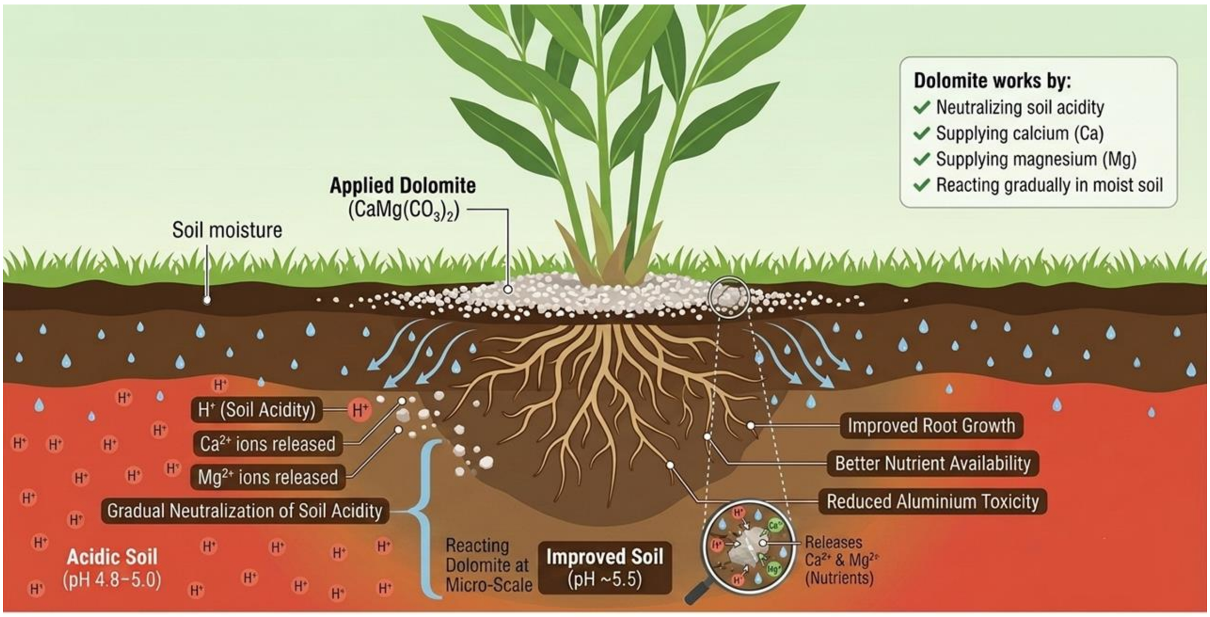
More importantly, this practice is not included in the current Kerala Agricultural University Package of Practices for cardamom. The official recommendation advises direct application of dolomite under moist soil conditions rather than preparing a suspension or solution for drenching. Likewise, the package of practices does not recommend mixing sulphur with dolomite as a routine soil acidity management practice.

This distinction is important because adopting practices that are not supported by scientific recommendations may reduce the effectiveness of soil amendments, increase unnecessary labour, and create confusion regarding proper nutrient management. Understanding how dolomite actually works in the soil helps explain why the recommended method differs from the observed field practice.

Why dolomite is recommended instead of agricultural lime?

Many farmers use the terms ‘lime’ and ‘dolomite’ interchangeably, but they are not exactly the same. Both materials are used to reduce soil acidity, yet they differ in composition. Agricultural lime is primarily composed of calcium carbonate and is widely used to neutralize acidic soils. Dolomite, on the other hand, contains both calcium carbonate and magnesium carbonate. As a result, besides correcting soil acidity, dolomite also supplies magnesium, an essential nutrient required for chlorophyll formation and photosynthesis.

In many cardamom-growing areas, magnesium deficiency may develop because of prolonged leaching under high rainfall conditions. Therefore, applying dolomite not only improves soil reaction but also replenishes magnesium removed from the soil over time. Another important point is that liming materials are intended to react gradually with acidic soil. Their effectiveness depends on close contact with soil particles, adequate soil moisture, appropriate particle size, and sufficient time for the neutralization reaction to occur. They are not designed to function like completely water-soluble fertilizers.



Dolomite is applied directly to moist soil. It reacts gradually with acidic soil rather than dissolving completely in water.

Figure 2. Dolomite gradually reacts with acidic soil, supplying calcium and magnesium while neutralizing soil acidity.

Maintaining adequate soil moisture during application is recommended. Moisture helps the reaction proceed efficiently after dolomite has been applied to the soil. It does not imply that the material should first be dissolved or converted into a liquid drench.

How does dolomite work in acidic soils?

To understand the correct method of application, it is important to know how dolomite functions after it is added to the soil. Unlike fertilizers such as urea or potassium chloride, dolomite is only sparingly soluble in water. Rather than dissolving rapidly, it reacts slowly with acidic soil. During this process, excess soil acidity is neutralized, soil pH gradually increases, aluminium toxicity declines, and the availability of nutrients such as phosphorus improves. At the same time, calcium and magnesium released from dolomite become available for plant uptake.

The effectiveness of dolomite depends largely on the quality of the material, particle size (finer particles react faster), the recommended application rate, and good contact between the particles and moist soil. Maintaining adequate soil moisture after application promotes this natural reaction, which is why direct application to moist soil is recommended.

Can dolomite be dissolved in water?

> ***Did You Know?***
> *Dolomite is not a highly water-soluble fertilizer. It gradually reacts with acidic soil, supplying calcium and magnesium while helping to correct soil acidity under moist conditions.*

Some growers believe that dolomite can be dissolved in water and applied as a liquid soil amendment. However, dolomite does not behave like a water-soluble fertilizer. When mixed with water, it forms a suspension in which fine particles remain dispersed temporarily before gradually settling at the bottom unless continuously stirred.

Preparing such a suspension does not make dolomite more soluble or improve its ability to correct soil acidity. The amendment still functions only after the particles come into contact with the soil. Accordingly, the current Kerala Agricultural University Package of Practices recommends applying dolomite directly to moist soil and does not recommend dissolving or drenching it in water.

Should dolomite be mixed with sulphur?

