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Research Trends in Agriculture Science Volume II

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PREFACE

We are delighted to publish our book entitled ***"Research Trends in Agricultural Science Volume II".*** *This book is the compilation of esteemed articles of acknowledged experts in the fields of basic and applied agricultural science.*

The Indian as well as world population is ever increasing. Hence, it is imperative to boost up agriculture production. This problem can be turned into opportunity by developing skilled manpower to utilize the available resources for food security. Agricultural research can meet this challenge. New technologies have to be evolved and taken from lab to land for sustained yield. The present book on agriculture is to serve as a source of information covering maximum aspects, which can help understand the topics with eagerness to study further research. We developed this digital book with the goal of helping people achieve that feeling of accomplishment.

The articles in the book have been contributed by eminent scientists, academicians. Our special thanks and appreciation goes to experts and research workers whose contributions have enriched this book. We thank our publisher Bhumi Publishing, India for taking pains in bringing out the book.

Finally, we will always remain a debtor to all our well-wishers for their blessings, without which this book would not have come into existence.

Editors

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SAFEGUARDING CROPS: A COMPREHENSIVE GUIDE TO MANAGING INSECT PEST IN PROTECTED CULTIVATION

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Abstract:

Insect-borne diseases pose the greatest threat to greenhouse agricultural output and productivity worldwide. Because of the year-round mild temperatures, relatively high humidity, and ample food, the enclosed atmosphere of greenhouses is extremely favourable to diseases and insect pests. While much is known about disease epidemiology and insect behaviour, little attention has been paid to greenhouse environment manipulation expressly to avoid disease epidemics and insect infestations, which can easily account for 30% crop losses. According to the pest and the season, arthropod pests cause various sorts of damage to greenhouse crops. The degree of damage that can be tolerated varies greatly depending on the crop. IPM is a systematic approach to pest management that incorporates a number of approaches and strategies for either reducing pest populations or lessening their economic impact. It is a form of pest management that is site-specific and relies on accurate pest identification and an understanding of pest biology. Long-term, it is easier to understand how an investment in IPM will surely pay for itself in higher crop quality and a cleaner environment in greenhouse crop production.

Introduction:

Protected farming is the technique of cultivating crops in a controlled environment. This means that temperature, humidity, light, and other factors can be altered to fit the crop's needs. This promotes to larger and healthier produce. A range of agricultural practises are protected (Rabbi *et al.,* 2019). Some of the most common approaches are forced ventilated greenhouses, naturally ventilated polyhouses, insect resistant net houses, shade net houses, plastic tunnel and mulching, raised beds, trellising, and drip watering. In terms of protected cultivation area for fruit and vegetable crops, China ranks first (27,60,000 ha), whereas India ranks seventh (25,000 ha) worldwide (Nair and Barche, 2014).

Crops cultivated under controlled conditions High-value foods like tomato, cherry tomato, colourful capsicum, parthenocarpy cucumbers, pole type french beans, winter watermelon, muskmelon, and strawberries can be grown effectively out of season in Northern India under polyhouses/walk-in tunnels. The knowledge has also been proved valuable to produce grafted fruit plants year-round. Climate change is becoming an increasingly significant global problem that can no longer be ignored. The main underlying cause is anthropogenic, i.e., unsustainable use of fossil fuels, forest degradation for industrialization, and rapid urbanization with an overpopulation (Mukherjee *et al.*, 2016).

Table 1: Crops Grownup Under Protected Farming (Source: Pattnaik and Mohanty, 2021)

Flowers	Carnation, Gerbera, Rose, Lilium, Orchid, Gladiolus, Chrysanthemum, etc.
Vegetables	Coloured Capsicum (Yellow and Red Bell Peppers), Tomato, Cucumber.
Fruits	Strawberry
Seedling and Nurseries	Vegetables, Flowers, Tissue Culture, Clonal for Forestry, Fruit Grafting (like Lemon, Citrus, Mango, Pomegranate, Guava, Litchi, etc.)
Leafy vegetables	Lettuce, Kale, Argula, Celary, Parsley, Spinach, Green Amaranthus, Red Amaranths
Herbal Crops	Basil, Mint, Coriander, Rosemary, Thyme, Oregano
Micro greens	Red Cabbage, Beet Root, Pink Radish, White Radish, Broccoli
Rhizomes	Turmeric
Tubers	Potato
Edible flowers	Nasturium, Sweet William, chamomile

Under protected circumstances, the warm, humid weather and plenty of nourishment provide a great, steady environment for pest development. Natural enemies that keep bugs in check outside are frequently absent in a protected environment. For these reasons, pest problems typically grow faster and with more severity indoors than outdoors. Arthropod pest harm caused to crops grown in greenhouses differs based on the pest and season (Sunitha, 2018). Insects and diseases are the major challenge to protected cultivation (glasshouses and plastic houses and tunnels). It is estimated that, worldwide, the area of protected crops is 307,000 ha, with vegetables occupying 65 % (200,000 ha) of this area and ornamentals 35 % (107,000 ha). Year-round mild temperatures and relatively high humidity make greenhouses' sheltered habitat ideal for arthropod pests (Reddy and Reddy, 2016a). In many countries, production from protected cultivation is export oriented, and therefore, the grower has to comply with the maximum residue levels set by market regulatory bodies.

IPM is a systematic method to pest management that includes a variety of methods and tactics designed to either reduce pest populations or reduce their economic effect. It is a site-specific pest control strategy that relies on accurate pest identification and an understanding of pest biology. In the long run, it is simpler to understand how an investment in IPM can pay for itself in greater crop quality and a more sustainable environment.

Table 2: Insect-pest scenario in India's protected environment (Source: Sood, 2010)

Common name	**Scientific name**	**Host**
Sucking pest		
Aphids	*A. gossypii*	Capsicum
	M. sanborni	Chrysanthemum
	Macrosiphum luteum	Orchid
	Myzus escalonicus	Strawberry
	M. persicae	Capsicum, Gerbera
	Toxoptera aurantii	Orchid
Thrips	*S. dorsalis*	Rose
	Thrips palmi	Gerbera
	T. tabaci	Gerbera
Whiteflies	*B. tabaci*	Gerbera, capsicum
	T. vaporariorum	Tomato, Cucumber, Capsicum, Beans, Gerbera and more than 30 hosts
Mites	*Aceria lycopersici*	Tomato
	Polyphagotarsonemus latus	Capsicum
	Stenotarsonemus fragariae	Strawberry
	Tetranychus cinnabarinus	Carnation
Mealybugs	*Planococcus citri , Pseudococcus affinis , and P. longispinus*	—
polyphagous scale	*Coccus hesperidum and Diaspis boisduvalii*	Orchids
Defoliators		
Caterpillars	*H. armigera*	Capsicum, Tomato, Carnation
Leaf Rollers (Tortricidae)	*Adoxophyes orana Cacoecimorpha pronubana, Clepsis spectrana, and Epichoristodes acerbella*	They are mainly brown or green caterpillars of tortricid leaf rollers, like, which live between leaves spun together. They feed on leaves and buds.
	S. litura	Rose, Tomato, Capsicum, Cucumber
Leaf miner	*L. trifolii*	Tomato, Cucumber, Chrysanthemum, Gerbera and many ornamentals

Diamond black Moth	*Plutella xylostella*	Cabbage, Cauliflower.
Nematodes		
Root-knot nematodes	*Meloidogyne incognita,* *M. javanica*	Capsicum (Bell-Pepper), Tomato, Chilli, Okra, Gherkins, Muskmelon, Watermelon, Carnations, Roses, Gerbera and Anthuriums
Reniform nematode	*Rotylenchulus reniformis*	
Slugs	*Arion spp., Deroceras spp., and Lehmannia spp.*	—


Aphid infestation

Mite infestation in Capsicum

Caterpillar infestation

Mealy bug infestation

Caterpillar infestation

Spodoptera infestation

Figure 1: Insect pest infestation in protected cultivation of crops (Photos: G Raja Reddy)

Mechanisms driving pest and disease progression

i. In protected farming as ground bed crops are rarely rotated, soilborne diseases and insects that pupate in the ground build up if cultivated soil is not disinfested.

ii. Disease propagation is aided by high host plant density and the accompanying environment.

iii. Inside the greenhouse, the temperature is normally warm, humid, and windless. Most crops grow rapidly under such conditions, but it is also suitable for the development of bacterial and fungal diseases (Jarvis, 1992), insects transmitting viruses, and insects that are herbivorous.

iv. Most greenhouse crops are labour-intensive and for long periods require daily routine operations (such as tying, pruning, and harvesting). The risks of spreading pathogens through workers and machinery are increased by the risks deriving from accidental wounds and from the exposure of large areas of tissues by pruning.
v. Greenhouses are intended to protect crops from a variety of adversities; however, most infections and pests are impossible to exclude.
vi. Windborne spores and aerosol containing bacteria enter entrances and ventilators; soilborne pathogens enter through windblown dust and attach to the footwear and equipment.
vii. Aquatic fungi can be found in irrigation water, and insects that enter the greenhouse can spread viruses as well as bacteria and fungi. Pathogens and pests are tough to remove once inside a greenhouse.

Managerial Approaches

As greenhouse conditions allow pest populations to grow quickly, successful insect pest control on greenhouse crops and ornamentals is dependent on a number of elements. The IPM programmes for protected cultivation can be thought of as a pyramid with three important components: problem avoidance, sampling and early detection, and curative measures.