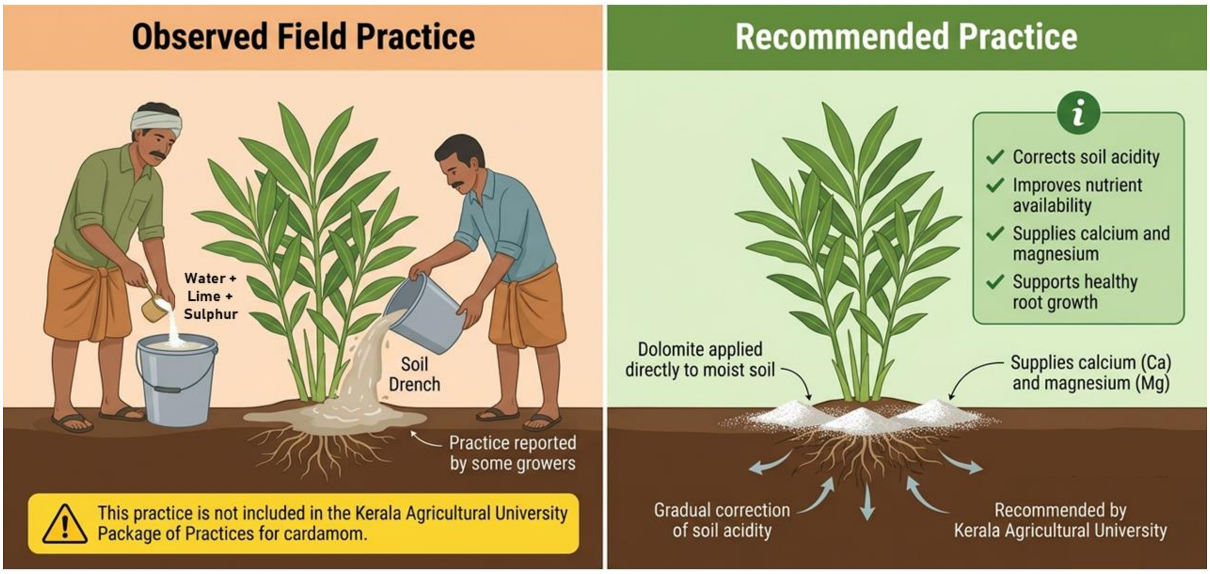


Figure 3. Observed field practice versus the recommended method of dolomite application in cardamom cultivation.

Sulphur and dolomite serve **different purposes** in soil management. Dolomite is used primarily to correct soil acidity while supplying calcium and magnesium. Sulphur, on the other hand, is an essential plant nutrient supplied to correct sulphur deficiency. These two materials are therefore applied to address different soil or crop requirements.

The present **Kerala Agricultural University Package of Practices for cardamom does not recommend mixing sulphur with dolomite for soil drenching**. Instead, liming materials and fertilizers are considered separate components of nutrient management, each applied according to recommended schedules and crop requirements.

Whenever nutrient deficiencies are suspected, decisions should ideally be based on soil testing or plant analysis rather than on unverified field practices. Following scientifically validated recommendations not only improves nutrient use efficiency but also avoids unnecessary expenditure on inputs that may not provide the expected benefit.

Table 1. Common misconceptions and scientific facts regarding dolomite application in cardamom plantations.

Myth	Fact
Dolomite should be dissolved in water before application.	Dolomite is intended to react gradually after direct application to moist soil.
Adding more water makes dolomite act faster.	Soil moisture supports the reaction after application, but water does not convert dolomite into a highly soluble material.
Mixing sulphur with dolomite improves acidity correction.	The current KAU Package of Practices does not recommend this practice for cardamom.
Any practice shared through social media is scientifically proven.	New practices should always be verified using recommendations from recognized research and extension institutions.

Recommended method of dolomite application

- ✓ Apply dolomite at the recommended dose.
- ✓ Split the application as advised in the Package of Practices.
- ✓ Ensure sufficient soil moisture during application.
- ✓ Apply the material uniformly around the active root zone and incorporate it lightly wherever feasible without damaging roots.
- ✓ Monitor soil pH periodically and discontinue liming once the recommended soil pH has been achieved.
- ✓ Follow fertilizer recommendations separately according to crop nutrient requirements and avoid fertilizer application for 14 days after liming.

Adopting these scientifically recommended practices improves nutrient availability, supports healthy root development, and contributes to long-term soil productivity.

Conclusion

Cardamom cultivation depends on maintaining healthy, productive soils capable of supporting vigorous plant growth under the high-rainfall conditions of the Western Ghats. Soil acidity is an important constraint, and correcting it through appropriate dolomite application remains one of the most effective management practices recommended for the crop. As new cultivation practices continue to spread rapidly through informal communication channels, it becomes increasingly important to distinguish between innovative ideas and scientifically validated recommendations. While farmers are always searching for better ways to improve productivity, changes in nutrient management should be adopted only after they have been supported by research recommendations. The current Kerala Agricultural University Package of Practices provides a clear recommendation for dolomite application under adequate soil moisture. It does not recommend dissolving lime in water or mixing it with sulphur for soil drenching. By following these established recommendations, growers can make better use of inputs, improve soil health, and ensure the long-term sustainability of cardamom production.

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AUTHORS' DETAILS:

Shubham Pal
Ph.D. Scholar, Division of Agronomy, ICAR-Indian Institute of Wheat & Barley Research (IARI Karnal Hub), Karnal, Haryana-132001, India

Gajender Yadav
Principal Scientist (Agronomy), Division of Soil and Crop Management, ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India

Anand Jejal
Ph.D. Scholar, Agronomy Section, ICAR-National Dairy Research Institute, Karnal, Haryana-132001, India

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BEYOND THE HARVEST:

AGRONOMY FOR NUTRITIONAL SECURITY

India today produces enough food to feed its population several times over. In 2024-25, the country recorded a foodgrain output of 357.73 million tonnes, along with 25.68 million tonnes of pulses, 42.98 million tonnes of oilseeds and 369.06 million tonnes of horticultural crops. It is the world's largest producer of milk, pulses, spices, jute, bananas, mangoes and millets, and the second largest producer of rice, wheat, sugarcane, cotton, groundnut, tea and vegetables. Agricultural exports touched nearly $52 billion in 2024-25. This is a remarkable turnaround from the food aid dependence of the 1960s, once described as a "ship to mouth" existence.

Yet the 2025 Global Hunger Index places India 102nd among the countries assessed. The granaries are full, but a large share of the population remains poorly nourished. This is the central paradox of India's food story: growing enough calories has not automatically meant a well nourished population.

Malnutrition Wears Many Faces

The World Health Organization (WHO) defines malnutrition broadly, as deficiencies, excesses or imbalances in a person's intake of energy and nutrients. India carries an unusual double burden: undernutrition and overnutrition exist side by side, often within the same household, along with widespread micronutrient deficiency. Researchers call this the "triple burden of malnutrition": stunting and wasting on one side, anaemia and other micronutrient gaps in the middle, and rising overweight and obesity on the other.

The National Family Health Survey (NFHS-5, 2019-21) found that among Indian children under five, 35.5% are stunted, 19.3% are wasted and 32.1% are underweight. Anaemia affects an estimated 67.1% of children and 59.1% of adolescent girls, while pregnant women record iron deficiency levels of nearly 61%. Across the wider population, pooled estimates show deficiency levels of roughly 54% for iron, 53% for vitamin B12, 37% for folic acid, 19% for vitamin A, 17% for iodine and as high as 61% for vitamin D. Much of this is "hidden hunger": people who do not look visibly undernourished but whose diets are quietly short of the vitamins and minerals needed for growth and development.

A Deficiency That Starts in the Soil

Part of the problem begins even before a seed is sown. Indian soils are themselves widely short of the micronutrients that human bodies need most. A crop grown in zinc deficient soil simply cannot produce zinc rich grain, no matter how high its yield. This is the logic behind the "One Health" approach, which treats soil health, plant health, animal health and human health as one connected system rather than four separate concerns.

Table 1. Micronutrient deficiency across Indian soils

Micronutrient	Deficiency in Indian Soils (%)
Zinc (Zn)	36.5
Boron (B)	23.4
Iron (Fe)	12.8
Molybdenum (Mo)	11.0
Manganese (Mn)	7.1
Copper (Cu)	4.2

Source: Indian Journal of Fertilisers, 2018; PwC Analysis.

The Four Pillars of Food Security

The Food and Agriculture Organization defines food security as existing when all people, at all times, have access to sufficient, safe and nutritious food that meets their dietary needs. This rests on four pillars: availability, accessibility, utilisation and stability. India has largely solved availability. The harder task now is ensuring that affordable, diverse and nutrient dense food actually reaches people, and that their bodies can absorb what they eat. This is where agronomy, the science of how crops are grown, has a direct role to play.

What Agronomy Can Actually Do

The encouraging part is that closing this gap does not need exotic new technology. It needs a return to fundamentals, how crops are fertilised, which crops are grown together, which grains are prioritised, and how soil is nurtured, applied with scientific precision. Four broad approaches stand out.

1. Biofortification: This means increasing the nutrient density of food crops through breeding, better agronomic practice or biotechnology, without giving up the traits farmers and consumers already value. The agronomic route, applying minerals such as zinc and iron directly to soil or leaves, is the fastest and most flexible option. A 2025 global analysis of wheat studies found that later foliar sprays were generally more effective, and identified 40 mg/kg grain zinc as a realistic target for nutritional impact. Soil application alone lifted grain zinc by about 29%, short of this target, while foliar and combined soil plus foliar applications raised it by 55% and 62% respectively, comfortably crossing the threshold. In Indian basmati rice trials, three foliar sprays of a chelated zinc compound at key growth stages raised grain zinc from about 21 to nearly 30 mg/kg while also improving yield. Even the seed stage offers an opening: priming direct seeded rice with selenium and zinc nanoparticles before sowing has been shown to raise both nutrient uptake and grain yield.

2. Crop Diversification: Decades of continuous rice and wheat cultivation, backed by heavy fertiliser use, have visibly tired out the soils of the Indo-Gangetic Plains. Long term trials show that rotations built around pulses steadily improve soil organic carbon and microbial activity compared with cereal only systems. The nutritional gains can be striking too: compared with a conventional rice-wheat-fallow system, a maize-mustard-mungbean rotation under conservation agriculture produced roughly 31% more protein, 119% more iron and 26% more zinc per hectare. The message is simple: diversifying what is grown improves both the soil and the nutrition it delivers, not just the tonnage.

3. The Millet Renaissance: Millets, India's traditional “nutri-cereals,” have returned to the national conversation since the International Year of Millets in 2023, and the science supports the enthusiasm. A large meta-analysis found that every millet tested had a significantly lower Glycemic Index than white rice, refined wheat or standard glucose, meaning they raise blood sugar more slowly and gently. In people with diabetes, sustained millet consumption was linked to roughly 12% lower fasting blood glucose, 15% lower after meal glucose and a 15% improvement in long term blood sugar markers. Millets also carry strong antioxidant activity from their high phenolic content. They combine climate resilience with a genuinely protective nutritional profile, a rare pairing.

4. Regenerative Practices: Organic methods can also move the needle. A long term trial on chickpea in the Himalayan foothills, using farmyard manure,

vermicompost and a neem and cow urine biopesticide in place of synthetic inputs, found that organically grown plants nodulated better and yielded more grain per pod than conventionally grown ones. More strikingly, the iron and zinc content of the organic grain was almost double that of the conventional crop.

Beyond these four, integrated farming systems that combine crops, livestock, horticulture and fisheries on the same holding have been shown to raise both farm income and household dietary diversity. Even a small kitchen garden can meaningfully supplement a family's iron, zinc, vitamin A and vitamin C intake directly from the doorstep.

Table 2. Summary of the four agronomic approaches

Approach	What It Involves	Key Nutritional Gain
Biofortification	Foliar and soil application of zinc/iron; seed priming with micronutrients	Grain Zn raised by up to 62% with foliar + soil application
Crop Diversification	Pulse and oilseed based rotations replacing rice-wheat monoculture	Up to 119% more iron and 26% more zinc per hectare
Millet Renaissance	Reintroducing nutri-cereals like ragi, jowar and bajra into diets	12-15% improvement in blood sugar markers in diabetics
Regenerative Practices	Organic manures, vermicompost and biopesticides instead of synthetic inputs	Nearly double the iron and zinc content in grain

Policy Is Catching Up

Better agronomy alone cannot solve this problem; it has to be matched by policies that widen access to diverse, nutritious food. ICAR has released biofortified varieties such as CR Dhan 315 (rice), HI 1633 (wheat), CFMV-1 (finger millet) and PM-32 (mustard), backed by a research network that includes ICMR-NIN, ICRISAT, CGIAR and HarvestPlus. On the delivery side, programmes such as POSHAN Abhiyaan, ICDS, Saksham Anganwadi and POSHAN 2.0, PMMVY, NFSA, NHM and Anemia Mukt Bharat each address a different piece of the puzzle, from maternal nutrition to micronutrient supplementation. The newest addition is Mission SEHAT (Science Excellence for Health through Agricultural Transformation), launched jointly by ICAR and ICMR in May 2026, which brings agriculture, nutrition and public health researchers into one common framework built around biofortified crops, diversified farming and the One Health approach.

Not a Silver Bullet

None of this should be oversold as a single fix. Results vary by crop, soil and season, and there is a real risk of nutrient imbalance if micronutrient application is not carefully calibrated. Farmers currently have little economic incentive to adopt biofortification unless premium prices or assured markets exist for the produce. Uptake also depends on farmer training and precise timing of application, which is difficult to guarantee at scale. And how much of the added nutrient the human body actually absorbs, its bioavailability, remains under researched and needs to be studied alongside production data. Agronomic biofortification is best understood as a seasonal enhancement that works alongside crop breeding, not a permanent replacement for it.

The Road Ahead

India has largely solved the question of whether there is enough food. The next challenge is making sure that food actually nourishes. Bringing approaches such as biofortification, seed priming, pulse and millet based diversification and better soil management into mainstream farming will need farmer awareness, real economic incentives and stronger coordination between agronomy, plant breeding, soil science and nutrition programmes. The goal is not just full granaries, but healthier, better nourished people, supported by farming that is productive, diverse, climate resilient and genuinely focused on nutrition.

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AUTHORS' DETAILS:

Dr. P. V. Patil
College of Veterinary and Animal Sciences, Udgir Dist.Latur, Maharashtra-413517

Dr. M. K. Patil
College of Veterinary and Animal Sciences, Udgir Dist.Latur, Maharashtra-413517

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FACTORS AFFECTING MILK COMPOSITION OF ANIMALS

ABSTRACT

The quality and price of milk are significantly influenced by its fat and SNF content, requiring a multifaceted approach to improve these parameters. Understanding factors like heredity, physical condition during gestation, mastitis control, and balanced nutrition is crucial. Adequate feeding practices that ensure the right ratios of concentrate, fodder, and fiber, along with the appropriate size and maturity of fodder, play a vital role. Dietary composition, including the right levels of carbohydrates and fiber, alongside careful management of feeding frequency and types of feed, further impacts milk constituents. Finally, the prudent use of nutritious additives such as oils and bypass proteins can help increase milk fat. Overall, proper animal care, nutrition, and management are essential for enhancing both milk quality and profitability in dairy farming.