1.Preventive measures

1.1 Utilisation of physical constraints

Physical exclusion of insects from the greenhouse should help reduce the incidence of direct crop damage as well as insect-transmitted virus diseases; theoretically, this exclusion can be accomplished by fitting fabric screens with mesh apertures smaller than the insects' body width over ventilators and doorways or by insect-repellent fabrics, but in practise, significant insect penetration may still occur. Some of the unique mechanisms will be discussed more below.

1) Insect Screening

Pests cannot be controlled or removed by screens; they just keep the majority of them out. As a result, they must be installed before they appear, and further pest management procedures, such as biocontrol, are still required (Berlinger *et al.*, 1988). Insect parasitoids and predators that are smaller than their prey can still enter the greenhouse through pest screens, but larger ones must be introduced. They must be protected since they provide an inexpensive means of biological pest control, and damaging insecticides should be avoided. Insect netting systems are used in greenhouses in order to control the movement of insects inside and outside the greenhouse. In this way, harmful insects are kept out and useful insects are kept indoors in a sustainable and environment-friendly way. Insect fabrics come in many hole sizes based on the size of the smallest insect (white fly, aphids, thrip) you are looking to control. The denser the insect screen the better the insect protection, and a proper design of the area covered needs to consider ventilation requirements in order to provide enough surface area to enable adequate airflow. The mesh size is determined by the insect being targeted (Table 3). For total thrips exclusion, mesh with holes smaller than 200 micrometres is required; nevertheless, screening with holes as large as 600 mm is sufficient for excluding leaf-miners (Sharma *et al.*,2021).

Table 3: Screen mesh sizes must be adequate to keep the primary greenhouse pests away

Insect-Pest	Hole size (micron)	Mesh (number of threads per linear inch)
Leaf-miner (*L. trifoli*)	610	34
Cotton whitefly (*B. tabaci*)	462	42
Aphid (M. *persicae*)	340	52
Greenhouse whitefly (T. *vaporariorum*)	290	58
Thrips (Thrips spp.)	192	76

To protect crops from insects, various types of screens and plastic covers have been developed; the problem for the producer is to match the appropriate type of screen to local insect population.

Figure 2: **Insect Screens for Greenhouses**

2) UV-absorbent plastic sheets

According to unsubstantiated states, UV-absorbing plastic sheets protect crops from insect pests and virus illnesses transmitted by insects by altering insect behaviour (Antignus *et al.,* 1996). Nonetheless, these UV-absorbing plastic sheets are now commercially available. Insects use their compound eyes to detect light signals. The compound eye's architecture and physiology are designed to detect UV wavelengths alone or a combination of UV and visible photons. The UV portion of the solar spectrum is vital in the ecological behaviour of insects, including orientation, navigation, eating, and sex interaction. Commercially available spectrally modified sheets are made by incorporating a UV-absorbing additive into the raw material, which prevents the transmission of most UV wavelengths below 370–380 nm while not interfering with the transmission of photosynthetically active energy (400–700 nm). The quantity of whiteflies, aphids, and thrips trapped on sticky yellow cards covered with a UV-absorbing film was 10 to 100 times lower than the number trapped on conventional films. The use of UV-A films also assisted in reducing the number of insecticide applications for the management of *Spodoptera lituralis* by 50–80%. UV-absorbing plastic roofing had the most pronounced thrips deterrence effect.

3) Use of metalized or reflective mulches

These are generally utilised for insect repellent properties. Metalized mulch was 90% effective in limiting silverleaf whitefly entry. Screening and metalized mulch should be used combined to achieve the highest total decrease of whitefly invasion. Complete mulching of the greenhouse floor to prevent weeds and to function as a mechanical barrier to some insect life stages (leaf miners, thrips, and other lepidopteran pests) preventing them from migrating into the soil for pupation (Summers and Stapleton, 2002).

1.2. Sanitation and cultural practices

1) Sanitation

Sanitation is the removal of both contaminated materials and potential sources of infestation, followed by surface and equipment disinfection. Quarantine, seed disinfestations, the use of healthy mother plants for cuttings, micropropagation, removing and properly disposing of all previous crop debris, pasteurising or solarizing soil and soilless media, and disinfesting the greenhouse structure, benches, trays, stakes, and other materials all help to reduce inoculum (Jarvis 1992). Formaldehyde (as formalin) and hypochlorite are disinfectants, but both are hazardous to humans and their remains are phytotoxic. A persulfate oxidising agent, on the other hand, kills viruses and bacteria without causing severe negative effects.

2) Cultural Practices

a) Preseason Cleaning

Sanitation is a fundamental component of cultural practises. Infestations are easier to avoid than to treat. Insects can penetrate the protected structure in three ways, according to observations:

- Use of contaminated seedlings/planting material
- Plant infestation within the protected structure
- Infestation by host plants outside but close to protected structures

Before bringing in a new crop, it is necessary to eradicate pests from the preceding crop. Remove any plant waste and weeds from the greenhouse. Many pests can be found on different crops as well as broadleaf weeds. As a result, it is vital to avoid growing other crops next to the greenhouse and to keep broadleaf weeds at bay along the border of the greenhouse. In sheltered areas, monoculture is preferred; nevertheless, if polyculture is essential, avoid staggered planting. A two to four-week fallow interval reduces insect load dramatically. After watering, place yellow sticky cards and indicator plants to identify the presence of thrips, whiteflies, leaf miners, and other insects.

b) Spacing

Plants with close horizontal and vertical spacing, both on the bench and in the ground bed, promote the rapid spread of walking insects from plant to plant. Viruses spread mostly via water and soil splash, insects, and workers handling plants with contaminated tools and fingers. Because air movement is restricted in dense plantings, airborne propagule movement is constrained, leading in a patchy distribution of diseases and insects (Burdon *et al.*, 1989).

c) Growing Medium

Organic matter, for example, routinely added to greenhouse soils, raises populations of omnivorous Collembola and non-cryptostigmatic mites. Fungal parasites of insects and nematodes are also favoured in good tilth soils. Meloidogyne incognita, a root-knot nematode, can survive at 1-2 m, much below soil disturbance levels.

Most substrates can be fumigated or heatsterilized, but pasteurisation at 70 °C (Baker 1957) or solarization at 40-55 °C are preferable (Katan, 1981) Because thermophilic biocontrol organisms are kept, complete steam sterilisation to 100 °C is preferred. The entire greenhouse can be closed in bright sunlight to allow solarization of both the substrate and the roof structure. High temperatures and a lack of vapour pressure in closed greenhouses can kill the western flower thrips (*F. occidentalis*), but also its predator *Neoseiulus (Amblyseius) cucumeris* (Weintraub, 2003).

d) Inspection upon arrival

One of the most important parts of protected horticulture is starting with insect-free planting material. When new plants arrive at the greenhouse, inspect them thoroughly for signs of pest infestation. Lower or damaged leaves should be removed as needed to avoid bug spread. Determine whether therapy is needed at the first sign of bug or mite problems. Treating a group of young plants (at seedling stage) rather than larger plants where the dense canopy makes thorough coverage impossible simplifies pest management.

e) Nutrition

Plants can be predisposed to most insect pests due to deficiencies and excesses of macro- and micronutrients, as well as imbalances in fertiliser quantities. Nutrient balancing fertilisation programmes should be observed. Nitrogen should only be provided when absolutely necessary for optimal growth. Periodic heavy treatments generate nitrogen surpluses, which promote excessive growth and insect population expansion. It has been established that using potassium in the appropriate amounts minimises the occurrence of insect pests. Foliage overgrowth encourages sap-sucking insects like aphids to wreak additional damage (Bala *et al.*,2018).

f) Pruning and Training

Pruning and training tall staked and wire supported crops like peppers, tomatoes, and cucumbers not only changes the environment by modifying spacing and the disease susceptibility of various tissues. Pest populations can be controlled by removing leaves carrying pest prepupal and pupal stages, although premature removal of leaves carrying infested stages can result in biocontrol loss. This strategy could help to reduce the pest population of all pests targeted. Pruning lower leaves after harvesting lower fruit clusters is an excellent way to eliminate a large number of developing leaf-miners and whiteflies.

g) Trap crop/Indicator plants

Some of the preferred hosts of the target pests can be used to discover and catch the target pests early. In a protected area, planting border rows of Portulaca oleracea in rose can be used as a tobacco caterpillar trap crop.

h) Plant Quarantine

Greenhouse professionals and workers are one of the mechanisms for the spread of insect and mite pests. Plants with mites or thrips should not be moved, and they should not be touched or moved immediately after touching clean and healthy plants.

Scouting and early detection

Scouting and early detection are critical for effectively managing the insect invasion. Monitoring, also known as scouting, is the regular inspection of plants and exteriors to identify and analyse pest threats. It includes visual inspection of foliage and blossoms, as well as the use of sticky or light traps. Many insect infestations begin in small pockets of the greenhouse. Crop monitoring in real time identifies situations in which pests are absent or at levels much below economic impact, hence eliminating unnecessary control treatments and expenditures (Mani, 2022).