Introduction

As we know, the price of animal milk is determined by its fat and SNF (Solids-Not-Fat) content. Therefore, to ensure a profitable dairy enterprise, merely increasing milk production is not sufficient; improving the quality of the milk is equally important. Consequently, to secure a better price for milk, it is essential to understand the factors that influenceand can help increase its fat and SNF levels. To this end, let us study the various factors that affect the fat and SNF content of milk.

What is Milk Fat?

Fat specifically milk fat—is primarily composed of dietary fats, stored body fat, and fats synthesized within the udder. If livestock are fed fodder rich in energy and fibrous components, it promotes the healthy proliferation of beneficial microorganisms within the animal's body; these microorganisms then produce adequate amounts of fat, which is transported via the bloodstream to the udder and subsequently secreted into the milk. Milk fat consists predominantly of triglycerides (98%).

What is SNF in Milk?

SNF stands for "Solids-Not-Fat." It is a key parameter used to determine milk quality and is frequently tested at many dairy centers to decide the price of milk. Measuring SNF is beneficial for quantifying the total solid constituents present in milk, excluding water. Milk contains a protein called Casein, along with various vitamins, minerals, and sugars (specifically Lactose). The concentration of these constituents within the milk is determined through SNF analysis. In essence, it serves as a measure of the milk's richness or density. The higher the SNF content, the superior the quality of the milk. An instrument known as a Lactometer is used to measure SNF. Casein is the primary constituent that influences the SNF level in milk. Research has demonstrated that if the concentration of Casein decreases, the milk fails to meet the required SNF standards. In milk, Casein does not exist in a free state; rather, it is found in association with phosphates and calcium.

By now, it must be clear that if one wishes to increase the SNF specifically the Casein content—in milk, it is essential to provide the animal with a diet containing all three components: proteins, calcium, and phosphorus. Of these, proteins are found abundantly in leguminous plants, fodder crops characterized by their small leaves such as Fenugreek grass, Cowpea, Berseem, etc. Additionally, calcium and phosphorus are supplied through mineral mixtures.

Factors Affecting Milk Fat Content

1. **Heredity**: The fat content in milk is controlled by genetics (chromosomes). Consequently, there is a very close correlation between milk yield and milk fat percentage. Generally, cows that produce a higher volume of milk tend to have a relatively lower fat content in their milk. Therefore, for breeding purposes, it is advisable to select cows that exhibit both high milk production and high milk fat content; furthermore, the bull used for breeding should ideally be descended from a high-yielding cow with a high milk fat percentage.

2. Physical condition of cows and buffaloes during gestation: Cows that are physically weak during the final stages of pregnancy tend to produce milk with a lower fat content. Conversely, animals that maintain good physical condition throughout their gestation period produce milk with a healthy fat content. Therefore, during the final stages of pregnancy, a cow's Body Condition Score (BCS) should ideally be maintained at approximately 3.5. To ensure that the physical condition of pregnant animals remains optimal, it is essential to provide them with a diet comprising both cereal and legume fodder during gestation. Additionally, it is crucial to incorporate appropriate quantities of concentrate and mineral mixture into their diet. Pregnant cows and buffaloes require supplementation with Vitamins A, D, and E, as well as Selenium. Silage should also be included in the diet in appropriate proportions. Finally, animals must be provided with an abundant supply of clean drinking water.

3. Mastitis: This is an important disease that adversely affects both the quantity of milk produced and the levels of its various constituents. A deficiency of essential nutrients specifically Selenium and Vitamins A, D, and E within the animal's body compromises its immune system, thereby increasing susceptibility to mastitis. To prevent this disease and maintain robust immunity in livestock, it is essential to regularly incorporate Selenium and Vitamins A, D, and E into their diet. Furthermore, it is imperative to ensure that the barn or shed remains consistently dry and clean.

4. Ratio of concentrate and fodder: Milk fat is primarily generated through the digestion of fibrous materials present in the diet. If animals are fed an excessive amount of concentrates (animal feed) relative to fodder, the fat content in their milk tends to decrease. Based on dry matter content, the ideal ratio of concentrate to fodder should be 40:60. Feeding fodder with high moisture content can lead to a reduction in milk fat levels. To maintain optimal levels of milk constituents, animals should be provided with a balanced diet consisting of appropriate proportions of concentrate, green fodder, and dry fodder; this mixture should be fed two to three times a day in the form of a 'TMR' (Total Mixed Ration). Feeding animals exclusively with lush green fodder results in a decline in milk fat content. Rather than relying solely on protein-rich sources as animal feed, the diet should consist of a properly balanced mixture of grains, oil cakes, agro-byproducts, bran/chuni, mineral mixtures, and salt. For animals that receive an abundant supply of green fodder throughout the year but are not provided with dry fodder, concentrate should be incorporated into their diet in a dry form.

5. Feeding a diet rich in highly digestible energy sources disrupts the environment within the animal's rumen. This leads to a decrease in pH levels, which in turn reduces the digestion of dietary fiber. Consequently, the production of acetic acid diminishes, resulting in a reduction in the fat content of the milk.

6. Dietary carbohydrate content: Non-fibrous carbohydrates such as starch and sugar undergo rapid fermentation within the rumen. This process impacts the levels of both fat and protein in the milk. While non-fibrous carbohydrates tend to increase the protein content of milk, they simultaneously cause a decline in the milk fat percentage. This reduction in fat percentage is attributed to the increased production of propionic acid, as well as the lower quantity and reduced digestibility of dietary fiber.

7. Size of chaffed fodder: If the fodder is chopped into very small pieces, the fat content of the milk tends to decrease. Therefore, to maintain optimal milk fat levels, the size of the chopped fodder fed to animals should ideally range between 0.64 cm and 2 cm. This ensures proper digestion of the fibrous components, thereby helping to sustain a healthy fat percentage in the milk.

8. Harvesting stage of fodder crops: If fodder is harvested at an overly mature stage, its digestibility decreases, leading to a reduction in the levels of milk components. Conversely, when fodder is harvested at the appropriate stage, its digestibility remains excellent, thereby maintaining good levels of milk components.

9. Dietary levels of Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF): If the diet contains 28–35% Neutral Detergent Fiber (NDF) and 18% Acid Detergent Fiber (ADF), feed intake and digestibility remain optimal, resulting in good milk production and high levels of milk components. The daily NDF requirement for livestock is approximately 1.2% of their body weight.

10. Frequency of Feeding Concentrates: High-yielding animals require larger quantities of concentrate feed. If this large quantity of concentrate is fed in just two separate servings per day, it can disrupt the environment within the animal's rumen, potentially leading to a decrease in milk fat levels. However, if the same quantity of concentrate is divided into 4–5 smaller servings throughout the day, it can help improve milk fat levels.

11. Dietary level of rumen-degradable proteins: If the dietary level of proteins that undergo degradation within the rumen is low, the growth of beneficial rumen bacteria is inhibited; their population declines, and their functional efficiency diminishes. Consequently, the digestion of dietary fibrous matter is reduced, leading to a decrease in the fat content of the milk.

12. Dietary proportion of grains/silage: If the diet contains an excessive proportion of grains or silage, the pH level within the rumen drops. This impairs the digestion of fibrous matter and results in a decline in milk fat content. Therefore, when feeding a diet rich in grains or silage, the inclusion of dietary buffers can significantly aid in improving the milk fat percentage. If "hay" is fed to cows and buffaloes before feeding their regular animal feed, it effectively prevents a drop in rumen pH and ensures that digestive processes remain healthy.

13. Use of oil, bypass fats, and bypass proteins in animal feed: Studies have shown that incorporating oils such as cottonseed, mustard, sunflower, or soybean oil into the animal diet at a daily rate of 100 ml helps to increase the milk fat content. However, the oil content in the diet should not exceed this limit; doing so can lead to various complications, such as the elimination of beneficial rumen bacteria and a disruption of digestive functions. Furthermore, the inclusion of bypass fats and bypass proteins in the animal diet aids in boosting both the fat and SNF (Solids-Not-Fat) levels in the milk.

14. Instead of relying solely on cereal fodder in animal diets, a combination of cereal and legume fodder should be included. Rather than using only Napier grass, other fodder varieties such as maize, sorghum (Kadval), and Mega Sweet should be incorporated alongside it. Substituting dry fodder (Kadbi) with 'Hay' in the animal diet helps increase the levels of various constituents in the milk.

15. Incorporating yeast culture into the animal diet enhances the digestion of fibrous materials and improves the utilization of lactic acid; consequently, this aids in boosting both overall milk production and the fat content of the milk.

16. The use of mineral mixtures in animal feed facilitates the production of various beneficial enzymes, improves digestive processes, and enhances the metabolism of nutrients. Overall, this contributes to increased milk production and higher levels of milk constituents.

17. Use of probiotics in animal diets: Probiotics should be included in the animal diet in situations involving reduced digestive capacity, the onset of gastric disorders, post-abdominal surgery recovery, the use of low-quality fodder, periods of physical stress on the

animals, during summer or hot weather conditions, when the diet consists predominantly of fodder, when the animals are not receiving adequate amounts of concentrate feed, or if the rumination process has ceased. This practice invariably improves digestibility, boosts productivity, and helps enhance the overall quality of the milk.

18. During periods of fodder scarcity, to enhance the digestibility of available dry, low-quality fodder, animals should be provided with components that supply ready energy when such fodder is fed. Examples include jaggery, molasses, coarse maize, etc. This is because these substances stimulate the growth of bacteria within the animal's rumen (the first stomach chamber) that are essential for digesting fibrous matter; furthermore, the increased activity of these bacteria improves the overall digestibility of the low-quality fodder. Consequently, this helps in improving the quality of the milk produced.

19. During times of scarcity, if animals suffer from a deficiency of nitrogen and sulfur, the activity of the beneficial bacteria within the rumen which are crucial for digestion becomes restricted. This leads to reduced fodder digestion, causing the animals to become weak. Simultaneously, there is a significant decline in milk yield. To prevent this, animals should be provided with of mineral mixture in required dose containing nitrogen and sulfur during periods of fodder scarcity.

20. During scarcity periods, the available fodder often fails to supply the necessary amounts of minerals and salt required for their physiological needs. This disrupts the body's water balance and reduces the production of hormones and other vital bodily fluids. Furthermore, the functionality of the beneficial rumen bacteria diminishes, leading to reduced fodder digestibility; such deficiencies can eventually trigger various diseases. This has an adverse impact not only on milk production but also on the composition of the milk itself. To prevent these issues both during scarcity periods and at other times mineral lick blocks should be kept in the barn, allowing the animals to lick them as needed to fulfill their body's mineral requirements.

21. Environmental temperature: In crossbred cows, once the ambient temperature rises above 27°C, a noticeable impact is observed on both milk production and milk composition. This rising temperature can lead to a reduction of up to approximately 25% in the milk's fat content. Generally, for every 5°C rise in temperature above 27°C, a decline of 0.2% is observed in the milk fat content.

22. **Days in lactation**: In cows and buffaloes, the fat content in the milk is typically high during the first ten days following calving. As milk production increases thereafter, the fat content tends to decrease. Subsequently, from the second to the fourth month, the fat content begins to rise gradually, and this upward trend continues until the lactation period draws to a close.

23. **Milking Method**: Since milk fat is lighter in density, it tends to accumulate in the upper regions of the udder. If the animal does not properly let down her milk (release the flow) or if the milker does not extract the milk rapidly, the fat-rich milk remains trapped within the udder; consequently, the recorded fat percentage in the milk appears lower than its actual value. It is advisable to feed the calf the initial milk drawn, rather than the last milk (strippings), as this helps to ensure a higher fat percentage in the milk intended for human consumption. The individuals responsible for milking should not be changed frequently. The milking environment should be calm and quiet. Animals should not be frightened or distressed during the milking process. During the winter season, lukewarm water should be used to wash the udder; this facilitates a proper milk let-down, resulting in a higher fat yield. Conversely, the use of cold water hinders the proper let down of milk. The entire quantity of milk contained within the udder should be extracted within 6 to 7 minutes.

24. **Irregularities in Milking:** Frequently altering milking times, varying the intervals between milkings, or changing the person performing the milking results in adverse effects on both milk production and the composition of the milk.

25. In sick animals, a decrease in milk production is observed, often accompanied by an apparent increase in the milk fat content.

26. In animals allowed to graze outdoors, the composition of the milk undergoes daily fluctuations.

The levels of various milk constituents depend directly on the specific type of fodder consumed by the grazing animals on any given day.

27. The levels of various constituents in the milk of cows and buffaloes begin to decline gradually after the sixth lactation cycle. As the animals age progresses, the fat content decreases by approximately 0.02% with each subsequent lactation; notably, the decline in the Solids-Not-Fat (SNF) content is even more pronounced than that of the fat content.

28. Sudden changes in an animal's diet disrupt its digestive system, leading to detrimental effects on both milk production and milk composition. Dietary changes should, therefore, be introduced gradually.

29. Treating dry fodder with agents such as ozone, sodium hydroxide, urea, or alkalis enhances its digestibility, thereby contributing to increased milk production and improved milk composition. If a decline is observed in the levels of fat or other constituents in the milk, all the aforementioned factors should be carefully evaluated, and appropriate remedial measures should be implemented accordingly.

Conclusion

Proper animal care, nutrition, and management are essential for enhancing both milk quality and profitability in dairy farming.

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AUTHORS' DETAILS:

Nilima Karam
Associate Professor, Department of Entomology, College of Agriculture Kyrdemkulai, CAU, Imphal

Souvik Mohanty
Department of Entomology, College of Agriculture, Central Agricultural University, Imphal – 795004, Manipur, India

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DOMESTICATION OF STINGLESS BEE SPECIES IN NORTH EAST HILL REGION

Introduction

Stingless bees are an important group of eusocial insects belonging to the family Apidae, subfamily Meliponinae. They live in highly organized colonies comprising a queen, workers, and males. As key pollinators in tropical and subtropical ecosystems, they play a significant role in maintaining biodiversity and supporting agricultural productivity. Northeast India, recognized as a biodiversity hotspot, harbors a rich diversity of stingless bee species. The practice of keeping stingless bees in traditional bamboo beehives is not only culturally significant but also ecologically sustainable. The honey they produce often referred to as "pot-honey" is highly valued for its medicinal properties, distinctive flavor, and rising market demand. Beyond honey, stingless bees also produce propolis, pollen, and cerumen (a mixture of wax and plant resin), all of which have diverse applications in medicine, cosmetics, and agriculture.