Yellow sticky cards (4″x12″ or 8″x12″) are a good adjunct to pest observation in a protected environment for adults of whiteflies, aphids, thrips, and leaf-miners. Yellow cards, on the other hand, will not allow monitoring of aphids within the crop because the majority of the aphids will be wingless. Blue-colored sticky traps can also be used to catch thrips. The traps are laid up in a grid arrangement, with 1-2 yellow sticky cards used for every 100 square metres of floor surface. Different aphid species prefer different sections of their host plants to infest. Green peach aphids tend to congregate on the juicy early growth, whereas melon aphids are normally scattered equally over the plant stems. Melon aphid populations had fewer winged adults than green peach aphid populations. Monitoring adult moths by trapping can provide information on the proper timing of application, when the pests' sensitive phases are exposed (i.e., larvae before leaf rolling or flying adults)

Light emitting traps used

Yellow Sticky Trap

Blue Sticky Trap

Funnel trap

Figure 3: Trap- To monitor and control of insect pests

Managing the Crop Environment

1. Temperature

In broad terms, diseases and arthropods both have optimal temperatures for dispersal and development (Jarvis 1992), although these cardinal points are the sum of the optima of various pathogen growth phases as well as distinct host defence mechanisms. Like diseases, insects and mites have an optimal temperature for activity, dissemination, and development. In general, greenhouse pests are thermophilic and thrive in temperatures ranging from 20 to 30 degrees Celsius at night and day. Aphids and greenhouse whiteflies require a little lower temperature, 15-25 °C. Shipp and Gillespie (1993) studied the effect of temperature and VPD on the survival of western flower thrips. Temperature, of course, influences not only arthropod pests but also their natural adversaries. Natural enemies may work poorly if temperatures are too high or too low, which can occur in the Mediterranean region during summer and winter, respectively.

2. Humidity

While free water and low VPD should be avoided if pathogens are present, these circumstances are required to generate epidemics of insect fungal infections such as *Verticillium lecanii, Beauveria bassiana, and Paecilomyces fumosoroseus* (Quinlan 1988). Similar divergent proof has been found for arthropod pests and their predators. While spider mites are most active at relatively high temperatures and low VPDs, *P. persimilis* is inhibited at those same temperatures and VPDs. Shipp and van Houten (1996) determined optimal humidity conditions for *N. cucumeris* predatory activity.

5. Light

Light Low and high light intensities are major stresses in crops, resulting in physiologic strains that predispose crops to disease (Schoenweiss, 1975). Light's effects on assimilate partitioning and the relative susceptibility of different tissues and organs to disease are especially important when combined with crop management procedures such as plant spacing, row orientation, training and pruning systems, irrigation, and nutrition (Jarvis, 1992). In contrast, the length of the day is important in determining diapauses in both arthropod pests and their predators. Early diapauses may be a considerable barrier to their utilisation. Non-diapausing strains can, to some extent, overcome this problem.

5. Air movement

The passive transport of spider mites on webs floating through the air and becoming caught on neighbouring plants is likewise affected by air movement. Despite some barriers, forced airflows can move larger insects into the greenhouse. Airborne semiochemicals restrict insect aggregation, however pheromone diffusion on excessive air currents can interfere with mating disruption as a biological control or attraction into sticky traps.

Curative measures

1. Biological control

Almost all agricultural pests have natural enemies in the form of parasitoids or predators. Biological control entails large-scale replication and release of such agents, or the creation of conditions in which naturally existing agents can act effectively (Bueno and Poletti, 2009). In field conditions, biocontrol agents have yielded some exceptional results, but the strategy has suffered a setback due to the widespread and indiscriminate use of insecticides.

The utilisation of specific predators and parasitoids in greenhouse environments is one of the fundamentals of biological pest management. However, for biological control to be effective, it must be well planned and implemented when the target populations are low. Bioagents are commercially accessible in Western Europe and North America and are successfully utilised to address pest problems in controlled environments (Table 4).

However, while this approach has potential in Indian settings, it has the following limitations:

- Temperature extremes and the impact of chemical pesticides on natural enemy capabilities
- Consumers have a low tolerance for pest damage, particularly in ornamentals.
- A lack of a system for supplying high-quality natural enemies

Table 4: Major biocontrol agents of Greenhouse Pests

Pest	**Parasitoid**	**Predator**	**Entomopathogens**
Mites	–	*Phytoseiulis persimilis Neoseiulis cucumeris Orius laevigatus*	–
Whitefly	*Eretmocerus mundus Encarsia Formosa Erectmocerus eremicus (Ercal), Amblyselus swirskii (Swirski-Mite)*	*Orius laevigatus Chrysoperla spp (Delphastus catalinae or D. pusillus)*	*Verticillium lecanii Beauveria bassiana*
Thrips	–	*Orius laevigatus Neoseiulis cucumeris*	–
Leaf miner	*Diglyphus isaea Dacnusa siberica*	–	*Bacillus thuringiensis*
Aphids	*Aphidus colemani Aphidus matricarae*	*Orius laevigatus Chrysoperla spp. Apidoletes aphidomyza*	*Beauveria bassiana, Verticillium lecanii*
Mealy bugs	*Leptomastix dactylopii,*	*Cryptolaemus montrouzieri*	*Beauveria bassiana, Verticillium lecanii*
Caterpillars	*Trichogramma spp*	*Chrysoperla carnea*	*Bacillus thuringiensis, SlNPV, HaNPV,* *Beauveria bassiana*
DBM	*Diadegma semiclausm* *Cotesia plutellae* (plains)		*Bacillus* *thuringiensis var kurstak*i 2g/lit
Slugs	–	–	*Phasmarhabditis hermaphrodita.*
Nematodes	–	–	*Paecilomyces lilacinus, Pachonia chlaydosporium and Pasteuria penetrans*

There are a number of advantages to using biological control agents. Pests cannot build up resistance against biological agents as easily as they can with pesticides. The cost of biological control is less than that of pesticides. There is no fear of phytotoxicity or persistence of chemicals potentially hazardous to human health. Generally, biological control does not completely eliminate the pest, as a certain level of pest population is necessary to sustain the predator population. For this reason, emphasis is on integrated control, using biological control agents with cultural and chemical control measures. The objective is not complete pest elimination, but pest management, whereby pest populations are maintained at a level below any significant plant damage.

With an IPM program, only certain pesticides must be used, which do not harm the predatory agents. However, highly infested areas may be spot treated by other more poisonous pesticides if pest populations cannot be controlled by the biological agents. Once such infestations are reduced, the use of these chemicals should be restricted. Pesticides such as insecticidal soaps, insect growth regulators or hormones, yellow sticky traps, and bacterial or fungi insecticides may be used with the biological agents without harming them

2. Chemical control

Insecticides have curative properties and are a significant tool for controlling pest populations. Insecticides of various types, such as botanical pesticides, microbiological pesticides, insect growth regulators (IGRs), synthetic chemical pesticides, and so on, are in use (Reddy and Reddy, 2016). In recent years, several of the significant limitations of pesticides have been highlighted. The problems of insecticide residues on crops have been disturbing the minds of people in both developed and developing countries around the world as a result of pesticide indiscriminate use. However, the prudent and widely acknowledged approach is for need-based judicious and safe insecticide use.

To avoid pesticide residue contamination of food in a protected environment, use pesticides with lower persistence and adhere to the recommended waiting interval between last insecticidal treatment and harvesting. Another problem for pest management is to limit the development of chemical resistance in insect species. This can be avoided or delayed by not using the same insecticide from the same group more than once. In the pesticide resistance management programme, including botanicals, microbials, and other agents in the management schedule improves performance (IRMP).

Aside from that, the safety of the pesticide applicator should be considered, as chemical pesticides become more volatile in the protected environment's high-temperature regimes. To avoid pesticides having a direct effect on the applicator, pesticides should be applied with all safety precautions, including a protective kit. Following pesticide treatment, a re-entry time of at least 12 hours should be observed. Under protected structures, insecticides having fumigant action should be avoided. The following are some pesticides approved for the control of insect and mite infestations (Table 16.5).

Table 5: Some of the key chemical formulations used for combating greenhouse insect infestations

Insect pest	Main insecticides	Space Treatments
Thrips, Whiteflies, Aphids	Imidacloprid @ 0.4g/L, Acephate @ 1g/L or Acetamiprid @ 0.2g/L, Abamectin @ 0.5 ml/L, Phosphomidan 0.2 mL and Azadirachtin.	Diazinon, dichlorvos, nicotine, pirimicarb, propoxur, or sulfotep.
Mites	Fenazate, Diafenthiuron, Fenpyroximate, Abamectin @ 0.5ml/L	
Caterpillars	Spinosad, Chlorantraniliprole @ 0.3ml/L, Flubendiamide @ 0.1ml/L	Dichlorvos or pyrethroids
DBM	Flubendiamide 19.92% + Thiacloprid 19.92% w/w SC (480 SC) or Spirotetramat 150 OD	
Leaf Miners	Abamectin, Spinosad @ 0.3ml/L, Abamectin @ 0.5ml/L	Dichlorvos or pyrethroids
Leaf Rollers	Acephate, bifenthrin, cypermethrin, cyfluthrin, deltamethrin, diflubenzuron, fenpropathrin, lufenuron, methomyl, permethrin, teflubenzuron, and trichlorfon	Dichlorvos or pyrethroids
Scale Insects and Mealybugs	Acephate, buprofezin, bifenthrin, mineral oil, oxamyl, pirimiphos-methyl, and propoxur	–
Slugs	Mercaptodimethur pellets and metaldehyde pellets	–
Nematodes	Carbofuran 10g/ m2, dazomet 40 g/ m2 and Methyl Bromide 0.12 g/L.	–

3. Drip insectigation for insect pest control

Chemigation provides gardeners with a viable alternative to standard foliar pesticide sprays for the control of certain pests of vegetables grown using a drip/trickle irrigation method. The use of a drip/trickle irrigation system for pesticide application enables for precise delivery of systemic insecticides into the root zone of vegetable crops, minimising the need for several pesticide foliar sprays. Many growers presently utilise drip irrigation systems to manage water, and the inclusion of an agrichemical injection system provides a cost-effective pesticide delivery strategy. It allows gardeners to apply a pesticide in nearly any weather condition to manage a variety of pests such as whiteflies, aphids, leafhoppers, leaf miners, beetles, caterpillars, and others while reducing overall pesticide inputs when compared to foliar sprays. Many of the new-chemistry pesticides labelled for drip/trickle irrigation system administration are selective to certain pests and, because they are sprayed to the plant root zone, are generally less hazardous to beneficial and nontarget organisms.

Future thrusts:

Pest management techniques must be developed in a safe environment, with a focus on pesticide aversion and selective application. Because this information is completely unavailable, safe waiting intervals for pesticide residues based on harvest time must be specified for crops cultivated in a protected environment. Aside from that, boosting grower awareness of early diagnosis and appropriate insecticide use should be prioritised. The recent availability of innovative, systemic insecticides such as neonicotinoids and anthranilic diamides, as well as more future pesticides in development, has increased the prospects for drip chemigation as an effective and environmentally sound pest management strategy.

Conclusion:

Based on the available research, it has been established that an integrated approach to greenhouse pest management can be employed successfully. To deal with insect pests, Indian greenhouse farmers must apply as many IPM exclusion techniques as feasible. Once these pests enter the greenhouse, growers have few options for controlling them. As a result, keeping pests out of the greenhouse is vital. Biocontrol agents, botanicals, and microbial diseases, as well as limited and environmentally safe pesticides to non-target organisms, must be developed and widely employed. Because of their capacity to act as vector plant viruses, several key insect pests of greenhouse crops, such as aphids, silverleaf whitefly, mites, and thrips, demand specific control strategies.

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BRIDGING THE GAP: AGROFORESTRY'S CONTRIBUTION TO SUSTAINABLE AGRICULTURE

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Abstract:

This chapter explores the significant role of agroforestry in promoting sustainable agriculture. Agroforestry, the integration of trees and shrubs with agricultural crops and/or livestock, offers a holistic approach that addresses various environmental, social, and economic challenges faced by modern agricultural systems. The chapter highlights the key principles, benefits, and challenges of agroforestry systems and examines their potential to enhance sustainability, resilience, and productivity in agriculture. It also discusses various agroforestry practices and case studies that demonstrate their effectiveness in mitigating climate change, conserving natural resources, improving soil health, promoting biodiversity, and supporting local communities. The chapter concludes with recommendations for policymakers, farmers, and researchers to further promote the adoption and expansion of agroforestry as a sustainable agricultural practice.

Introduction:

Agroforestry is an innovative and sustainable approach to agricultural land management that involves the intentional integration of trees and shrubs with agricultural crops and/or livestock within the same land area. It is a practice deeply rooted in traditional farming systems around the world and has gained increasing attention in recent years due to its potential to address various challenges faced by modern agricultural systems.

The conventional agricultural practices, characterized by monoculture cropping and extensive livestock production, have often led to detrimental environmental impacts, such as soil degradation, water pollution, loss of biodiversity, and increased greenhouse gas emissions. These practices also tend to be more vulnerable to climate change impacts, pests, and diseases. Recognizing these limitations, the concept of sustainable agriculture emerged, emphasizing the need to develop farming systems that are environmentally friendly, economically viable, and socially responsible.

Agroforestry aligns closely with the principles of sustainable agriculture by integrating trees and shrubs into agricultural landscapes. It offers a range of ecological, economic, and social benefits that contribute to the overall sustainability of the farming systems. Agroforestry helps to restore and enhance ecosystem services, improve soil health and fertility, conserve water resources, enhance biodiversity, and reduce greenhouse gas emissions. It also provides farmers with diversified income streams, increased resilience to climate variability, and opportunities for value-added products.

The significance of agroforestry in sustainable agriculture is further underscored by its potential to mitigate climate change. Trees and vegetation in agroforestry systems act as carbon sinks, sequestering atmospheric carbon dioxide and reducing greenhouse gas emissions. The increased biomass and organic matter in the soil contribute to carbon sequestration, thus playing a crucial role in climate change mitigation and adaptation.

Moreover, agroforestry offers opportunities for rural development and poverty alleviation by creating employment, improving food security, and empowering local communities. It enables smallholder farmers to maximize the productive use of limited land resources and diversify their income through sustainable agroforestry products, such as fruits, nuts, timber, fuelwood, and medicinal plants.

Given its multifunctional nature and potential to address pressing agricultural and environmental challenges, agroforestry has gained recognition at global, national, and local levels. International organizations, governments, research institutions, and farmers' networks have increasingly acknowledged the importance of agroforestry in promoting sustainable agriculture and have actively promoted its adoption and integration into agricultural policies and practices.

In the subsequent sections of this chapter, we will delve into the principles, benefits, and challenges of agroforestry systems, examining their potential to enhance sustainability, resilience, and productivity in agriculture. We will explore various agroforestry practices and present case studies that demonstrate the effectiveness of agroforestry in mitigating climate change, conserving natural resources, improving soil health, promoting biodiversity, and supporting local communities. Finally, we will provide recommendations for policymakers, farmers, and researchers to further promote the adoption and expansion of agroforestry as a sustainable agricultural practice.

Agroforestry principles and concepts:

1. Definition and Components of Agroforestry Systems

Agroforestry is a land-use management approach that involves the deliberate integration of trees and shrubs with agricultural crops and/or livestock within the same land area. It is characterized by the simultaneous and interactive management of both woody and non-woody components, creating a diverse and multifunctional system.

The key components of agroforestry systems include:

a) Trees or woody perennials: These can be fruit trees, timber trees, shade trees, or nitrogen-fixing trees, depending on the specific objectives of the agroforestry system. Trees provide a range of ecosystem services, such as carbon sequestration, shade, windbreaks, erosion control, and habitat for wildlife.

b) Agricultural crops: These include annual or perennial crops that are grown for food, fodder, fiber, or medicinal purposes. They can be intercropped with trees, planted in alleys between tree rows, or grown in the understory of tree canopies.

c) Livestock: Agroforestry systems can integrate livestock, such as cattle, sheep, goats, or poultry, either by allowing them to graze in the tree areas (silvopasture) or by incorporating them into a rotational grazing system within the agroforestry landscape.

d) Soil and ground cover: The management of the soil and ground cover, including herbaceous vegetation and mulch, is crucial in agroforestry systems. It helps to improve soil fertility, moisture retention, and weed control.

2. Basic principles and design considerations

Agroforestry systems are designed based on certain principles to maximize their benefits and overall sustainability. These principles include:

a) Biodiversity and ecological interactions: Agroforestry systems aim to enhance biodiversity by creating diverse habitats for plants, animals, and microorganisms. The interactions between different components, such as tree-crop or tree-livestock interactions, promote ecological processes and improve system resilience.

b) Functional complementarity: Agroforestry components are selected and managed based on their ability to complement each other functionally. For example, nitrogen-fixing trees can enhance soil fertility, shade trees can protect crops from excessive sunlight, and windbreaks can reduce wind erosion.

c) Resource cycling and nutrient management: Agroforestry systems promote efficient resource cycling by utilizing organic matter, nutrients, and water within the system. Nutrient-rich leaf litter from trees can be used as mulch or incorporated into the soil to enhance fertility.

d) Spatial and temporal management: Agroforestry systems require careful consideration of spatial arrangement and timing of activities. Proper spacing between trees and crops, as well as appropriate timing of planting, pruning, and harvesting, is essential for optimizing resource utilization and minimizing competition.

e**) Adaptive management:** Agroforestry systems should be designed and managed in a flexible and adaptive manner to respond to changing environmental conditions, market demands, and farmer needs. Continuous monitoring and evaluation allow for adjustments and improvements over time.

3. Classification of Agroforestry Practices

Agroforestry practices can be classified into different categories based on their spatial arrangement and management strategies. Some common agroforestry practices include:

a) Alley cropping: In alley cropping, rows of trees are planted with wide alleys in between, where annual or perennial crops are cultivated. The trees provide shade, wind protection, and organic inputs to the soil while allowing for the production of crops in the alley spaces.

b) Silvopasture: Silvopasture integrates trees, forage crops, and livestock in a mutually beneficial manner. Trees provide shade, forage, and browse for livestock, while livestock contribute to nutrient cycling and help manage vegetation.

c) Windbreaks and shelterbelts: These are linear plantings of trees and shrubs strategically placed to reduce wind velocity, protect crops and livestock from wind damage, and control soil erosion.

d) Homegardens and multistrata systems: Homegardens are small-scale agroforestry systems found around homes, where a diverse mix of trees, shrubs, and crops are cultivated for household use. Multistrata systems involve the vertical layering of vegetation, including tall trees, understory trees, shrubs, and ground cover plants.

e) Forest farming and agroforestry in forested landscapes: Forest farming involves the cultivation of crops under the shade of existing forests, utilizing the natural forest ecosystem for sustainable production. Agroforestry in forested landscapes focuses on integrating trees, crops, and livestock within forested areas to enhance productivity and conservation objectives.

Understanding these principles and concepts of agroforestry systems helps in the design, implementation, and management of sustainable and productive agroforestry practices.

Environmental benefits of agroforestry:

Agroforestry systems offer a range of environmental benefits that contribute to the sustainability and resilience of agricultural landscapes. These benefits include:

1. Climate change mitigation and carbon sequestration: Agroforestry plays a crucial role in mitigating climate change by sequestering carbon dioxide from the atmosphere and reducing greenhouse gas emissions. Trees in agroforestry systems act as carbon sinks, capturing and storing carbon in their biomass and soil. The increased biomass and organic matter in the soil contribute to long-term carbon sequestration. Agroforestry practices, such as alley cropping and silvopasture, have been found to have higher carbon sequestration potential compared to conventional agricultural systems, thereby helping to mitigate climate change.