In Northeast India, indigenous communities have long recognized the significance of these bees and traditionally harvest wild colonies. However, systematic and scientific domestication termed meliponiculture is still in its early stages in the region. Promoting their organized domestication can lead to economic empowerment of rural communities while simultaneously supporting biodiversity conservation efforts.

About the Bee Species

A survey was conducted in Riha village, Ukhrul district, Manipur, which identified two species of stingless bees. Species identification was confirmed by the Indian Agricultural Research Institute (IARI), New Delhi. The species found were:

- *Tetragonula srikantanathi* (Viraktamath & Rojeet, 2021)
- *Lepidotrigona arcifera* (Cockerell, 1929)

These findings are significant as they confirm that species previously recorded in neighboring states of Tripura and Nagaland also occur in Manipur, thereby extending their documented range in Northeast India.

Fig 1: *Tetragonula srikantanathi* (Viraktamath & Rojeet 2021)

Fig 2: *Lepidotrigona arcifera* (Cockerell, 1929)

Nesting Structure of Stingless Bees

Stingless bee colonies are typically found in natural cavities such as tree trunks, wood logs, bamboo stems, and wall crevices. The most common method of domestication is "hiving," which involves carefully transferring a wild colony into an artificial bee box, log, or bamboo hive. In the study area, 26 colonies were successfully maintained in wooden hives and logs suspended from trees. The bees construct their nests using wax and plant resins, resulting in a characteristic dark brown color that provides natural camouflage.

The internal architecture of the hive is neatly organized into distinct functional zones. The brood area, located at the centre of the nest, contains oval, brownish cells where the queen lays eggs and larval development occurs. Surrounding the brood area are the food storage zones: pollen pots at the outer periphery, filled with sour-tasting compacted pollen pellets, and honey pots at the inner periphery, where the bees store their characteristic pot-honey. Table 1 summarizes the structural characteristics of the different nest components.

Fig 3: Bamboo Hives being used to domesticate stingless bees in IBDC COA, CAU, Imphal

Table 1: Internal structure of nesting hives of stingless bees

Parameters	Brood Cells	Honey Pots	Pollen Pots
Shape	Oval	Oval	Oval
Colour	Brownish	Dark brown	Dark brown
Location	Centre	Inner periphery	Outer periphery

Fig 4: Internal component of the bamboo hives showing distinct zones for pollen pots, honey pots and brood chamber.

Advantages of Rearing Stingless Bees

Meliponiculture offers significant ecological and economic benefits to farming communities:

- **Increased Crop Yields:** Stingless bees are highly efficient pollinators of small-flowered crops and medicinal plants due to their small body size. Their pollination activity can increase crop yields by 25–30%
- **High-Value Honey:** Stingless bee honey is popularly referred to as the "Mother of Medicine" owing to its exceptional antimicrobial, anti-inflammatory, and antioxidant properties (antioxidant activity: 171.81–173.24 mg AAE/kg honey; proline content: 587.12–649.28 mg/kg honey). Although individual colony yield is modest (200–500 g per season), the market price ranges from Rs. 4,000–6,000 per kilogram due to its superior quality and medicinal value.
- **Cerumen and Propolis:** Cerumen, the wax-resin mixture used to construct storage pots, has properties similar to propolis and contributes to enhancing the antimicrobial quality of stored honey.
- **Higher Household Income:** Selling medicinal honey and other bee products can boost household income by an average of 20–35%, making meliponiculture an attractive livelihood option for rural and tribal families.

Challenges and Future Prospects

Despite its promise, meliponiculture in Northeast India faces several challenges. A major constraint is the limited taxonomic research on the full diversity of stingless bee species in the region, which hampers targeted conservation and domestication efforts. Additionally, current practice largely depends on harvesting colonies from the wild, which may become unsustainable as the scale of beekeeping expands.

Future efforts should prioritize systematic surveys to document regional stingless bee diversity, development of colony multiplication techniques that reduce dependence on wild populations, and formulation of supportive policies for meliponiculture under agro-forestry and tribal farming systems. With growing market demand and increasing awareness of stingless bee honey's health benefits, the outlook for meliponiculture in the Northeast Hill Region is highly promising.

Conclusion

Stingless bee domestication in the North East Hill Region represents a convergence of ecological wisdom, cultural heritage, and modern agricultural opportunity. The two species identified *Tetragonula srikantanathi* and *Lepidotrigona arcifera* are well-suited for domestication in bamboo and wooden hives, and their domestication has demonstrated tangible benefits in terms of pollination services and high-value honey production. Strengthening research, building farmer capacity, and developing sustainable colony multiplication protocols will be essential to scaling up meliponiculture as a viable livelihood and conservation strategy across the region.

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AUTHORS' DETAILS:

Divyanshu Meena

Ph.D Scholar, Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur

Devendra Saini

Ph.D Scholar, Department of Entomology, Rajasthan College of Agriculture, MPUAT, Udaipur

Dr. Alok Kumar Srivastava

Assistant Professor, Department of Zoology (Entomology), DBS College, CSJM University, Kanpur

Kalpesh Shivaji Thorve

MD, MAXX-GROW BIOTECH

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Insect Pest Management in Sustainable Agriculture: Recent Advances and Future Perspectives

1. Introduction

Insect pests are among the major biological constraints to agricultural production worldwide. They attack crops at different stages of growth and may damage leaves, stems, roots, flowers, fruits and seeds, resulting in substantial reductions in yield and quality. Insect infestation can also reduce the market value of agricultural commodities and increase production costs because farmers have to spend additional resources on crop protection. The problem becomes more complex because changes in climate, cropping systems, international trade and agricultural intensification can influence insect distribution, reproduction, migration and outbreak frequency. Consequently, sustainable insect pest management has become an important component of modern agricultural production systems.

Historically, insect pest management relied heavily on synthetic chemical insecticides because of their rapid action, broad-spectrum activity and relatively easy application. Although pesticides remain valuable tools for protecting crops, their excessive or inappropriate use has created several environmental and biological problems. These include insecticide resistance, pest resurgence, secondary pest outbreaks, residues in food and water, toxicity to beneficial organisms, disruption of pollinators and natural enemies, and contamination of soil and aquatic ecosystems. The development of resistance is particularly important because repeated use of insecticides with similar modes of action can select resistant individuals, gradually reducing the effectiveness of the products. The emergence of these problems encouraged the development and adoption of Integrated Pest Management (IPM), which considers pest management as an ecological and economic decision-making process rather than simply the application of pesticides.

2. Concept and Principles of Sustainable Insect Pest Management

The first principle is prevention. Preventive management attempts to create conditions that are less favourable for pest establishment and multiplication. Crop rotation, intercropping, balanced fertilization, appropriate planting dates, field sanitation, resistant varieties, removal of infested plant material and maintenance of crop health can reduce pest pressure. FAO recommends crop rotation, intercropping, resistant varieties, optimized planting times, weed management and field sanitation as important components of IPM. These approaches are particularly valuable because they reduce pest populations before they reach damaging levels and consequently decrease the need for emergency pesticide applications.