2. Soil conservation and fertility improvement: Agroforestry systems help prevent soil erosion by providing effective windbreaks and reducing surface runoff. The presence of trees, shrubs, and ground cover plants helps to stabilize the soil, reduce water erosion, and improve soil structure. The leaf litter and organic matter from trees contribute to soil fertility by enhancing nutrient cycling, improving soil moisture retention, and promoting beneficial soil microorganisms. Agroforestry also reduces the need for synthetic fertilizers and agrochemicals, minimizing the associated environmental pollution risks.

3. Water resource management: Agroforestry systems contribute to improved water management by reducing water loss through evaporation and runoff. The canopy cover provided by trees helps to regulate soil moisture levels, reduce water stress in crops, and increase water infiltration into the soil. Agroforestry practices, such as alley cropping and multistrata systems, enhance water use efficiency by optimizing the distribution of water resources between trees and crops. This is particularly important in regions prone to drought or with limited water availability.

4. Biodiversity conservation: Agroforestry systems promote biodiversity conservation by providing habitats and ecological niches for a wide range of plants, animals, and microorganisms. The diverse structure and composition of agroforestry landscapes support a variety of species, including beneficial insects, pollinators, birds, and mammals. Agroforestry helps to maintain ecological balance, protect native species, and enhance landscape connectivity, contributing to overall ecosystem resilience. The presence of trees also enhances the provision of ecosystem services, such as pollination and natural pest control.

5. Agrochemical reduction and pollution prevention: Agroforestry systems reduce the need for synthetic fertilizers and pesticides due to improved nutrient cycling, pest regulation, and enhanced soil health. The integration of trees and shrubs can create a more balanced agroecosystem, reducing pest and disease pressures. This leads to a decreased reliance on agrochemical inputs, reducing the risk of water and soil pollution, and minimizing the negative impacts on human health and non-target organisms.

The environmental benefits of agroforestry contribute to the overall sustainability of agricultural systems, ensuring the long-term viability and resilience of food production while safeguarding natural resources and mitigating climate change impacts.

Economic and social benefits of agroforestry:

Agroforestry systems provide a range of economic and social benefits that contribute to the well-being of farmers, rural communities, and society as a whole. These benefits include:

1. Diversified income streams: Agroforestry allows farmers to diversify their income sources by integrating multiple products and services within the same land area. Trees in agroforestry systems can provide a variety of products such as fruits, nuts, timber, fuelwood, medicinal plants, and fodder. This diversification of income helps farmers reduce their dependency on a single crop or livestock product, mitigating financial risks associated with market fluctuations or climate variability.

2. Improved livelihoods and rural development: Agroforestry can contribute to improved livelihoods and rural development by providing employment opportunities, particularly in smallholder farming communities. The management, maintenance, and harvesting of trees and agroforestry products create jobs and income-generating activities, thus enhancing the economic well-being of farmers and local communities. Agroforestry practices can also stimulate local entrepreneurship, value-addition, and the development of rural industries.

3. Market opportunities and value-added products: Agroforestry systems offer market opportunities for farmers by providing a diverse range of products with high market demand. Fruits, nuts, specialty timber, and non-timber forest products from agroforestry systems often command premium prices in local, regional, and international markets. Additionally, value-added products such as processed foods, herbal medicines, and handicrafts derived from agroforestry resources can generate higher returns for farmers and stimulate rural enterprises.

4. Climate resilience and adaptation: Agroforestry enhances climate resilience by providing farmers with adaptive strategies to cope with climate variability and change. The presence of trees in agroforestry systems helps regulate microclimatic conditions, reducing temperature extremes and providing shade and windbreaks for crops and livestock. This reduces the vulnerability of agricultural production to adverse weather conditions, including droughts and storms. Agroforestry systems also contribute to the adaptive capacity of farming communities by diversifying production and increasing system resilience.

5. Food security and nutrition: Agroforestry systems contribute to food security and nutrition by increasing the availability and diversity of food products. The integration of food crops, fruits, and nuts in agroforestry systems provides a varied and nutritious diet for local communities. Agroforestry also helps address seasonal food scarcity by extending the availability of certain crops throughout the year. Moreover, the cultivation of multipurpose trees in agroforestry systems can provide a supplementary source of fodder for livestock, supporting livestock production and contributing to food security.

6. Cultural and social values: Agroforestry practices often have cultural and social significance, connecting communities to their traditional knowledge, values, and practices. Agroforestry systems can preserve cultural heritage, traditional farming systems, and indigenous knowledge related to the management of trees, crops, and natural resources. Furthermore, agroforestry landscapes provide aesthetic values, recreational spaces, and opportunities for community engagement and social cohesion.

The economic and social benefits of agroforestry contribute to poverty alleviation, rural development, food security, and the overall well-being of farming communities. Agroforestry provides a sustainable and resilient pathway for agricultural development that integrates environmental conservation, economic prosperity, and social inclusiveness.

Challenges and limitations of agroforestry:

While agroforestry offers numerous benefits, its implementation and widespread adoption face certain challenges and limitations. These challenges include:

1. Technical challenges: Agroforestry requires technical knowledge and expertise for successful implementation. Farmers may lack the necessary understanding of agroforestry principles, tree management techniques, and appropriate species selection. Inadequate access to training, extension services, and technical support can hinder the adoption of agroforestry practices. Additionally, the integration of trees with agricultural crops or livestock requires careful planning to ensure proper spacing, nutrient management, and pest control, which can pose technical challenges for farmers.

2. Financial constraints: Establishing and managing agroforestry systems often involve upfront costs, such as purchasing tree seedlings, implementing infrastructure (e.g., windbreaks, fencing), and managing tree maintenance. Farmers may face financial constraints and limited access to credit or investment capital, making it challenging to invest in agroforestry practices. The long-term nature of agroforestry systems, which may take several years to yield economic returns, can also deter farmers from adopting these practices due to short-term financial needs.

3. Land tenure and land-use policies: Land tenure issues and land-use policies can pose challenges to agroforestry adoption. Insecure land tenure or unclear property rights may discourage farmers from making long-term investments in agroforestry systems. Additionally, conflicting land-use policies, regulations, or zoning restrictions may limit the integration of trees with agricultural practices, impeding the expansion of agroforestry at larger scales. Alignment between land-use policies and agroforestry promotion is essential to overcome these challenges.

4. Market access and value chains: Limited market access and inadequate value chains for agroforestry products can hinder their commercial viability. Agroforestry products often face challenges related to market demand, product standardization, processing facilities, and distribution networks. Developing effective market linkages, creating market incentives, and supporting value-addition and marketing strategies for agroforestry products are crucial to ensure economic benefits for farmers and enhance market opportunities.

5. Knowledge and awareness gap: There is a need to bridge the knowledge and awareness gap surrounding agroforestry. Many farmers may not be aware of the potential benefits and technical know-how of agroforestry practices. Lack of information dissemination, limited access to research findings, and inadequate extension services can impede the adoption of agroforestry. Effective knowledge sharing, farmer-to-farmer learning, and capacity-building initiatives are essential to address this challenge.

6. Policy and institutional support: Inadequate policy support and institutional frameworks for agroforestry can hinder its wider adoption. The lack of clear policies that promote and incentivize agroforestry, and the absence of institutional arrangements for providing technical assistance and financial support, can discourage farmers from engaging in agroforestry practices. Policy reforms, favorable regulations, and institutional support that recognize and reward the multiple benefits of agroforestry are necessary to overcome these limitations.

Addressing these challenges and limitations requires a multi-stakeholder approach, involving policymakers, researchers, extension services, financial institutions, and farming communities. Collaborative efforts should focus on providing technical assistance, improving access to credit and markets, strengthening land tenure rights, enhancing knowledge transfer, and creating supportive policy and institutional environments to facilitate the widespread adoption and scaling up of agroforestry practices.

Agroforestry practices and case studies:

Agroforestry encompasses a wide range of practices that can be adapted to different ecological, socio-economic, and cultural contexts. Here are some examples of agroforestry practices and case studies showcasing their implementation and benefits:

1. Alley cropping: Alley cropping involves the integration of trees with agricultural crops in rows or alleys. The trees provide multiple benefits such as shade, windbreaks, and nutrient cycling. An example of alley cropping is the "Quesungual" system in Central America. Farmers in Honduras and El Salvador have successfully implemented this system, planting maize or bean crops in alleys between rows of nitrogen-fixing trees like Gliricidia sepium and Erythrina poeppigiana. The trees enrich the soil with nitrogen, enhance water infiltration, and provide timber and firewood, while the crops provide food and income.

2. Silvopasture: Silvopasture integrates trees, forage crops, and livestock, combining forestry and livestock production. In the Brazilian Amazon, the "Sistema Agroflorestal" (SAF) is a successful silvopastoral system. It involves planting fast-growing leguminous trees like Acacia mangium and Leucaena leucocephala in pastures to provide shade, fodder, and nitrogen fixation for grasses. Livestock, such as cattle or goats, graze in the shade of the trees, benefiting from the improved forage quality, reduced heat stress, and enhanced soil fertility.

3. Homegardens and multistrata systems: Homegardens are small-scale agroforestry systems found around homes, combining trees, shrubs, and crops. One example is the "Kandyan Forest Garden" in Sri Lanka. These gardens consist of multiple layers, including tall trees like jackfruit and breadfruit, understory trees like coffee and pepper, shrubs, herbs, and root crops. The homegardens provide diverse food, medicinal plants, and timber products, contributing to household food security, nutrition, and income generation.

4. Windbreaks and shelterbelts: Windbreaks are linear plantings of trees and shrubs designed to reduce wind speed and protect crops, livestock, and soil. A case study in Australia demonstrates the benefits of windbreaks for agricultural landscapes. Farmers in the wheatbelt region have implemented shelterbelts composed of native tree species like Acacia and Eucalyptus. These windbreaks reduce wind erosion, protect crops from wind damage, create microclimatic conditions, and provide habitat for beneficial insects and birds.

5. Forest farming and agroforestry in forested landscapes: Forest farming involves the cultivation of crops under the shade of existing forests. An example is the cultivation of shade-tolerant crops like coffee, cacao, or medicinal plants in the understory of tropical forests in countries like Brazil and Indonesia. Agroforestry in forested landscapes focuses on integrating trees, crops, and livestock within forested areas. For instance, in the Philippines, the "Tubay Agroforestry Project" promotes the integration of coconut trees, fruit trees, and root crops within coconut plantations. This diversification enhances ecosystem services, improves farmer incomes, and supports sustainable forest management.

These case studies highlight the diverse applications of agroforestry practices across different regions and landscapes. They demonstrate the multiple benefits of agroforestry, including increased productivity, improved soil fertility, enhanced biodiversity, climate resilience, and socio-economic well-being. By showcasing successful implementations, these case studies serve as inspiration and learning opportunities for farmers, policymakers, and practitioners interested in adopting agroforestry approaches.

Scaling up agroforestry adoption:

Scaling up agroforestry adoption is crucial to realizing its full potential in addressing sustainability challenges and transforming agricultural landscapes. Here are some key strategies and approaches for scaling up agroforestry:

1. Policy support and enabling environment: Effective policy support is essential for scaling up agroforestry adoption. Governments and policymakers should develop and implement policies that recognize and incentivize agroforestry practices. This includes providing financial incentives, such as subsidies or grants, for agroforestry establishment and maintenance. Additionally, supportive land-use policies, land-tenure reforms, and clear regulations can facilitate the integration of trees on farms and address barriers to adoption.

2. Capacity-building and extension services: Enhancing the capacity and knowledge of farmers, extension agents, and other stakeholders is crucial for scaling up agroforestry. Capacity-building programs should focus on providing training, technical assistance, and practical knowledge on agroforestry design, management, and benefits. Extension services play a vital role in disseminating information, conducting on-farm demonstrations, and facilitating farmer-to-farmer learning. Collaboration between research institutions, NGOs, and agricultural extension agencies can strengthen capacity-building efforts.

3. Financial mechanisms and access to credit: Access to financial resources and credit is a key factor in scaling up agroforestry. Governments, financial institutions, and development agencies should develop financial mechanisms that specifically support agroforestry initiatives. This can include providing low-interest loans, establishing agroforestry investment funds, and creating microfinance schemes tailored to agroforestry farmers. Additionally, innovative financial mechanisms, such as payment for ecosystem services or carbon credit schemes, can provide additional incentives for agroforestry adoption.

4. Market development and value chains: Developing robust market linkages and value chains for agroforestry products is crucial for scaling up adoption. Governments and stakeholders should support the development of markets for agroforestry products, including facilitating market access, improving product certification, and promoting fair trade practices. Strengthening value addition, processing, and marketing infrastructure can enhance the economic viability of agroforestry and create market opportunities for farmers.

5. Landscape-level approaches and collaboration: Scaling up agroforestry requires a landscape-level approach that considers the broader ecological and socio-economic context. Collaboration between different stakeholders, including farmers, researchers, policymakers, NGOs, and private sector actors, is essential. Landscape planning, participatory approaches, and multi-stakeholder platforms can facilitate coordination, knowledge sharing, and collective action for scaling up agroforestry adoption. Integrated landscape management approaches can help identify suitable sites, optimize land use, and promote synergies between different land uses.

6. Monitoring, evaluation, and knowledge sharing: Monitoring and evaluating the outcomes and impacts of agroforestry initiatives are crucial for evidence-based decision-making and learning. Long-term monitoring of agroforestry systems can provide data on ecological, economic, and social benefits, supporting the scaling-up process. Knowledge sharing platforms, networks, and partnerships should be established to facilitate the exchange of experiences, best practices, and lessons learned. This can include the creation of online repositories, farmer field schools, and regional or international conferences focused on agroforestry.

By implementing these strategies and approaches, agroforestry can be scaled up effectively, fostering its widespread adoption and contributing to sustainable agriculture, climate resilience, and rural development. The collaboration between various stakeholders and the integration of agroforestry into policy frameworks and financial mechanisms are key drivers for achieving large-scale impact.

Conclusion and recommendations:

Agroforestry plays a crucial role in promoting sustainable agriculture by integrating trees, crops, and livestock, and it offers a wide range of environmental, economic, and social benefits.

However, the full potential of agroforestry is yet to be realized, and scaling up its adoption is necessary to address sustainability challenges and transform agricultural landscapes. Based on the discussion presented in this chapter, the following conclusions and recommendations can be made:

Conclusion:

- Agroforestry practices provide multiple benefits, including improved soil fertility, enhanced biodiversity, climate resilience, diversified income streams, and improved livelihoods.
- Agroforestry contributes to environmental conservation, sustainable land management, and climate change mitigation and adaptation.
- Economic benefits of agroforestry include diversified income sources, market opportunities, value-added products, and increased resilience to market fluctuations.
- Agroforestry enhances food security, nutrition, and cultural values by providing diverse food products, supplementary livestock feed, and preserving traditional knowledge and practices.
- Agroforestry faces challenges and limitations related to technical knowledge, financial constraints, land tenure, market access, knowledge gaps, and policy support.

Recommendations

- Governments and policymakers should develop and implement supportive policies, including financial incentives, land-tenure reforms, and regulations that promote agroforestry adoption.
- Capacity-building programs, farmer training, and extension services should be strengthened to enhance the knowledge and skills of farmers and stakeholders in agroforestry.
- Access to credit and financial resources for agroforestry farmers should be improved through the development of tailored financial mechanisms and investment funds.
- Market development and value chains for agroforestry products should be prioritized, including improving market access, product certification, and processing infrastructure.
- Landscape-level approaches and collaboration between stakeholders should be encouraged to facilitate coordinated agroforestry planning, knowledge sharing, and collective action.
- Monitoring, evaluation, and knowledge sharing platforms should be established to generate evidence-based information, share best practices, and facilitate learning from successful agroforestry initiatives.

By implementing these recommendations, stakeholders can work towards scaling up agroforestry adoption and harnessing its full potential for sustainable agriculture. Agroforestry offers a promising pathway towards more resilient and environmentally friendly agricultural systems, contributing to the well-being of farmers, rural communities, and the planet as a whole.

NOVEL APPROACHES FOR NEMATODE IDENTIFICATION

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Abstract:

Nematode identification is essential to enhance our understanding the biodiversity. At species level accurate identification is important to implement management strategies. About ~27,000 species have already been described, with one million species yet to be discovered. Estimated annual loss by nematode ~$173 billion worldwide. Several approaches are available for nematode identification, from the traditional morphology-based techniques to the sophisticated high-throughput sequencing technologies. Traditionally, RKN species are identified by the analysis of the perineal patterns and esterase phenotypes. Methods based on the morphology of adults, isozymes phenotypes and DNA analysis have been used for the diagnosis of RKN. Over the last few decades, accurate and rapid molecular techniques have been validated for nematode diagnosis, including eggs, juveniles and adults as DNA sources. Different DNA based techniques used for nematode identification are [PCR-Restriction Fragment Length Polymorphism (PCR-RFLP), Amplified Fragment Length Polymorphism (AFLP), Random Amplification of Polymorphic DNA (RAPD), Multiplex-PCR, PCR-Denaturing Gradient Gel Electrophoresis (PCR-DGGE)]. New emerging identification techniques [(Micro-fluidic PCR technique, Matrix-assisted laser desorption–ionization time-of-flight (MALDI-TOF), Microarrays, Loop-mediated isothermal amplification (LAMP), Quantitative or Quantification PCR (qPCR), DNA Metabarcoding/ Metagenomics and Recombinase polymerase amplification (RPA)] (Cunha *et al.*, 2018). Molecular techniques in the field of biology have helped us to get the accurate identification of nematode species and to detect the smallest variations within species and even within individuals. Several parameters have to be taken in consideration when selecting a method for the identification of nematodes. All nematode identification techniques have advantages and limitations. Identification techniques depend on availability of resources. Traditional methods are important but molecular techniques provide confirmatory evidences (Oliveira *et al.*, 2011). Most of the nematode taxonomy remains unknown or unclear. A combination of approaches is always better in identification. Molecular identification is useful to meet regulatory demands or to enhance management decisions. It is necessary to utilize methods that are robust, reliable and inexpensive.

Introduction:

Nematodes are the most abundant group of multicellular organisms on earth. Most of the nematodes are free-living and some of them are parasites of plants, insects, other invertebrates, and vertebrate animals including humans and domestic animals. They live on feeding living organisms like plants (plant parasites) and animals (animal parasites), preying other nematodes (predatory), associating with insects (insect associates), killing insects with their bacterial symbionts (entomopathogenic nematodes), etc. It is considered that four out of every five multicellular animals on this planet are nematodes. So far about ~27,000 species have been described and more than a million species have yet to be discovered (Hugot *et al.,* 2001). The plant-feeding nematodes are a potential threat to the crop causing crop losses, the global annual loss in monetary terms amounting to the extent of ~$173 billion (Elling *et al.*, 2013). In India, plant-parasitic nematodes cause crops loss to the extent of 10,204 crores per annum (Kumar *et al.*, 2020). Nematodes Critical role in the flow of energy and cycling of nutrients.