The second principle is regular monitoring and correct pest identification. Farmers should not apply insecticides simply because insects are observed in a field. Many insects are harmless, beneficial or economically insignificant. Monitoring allows farmers to distinguish between pest and beneficial species and determine whether the pest population has reached an economically important level.

Sampling can involve direct plant inspection, sweep nets, sticky traps, pheromone traps, light traps, yellow or blue sticky cards, suction sampling and automated imaging systems. Accurate identification is also essential because different insect species can differ considerably in their biology, host range, natural enemies and insecticide susceptibility.

The third principle is the use of economic thresholds. An economic threshold is the pest population level at which control measures should be initiated to prevent the pest from reaching the economic injury level. Threshold-based management reduces unnecessary pesticide applications and helps farmers make economically rational decisions. In modern agriculture, threshold decisions can increasingly be supported by weather information, pest forecasting models, field sensors, remote sensing and digital decision-support systems.

The fourth principle is conservation of beneficial organisms. Predators, parasitoids, pollinators and other beneficial organisms perform important ecosystem functions. Ladybird beetles, lacewings, predatory bugs, spiders and predatory mites can suppress pest populations, while parasitoid wasps and flies can regulate many insect pests. Conservation biological control seeks to improve the survival and effectiveness of these naturally occurring organisms by reducing broad-spectrum insecticide use and providing suitable habitat and food resources.

3. Cultural and Ecological Approaches

Cultural control is one of the oldest and most sustainable methods of insect pest management. It involves modification of crop-production practices to make the agricultural environment unsuitable for pest development. Crop rotation is particularly useful against pests that depend on specific crops for feeding or reproduction. Rotation interrupts pest life cycles and can reduce the buildup of soil-associated pests and crop-specific insects.

Intercropping can also influence pest populations through changes in host finding, plant architecture, microclimate and chemical signals. In diversified systems, insects may have greater difficulty locating their preferred host plants. At the same time, flowering plants can provide nectar and pollen resources to parasitoids and predators. Habitat diversification can therefore contribute to both pest suppression and biodiversity conservation.

Trap cropping is another ecological approach in which a more attractive plant is cultivated around or within the main crop to divert pests away from the economically important crop. Similarly, push–pull systems manipulate insect behaviour by combining repellent or deterrent plants with attractive trap plants. These approaches can reduce pest pressure without relying primarily on synthetic insecticides.

4. Biological Control: A Major Pillar of Sustainable Pest Management

Biological control involves the use of living organisms to suppress insect pests. It includes predators, parasitoids, pathogens and other biological agents. Biological control is considered an important component of sustainable agriculture because it can reduce reliance on synthetic insecticides while taking advantage of natural ecological interactions.

Predators such as ladybird beetles, lacewings, syrphid larvae, predatory bugs, spiders and predatory mites consume large numbers of pest individuals. Parasitoids, particularly species belonging to Hymenoptera and Diptera, develop on or inside their insect hosts and eventually kill them. Important parasitoid groups include Trichogramma, Braconidae and Ichneumonidae. These organisms can be conserved naturally or introduced through augmentative biological control.

Microbial control is another important component of biological pest management. Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae*, bacteria such as *Bacillus thuringiensis*, and insect viruses such as nucleopolyhedroviruses can be used against specific insect pests. Their specificity and biological origin make them valuable alternatives or complements to conventional insecticides.

5. Botanical Insecticides and Biopesticides

Botanical insecticides have received renewed attention because many plants contain secondary metabolites with insecticidal, antifeedant, repellent, ovicidal or growth-regulating properties.

Table 1. Major sustainable approaches for insect pest management

Management approach	Major examples	Main contribution to sustainability
Cultural control	Crop rotation, intercropping, sanitation, planting-time adjustment	Prevents pest buildup and reduces pesticide dependence
Host plant resistance	Resistant/tolerant varieties	Reduces pest establishment and crop damage
Biological control	Predators, parasitoids, entomopathogens	Utilizes natural ecological regulation
Botanical control	Neem, essential oils, plant extracts	Provides alternatives to some synthetic insecticides
Biopesticides	*Bacillus thuringiensis*, fungi, viruses	Targeted pest suppression with reduced environmental burden
Behavioural control	Pheromones, attractants, repellents, traps	Disrupts pest behaviour and improves monitoring
Mechanical/physical control	Traps, barriers, hand removal, mulching	Reduces pest populations without chemical residues
Genetic approaches	Sterile insect technique, resistant crops, RNAi	Provides species-specific or trait-based suppression
Precision pest management	Sensors, drones, GIS, remote sensing	Enables site-specific and timely interventions
Chemical control	Selective insecticides and rotation of modes of action	Provides tactical control when other measures are insufficient

Neem-derived compounds, particularly azadirachtin, are among the most widely investigated botanical insecticides. Essential oils and plant-derived compounds containing terpenoids, alkaloids, phenolics and other bioactive constituents are also being explored.

The advantages of botanical insecticides include biodegradability, multiple modes of action and the possibility of local production. However, their effectiveness can be influenced by sunlight, temperature, formulation, pest species and application method. Therefore, standardization of active ingredients and improved formulation technologies are essential for their wider adoption.

6. Semiochemicals and Behaviour-Based Pest Management

Insect behaviour is increasingly being exploited for sustainable pest management. Semiochemicals are chemical signals involved in communication between organisms. Pheromones are especially important because they can be used for monitoring, mass trapping and mating disruption.

Pheromone traps are widely used to monitor populations of moths and other economically important insects. Regular trap observations can provide information about pest abundance and help determine the timing of control measures. Mating disruption works by releasing synthetic sex pheromones into the crop environment, making it difficult for males to locate females. This can reduce mating success and subsequently decrease the next generation of pests.

7. Host Plant Resistance and Genetic Approaches

Host plant resistance is an important preventive component of sustainable pest management. Resistant cultivars may possess morphological, biochemical or physiological characteristics that reduce insect feeding, oviposition, development or survival. Resistant plants can reduce the initial pest population and therefore lower the requirement for chemical control.

Traditional breeding has produced several insect-resistant crop varieties, while molecular breeding and genomics are expanding the possibilities for developing resistant cultivars. Marker-assisted selection, genomic selection and gene-editing technologies can potentially accelerate the development of pest-resistant crops.

8. RNA Interference and Molecular Pest Management

RNA interference (RNAi) represents an emerging molecular approach for insect pest management. RNAi works by reducing the expression of specific genes through sequence-specific mechanisms. Researchers can identify genes essential for insect growth, development, reproduction or survival and design corresponding RNA molecules to suppress their expression.

The potential advantage of RNAi is its high degree of target specificity. This could reduce effects on non-target organisms compared with broad-spectrum insecticides. However, field application presents challenges involving RNA stability, delivery, uptake, environmental persistence and cost. Recent research has investigated improved formulations and delivery systems, including nanoparticle-assisted approaches.

9. Precision Agriculture and Digital Pest Management

One of the most significant recent developments in insect pest management is the application of digital agriculture. Traditional pest scouting can be labour-intensive and may fail to detect early infestations across large areas. Digital technologies can improve the speed, spatial accuracy and objectivity of pest monitoring.