Developing protocols and the use of molecular identification methods help to understand the nematode problems and to investigate crop damage particularly for nematodes vectoring viruses in crop plants. The protocols for rapid diagnosis techniques are essential to prevent and spread of quarantine pests, which could be a potential biosecurity threat to Indian agriculture. Morphological characterizations are essential for species identification and molecular tools supplement the species information for a better understanding of species. DNA- or RNA sequence-based techniques are most widely used for molecular characterization, identification of nematodes, and phylogenetic analysis. Further, molecular methods are convenient to diagnose the nematodes based on the DNA sequences of eggs, juveniles and adults. The sequencing of diagnostic rRNA regions (ITS-I & II of 18S and D2D3 of 28S) and COX-I of mtDNA have been used successfully to identify and quantify many economically important plant-parasitic nematodes (Vrains *et al.*, 1992, Kanzaki *et al.*, 2002).

Why do we need to identify nematodes?

- To understand the biodiversity.
- Bio-security (rapid diagnosis techniques is essential to prevent and spread of quarantine pest).
- To recover and represent evolutionary history.
- The clear ordering of organisms and registration of species diversity facilitates practical work with the species.
- The accurate identification of nematode species is essential for implementing management strategies. Eg: *Globodera pallida* is not controlled as effectively by carbamates as *G. rostochiensis* is controlled.

Difference b/w Morphological and Molecular identification

	Morphological Identification	**Molecular Identification**
Set-up cost	Low	High
Long-term cost	High	low
Employee requirement	Highly trained, experienced	Minimal training
Length of process	Slower	Rapid
Morphological characters	Variable	NA
Females required	Yes	No
Mixed species populations	Difficult to distinguish	No

Different techniques are used for nematode identification:

- Morphological
- Biochemical and Molecular

Morphological identification:

Since the 19th century, the morphological and morphometric features allow to classify nematodes within their respective genus. Sometimes, the species can be identified based on the morphological features of the sexual organs of adult male nematode. The major advantage of this method is that it is almost costless, but the drawback lies in the need for substantial expertise and training and in the possible inability to identify specimen at the species level when only eggs or larvae are available to the taxonomist or when several specimens are needed to collect enough morphometric data to confidently classify the studied nematode. The morphology of the eggs (size, color, egg-shell aspect, etc.) collected from feces together with the clinical symptoms is usually sufficient to diagnose a human parasite infection.

Target	Principles of identification	Purpose	Advantages	Limitations
Whole nematode	Juvenile morphological features; nerve ring, esophageal lumen, intestine, rectum, excretory pore Etc. Sexual organs of adult male and female nematodes	Identification of known species Description of new species	Almost costless	Need for substantial expertise and training Inability to identify specimen at the species level when only eggs or larvae are observed Lack of distinctive morphological features in some cases (Juvenile) Individual identification

Biochemical method:

- Multilocus enzyme electrophore-sis (MEE), Isoenzymes phenotypes
- Enzyme-linked Immunosor-bent-assay (ELISA)

Isozyme phenotypes

Isoenzyme phenotyping is the routine diagnostic test for RKN in many laboratories worldwide. It is based on the relative mobility of enzymes extracted from mature females on gel electrophoresis. The whole procedure takes three to four hours, from sample processing to gel revelation. Protein extract from *M. javanica* females is applied on the gel for use as reference phenotype.

Esterase phenotype (EST) analysis is usually enough to identify *Meloidogyne* species. Although, other enzymes can also provide complementary information, such as malate dehydrogenase (MDH), superoxide dismutase (SOD) and glutamate oxaloacetate transaminase (GOT). In some cases, EST are similar between two species, such as *M. naasi* and *M. exigua*.

Intraspecific variations may occur in *M. javanica, M. arenaria, M. exigua and M. paranaensis* and other species, limiting the accuracy of the diagnosis. In addition, the procedure required the use of mature females and several individuals are needed in the case of species with small specimens, such as *M. exigua*.

DNA based methods:

- PCR- Restriction Fragment Length Polymorphism (PCR-RFLP)
- Amplified Fragment Length Polymorphism (AFLP)
- Random Amplification Of Polymorphic DNA (RAPD)
- Multiplex-PCR
- PCR- Denaturing Gradient Gel Electrophoresis (PCR-DGGE)

Several studies pointed out that the morphological identification was not efficient enough at deciphering the nematode taxonomy. These authors suggested a revision of the nematode classification based on sequence homology at the 18S ribosomal RNA locus that was targeted using the PCR method. The PCR is an in vitro amplification technique that reproduces a large number of copies from a small number of targeted DNA sequence molecules. This method required the reference taxa to be included at every run and necessitated specialized skills that did not facilitate technology transfer between laboratories.

In 1993, a species-specific PCR was designed for parasitic nematodes and allowed the discrimination between nematode species infecting sheep. Thereafter, the PCR method has been applied to the identification of Anisakidae nematodes isolated from fish or mammalian samples preserved in alcohol or formaldehyde or from frozen samples. Recently, the PCR has also been used to identify nematodes isolated from soil. PCR-based tools targeting satellite-DNA were developed for the identification of *Meloidogyne hapla,* a plant-parasitic nematode.

PCR methods, based on ribosomal and mitochondrial DNA targets, combined with Sanger sequencing and phylogenetic analyses. The identification and choice of a suitable DNA region (genetic marker or locus) are key issues to the development of a reliable PCR. Several genes were targeted for nematode identification such as the mitochondrial cytochrome b locus (mtDNAcytb), the gene encoding the mitochondrial cytochrome oxidase 2 (COX2) and the mitochondrial cytochrome oxidase 1 (COXI), the ribosomal RNA of the small (ssrRNA) and large subunit (lsrRNA). Other nuclear genes were also selected such as the internal transcribed spacer 1 (ITS1) of rDNA.

New emerging techniques used for nematode identification:

- Quantitative or Quantification PCR (qPCR)
- Loop-mediated isothermal amplification (LAMP)
- Recombinase polymerase amplification (RPA)

Quantitative or Quantification PCR (qPCR) or real –time PCR:

Conventional PCR is a qualitative method. A variation of this technique, real-time PCR or quantitative PCR (qPCR), allows the identification and real-time quantification of target sequences. qPCR is faster and more sensitive than conventional PCR, quantitative and does not require the preparation of gels. However, the high costs of equipment and reagents are still the main disadvantages of qPCR. Real-time PCR detects and quantifies DNA based on the emission of fluorescence. The optical unit of the thermocycler monitors fluorescence emitted during cycling and the data is processed by a computer.

The cycle threshold, that is, the number of cycles required to initiate the amplification of the target sequence, is then calculated. The two main systems used in the production of fluorescence in qPCR are hydrolysis probes (formerly Taqman®) and SYBR Green® dye. So far, qPCR-based diagnostics are available for *M. arenaria, M. incognita, M. hapla, M. enterolobii* and *M. minor* detection. Despite its importance, no qPCR diagnostics is available for *M. javanica.*

Loop-mediated isothermal amplification (LAMP):

- LAMP amplifies DNA with high specificity.
- Sensitivity (up to 10 times more sensitive than PCR).
- Efficiency and speed under isothermal conditions.
- This procedure requires the use of four to six primers.
- The whole procedure takes from 30 minutes to less than 2 hours, depending on the protocol, and isothermal conditions (57 - 65ºC).
- Amplification can be detected through visualization with naked eye, due to the formation of a white precipitate of magnesium pyrophosphate or the change of color of the solution by using dyes (SYBR Green, calcein, HNB, picogreen).

Principle of LAMP:

- This method employs a DNA polymerase and a set of four specially designed primers that recognize a total of six distinct sequences on the target DNA.
- An inner primer containing sequences of the sense and antisense strands of the target DNA initiates LAMP.
- The following strand displacement DNA synthesis primed by an outer primer releases a single-stranded DNA.
- This serves as template for DNA synthesis primed by the second inner and outer primers that hybridize to the other end of the target, which produces a stem–loop DNA structure.
- In subsequent LAMP cycling one inner primer hybridizes to the loop on the product and initiates displacement DNA synthesis, yielding the original stem–loop DNA and a new stem–loop DNA with a stem twice as long.
- The cycling reaction continues with accumulation of 10^9 copies of target in less than an hour (Niu *et al.,* 2012).

  Examples: Rapid detection of pecan root-knot nematode, *Meloidogyne partityla,* in laboratory and field conditions using loop-mediated isothermal amplification.

Recombinase Polymerase Amplification (RPA):

- Recombinase polymerase amplification (RPA) is a highly sensitive and selective isothermal amplification technique

- It operates at 37–42°C, with minimal sample preparation and capable of amplifying as low as 1–10 DNA target copies in less than 20 min.
- The detectable amount of DNA amplication can be achieved within 20 minutes
- With excellent sensitivity it is also possible to amplify DNA from a single worm.

Principle of RPA:

- In traditional approaches DNA polymerase is used for amplification but here recombinase enzyme is used for amplification.
- Recombinase enzyme form complexes with oligonucleotide primers and pair the primers with their homologous sequences in duplex DNA.
- A single-stranded DNA binding (SSB) protein binds to the displaced DNA strand and stabilizes the resulting D loop.
- DNA amplification by polymerase is then initiated from the primer, but only if the target sequence is present. The amplification can be detected by fluorescence, real time probes and sandwich assay formats.