Remote sensing can identify changes in crop canopy structure, colour, temperature and vegetation indices associated with pest injury. Drones equipped with RGB, multispectral or hyperspectral cameras can collect high-resolution information at field level. These data can help identify pest hotspots and support site-specific management.

Artificial intelligence and machine learning are increasingly being used for automated insect identification and crop-damage detection. Image-recognition systems can potentially distinguish pest species from beneficial insects and estimate pest density. AI-based systems can combine information from weather stations, traps, crop growth, pest observations and historical records to improve forecasting.

10. Artificial Intelligence and Decision-Support Systems

Artificial intelligence can support pest management through pest identification, forecasting, risk assessment and treatment recommendations. Machine-learning algorithms can analyse large datasets containing weather variables, pest counts, crop growth stages and historical infestation patterns. Such systems can generate early warnings and help farmers select appropriate management strategies.

Mobile applications are another promising tool. Farmers can photograph insects and receive identification assistance, access information about natural enemies and receive recommendations based on crop and pest conditions. Smartphone-based systems may be particularly useful in regions where conventional extension services are limited.

11. Targeted and Reduced-Risk Chemical Pest Management

Sustainable pest management does not necessarily eliminate the use of chemical insecticides. Instead, chemical control is integrated as a tactical component when pest populations exceed economic thresholds and other measures are insufficient. The objective is to select effective and selective insecticides, apply them at appropriate doses and timing, and minimize effects on beneficial organisms. Selective insecticides can reduce harm to predators and parasitoids. Rotation of insecticides with different modes of action is essential for delaying resistance development. Repeated application of the same mode of action can impose strong selection pressure on pest populations. Therefore, insecticide resistance management should be incorporated into IPM programmes.

12. Insecticide Resistance Management

Insecticide resistance is one of the major challenges facing modern pest management. Resistance occurs when genetically determined characteristics allow some insects to survive exposure to an insecticide that previously controlled the population. Surviving insects reproduce, causing resistant individuals to become increasingly common.

Resistance can arise through metabolic detoxification, target-site modification, reduced penetration, behavioural changes and other mechanisms. The problem is accelerated when farmers repeatedly use the same insecticide or products with the same mode of action.

13. Climate Change and Emerging Pest Risks

Climate change is expected to influence insect pest management considerably. Temperature affects insect development, reproduction, survival and distribution. Changes in rainfall, humidity and crop phenology can also modify pest population dynamics and natural-enemy interactions.

Warmer temperatures may allow some insect species to complete additional generations within a growing season. Climate change may also expand the geographical distribution of certain pests and facilitate the establishment of invasive species in new regions. Extreme weather events can disrupt natural enemies and cause unexpected pest outbreaks.

14. Role of Biodiversity in Sustainable Pest Management

Agricultural biodiversity is closely linked to ecological pest regulation. Monoculture systems can provide continuous and abundant resources for specialist pests, whereas diversified systems can disrupt pest movement and provide habitat for natural enemies.

Maintaining field margins, flowering strips, hedgerows and non-crop habitats can support predators and parasitoids. Diversified landscapes can also provide alternative food resources and refuges during periods when crop-associated prey are scarce.

Table 2. Recent advances and future directions in insect pest management

Emerging technology/approach	Recent advancement	Future potential
AI-based pest detection	Automated insect identification from images	Real-time field-level pest diagnosis
Remote sensing	Detection of crop stress and infestation hotspots	Large-scale early warning systems
UAVs/drones	Precision monitoring and targeted application	Autonomous pest management
Biological control	Improved agents and multi-agent systems	Climate-resilient natural pest regulation
Biopesticides	New microbial and botanical formulations	Replacement/reduction of broad-spectrum chemicals
RNAi	Gene-specific pest suppression	Highly targeted molecular pest management
Nano technology	Controlled and improved delivery	Lower-dose, precision pest control
Pheromone technology	Monitoring and mating disruption	Area-wide behavioural management
Genetic control	Sterile insect and other genetic techniques	Species-specific population suppression
Digital DSS	Integration of weather, pest and crop data	Farmer-specific real-time recommendations
Precision spraying	Site-specific pesticide application	Reduced pesticide use and cost
Ecological engineering	Habitat manipulation for natural enemies	Landscape-level biological control

16. Integration of Multiple Technologies

The future of sustainable pest management will not depend on a single technology. Instead, the greatest benefits are likely to arise from integration. For example, pheromone traps can provide pest-monitoring data, AI can analyse trap images, weather sensors can improve forecasting, biological-control agents can suppress the pest population, and precision sprayers can apply selective insecticides only when required.

This integrated approach can be described as data-driven IPM or precision IPM. It combines ecological knowledge with digital technologies and decision-support systems. Recent reviews indicate that the most effective future IPM systems are likely to integrate biological control, ecological engineering and digital technologies rather than treating these components as independent approaches.

18. Major Challenges

Despite substantial progress, sustainable insect pest management faces several challenges. Biological control can be inconsistent under variable environmental conditions. Natural enemies may be affected by temperature, humidity, pesticide exposure and habitat availability. Similarly, botanical and microbial products can show variable field performance because of environmental degradation and differences in pest susceptibility.

Digital technologies face challenges related to cost, internet connectivity, data quality, farmer literacy and algorithm reliability. AI models trained under one geographic or climatic condition may not perform equally well in another region. Regulatory frameworks for new technologies such as RNAi, genetic control and nanoparticle-based formulations also require careful development.

19. Future Perspectives

The future of insect pest management is expected to move from reactive pest control towards predictive, preventive and precision-based management. Early warning systems will increasingly combine climate data, pest surveillance, remote sensing and artificial intelligence to predict pest outbreaks before severe crop damage occurs.

Biological control is expected to become more sophisticated through the selection of climate-resilient natural enemies, improved mass production, advanced formulations and precision delivery. Multi-agent biological control systems may combine predators, parasitoids and microbial agents to improve reliability.

Molecular technologies such as RNAi and gene editing may provide highly targeted pest-management options. However, their ecological safety, regulatory acceptability and long-term effects must be carefully assessed. Genetic approaches such as sterile insect technology may become increasingly useful for area-wide management of specific pests.

Precision agriculture will increasingly enable farmers to manage pest populations at the level of individual plants or small field zones. Sensors, drones, robotics and AI-based decision systems could reduce unnecessary pesticide applications and labour requirements.

20. Conclusion

Insect pest management is undergoing a major transition from pesticide-dependent crop protection towards integrated, ecological and technology-supported approaches. Sustainable insect pest management recognizes that insect populations are components of agroecosystems and that long-term crop protection depends on maintaining ecological balance rather than attempting complete insect eradication.

Integrated Pest Management remains the foundation of sustainable insect pest management because it combines preventive, cultural, biological, behavioural, physical and chemical approaches. FAO emphasizes that IPM should minimize disruption to agroecosystems and encourage natural pest-control mechanisms while keeping pesticide use at economically justified levels.

Recent advances in biological control, biopesticides, RNA interference, genetic approaches, pheromone technology, remote sensing, drones, artificial intelligence and precision application are expanding the possibilities for sustainable crop protection. At the same time, climate change, insecticide resistance, biodiversity loss, technology costs and farmer adoption remain important challenges.

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