Examples: 1. Recombinase polymerase amplification assay for rapid detection of the root-knot nematode *Meloidogyne enterolobii*. 2. Point-of-care diagnostic (POCD) method for detecting *Bursaphelenchus xylophilus* in pinewood using recombinase polymerase amplification (RPA) with the portable optical isothermal device (POID).

Nematode databases:

- NEMBASE (www.nematodes.org/nembase4)
- WormBase (www.wormbase.org)
- WoRMS database (World Register of Marine Species, www.marinespecies.org).
- Nematol (http://nematol.unh.edu/index.php)
- Nemys (http://nemys.ugent.be/)

Conclusion:

Identification techniques depend on availability of resources. The accurate identification of nematode species is essential for implementing management strategies. Traditional methods are important but modern techniques provide confirmatory evidence. Several parameters have to be taken in consideration when selecting a method for the identification of nematodes. A combination of approaches is always better for identification. All nematode identification techniques have advantages and limitations. Molecular techniques in the field of biology have helped us to get the accurate identification of nematode species and to detect the smallest variations within species and even within individuals. It is necessary to utilize methods that are easy, robust, reliable, and relatively cheap. Modern nematode identification techniques are most useful to meet regulatory requirements and often it supports taking management decisions.

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SCENARIO OF AGRIBUSINESS MANAGEMENT IN INDIA

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Introduction:

John H. Davis of Harvard first used agribusiness term in 1955. Agribusiness is all business enterprises that produce, sell, and distribute farm products, especially on a large scale. The transaction may entail an input, a product, a service and other item such as:

1) Productive resources (seed, equipment, fertilizer, feed, pesticides, machinery, energy etc.)
2) Agricultural-related products (raw and processed commodities of food and fiber)
3) Supportive services (credit, insurance, marketing, storage, processing, distribution, transportation, packing, soil testing, consultancy etc.).

Scope for agribusiness in India

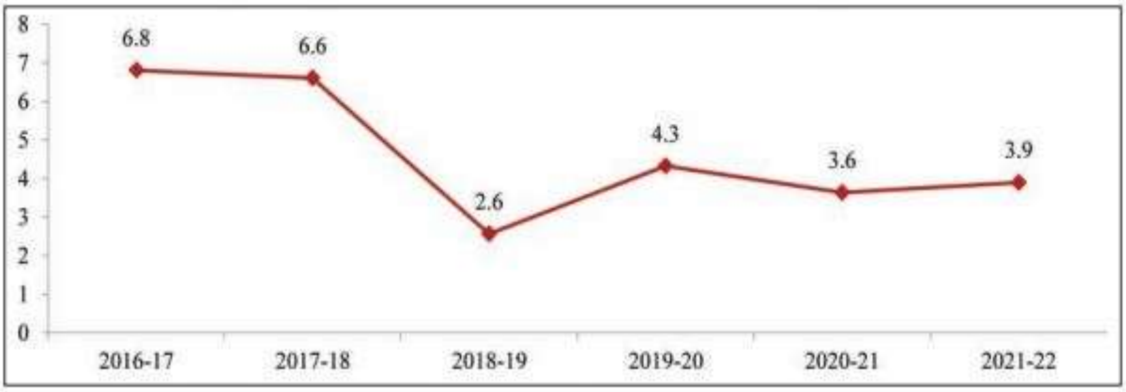
- The diverse agro-climate that India enjoys makes it possible to grow subtropical, tropical, and agricultural products.
- A wide range of agricultural biotechnology uses exist, including the creation of novel seed varieties, biocontrol agents, and the industrial exploitation of microorganisms for bakery products. Inputs used in agriculture, such as inorganic fertilisers, biofertilizers, pesticides, feed, and fodder, are in greater demand.
- Export can be used as a driver of economic expansion. India has enormous potential to improve its current standing in the global trade of agricultural commodities in both their raw and processed forms as a member of the World Trade Organization. Cereals, oilseeds and oils, oil meal, pulses, spices and condiments, flowers, fruits and vegetables, medicinal plants, and essential oils are among the products offered. Other items in the product line include milk, meat, fish, and fish products, ornamental fish, and forest by-products. At present processing is done at primary level only and the rising standard of living expands opportunities for secondary and tertiary processing of agricultural commodities.
- The huge coastal line and internal waterways offer tremendous opportunities for the production of marine and inland fish, as well as ornamental fish culture, which is becoming more and more popular among Indians as their appreciation of aesthetics grows.
- The abundance of livestock provides tremendous opportunity for the production of milk and milk goods, meat, poultry products, etc.
- The resources found in forests can be used to make forestry by-products.
- In India, apiaries and beekeeping can be practiced extensively.

- With advancements in production technology, mushroom production for domestic use and export can be increased.
- India has the best potential for organic farming because there are fewer pesticide and inorganic fertiliser applications there than in other industrialised countries. It is possible to educate and inspire farmers to transition to organic farming.
- Bio-pesticides and bio-control agents can be produced and promoted in large quantities to protect crops.
- Seeds, hybrid, and genetically modified crops have the greatest promise in India in future, as high yielding variety productivity has peaked.
- Due to decreasing groundwater levels and a labour shortage for agricultural tasks like weeding, transplanting, and harvesting, labor-saving farm equipment and micro-irrigation systems have a bright future.
- To tap into the export market, greenhouse production of fruits, vegetables, and flowers might be started.
- Due to decreasing state financial resources and the reduction of the current government agricultural extension workforce, trained human resources in agriculture and allied sciences will take over the agricultural extension system.
- As agricultural production rises, job possibilities in marketing, cold storage and warehousing, transportation, credit, insurance, and logistic support services become available.

Scenario of agribusiness in India

- The previous two years have seen rapid expansion for the agriculture industry, with growth rates of 3.6% in 2020–2021 and 3.9% in 2021–2022 being recorded. This became possible due to favourable monsoons and several government initiatives to increase loan availability, improve investments, build market facilities, encourage the development of infrastructure in the agriculture sector, and raise the supply of high-quality inputs to the industry.

Figure 1: Growth of Agriculture and Allied Sectors (per cent)

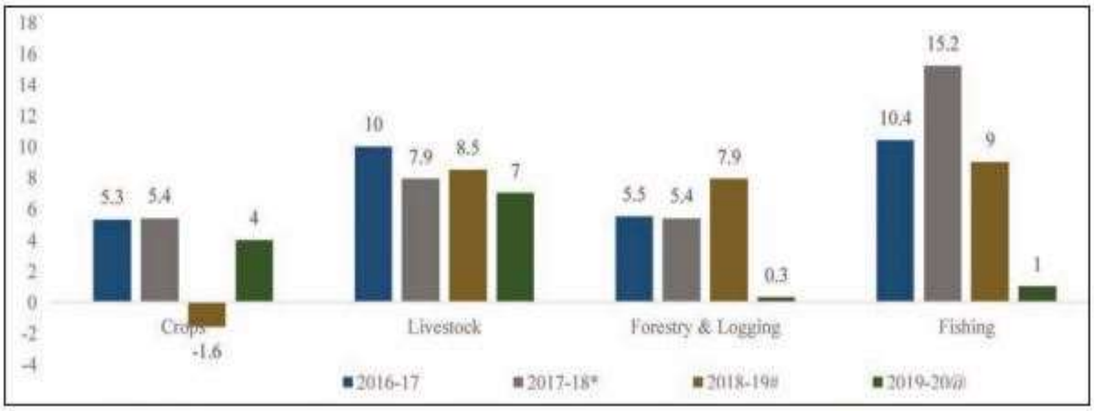


Source: First Advance Estimates of National Income, 2021-22

- It has been observed that fisheries and livestock have seen buoyant expansion, which has aided the sector's success. For instance, even if the growth of GVA for crops was -1.6%

in 2018–19, the performance of livestock and fisheries boosted the growth in agriculture.

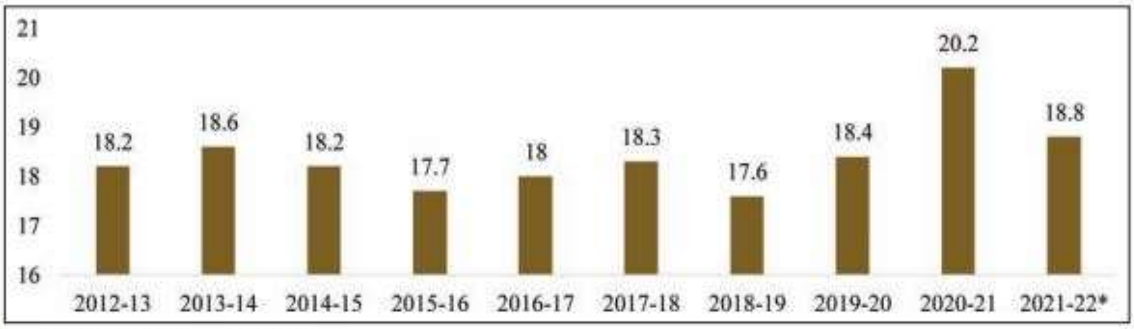
Figure 2: Growth of GVA of Agriculture & Allied Sector (at 2011-12 prices)



Source: Based on data received from Department of Agriculture & Farmers Welfare (DAFW).
*Third revised estimate, #second revised estimate, @ First Revised Estimates released on 29th January, 2021.

- The share of the agriculture and allied sector in total GVA of the economy has a long-term trend of around 18 per cent. However, the sector's contribution to overall GVA increased to 20.2% in 2020–21 and 18.8% in 2021–22.

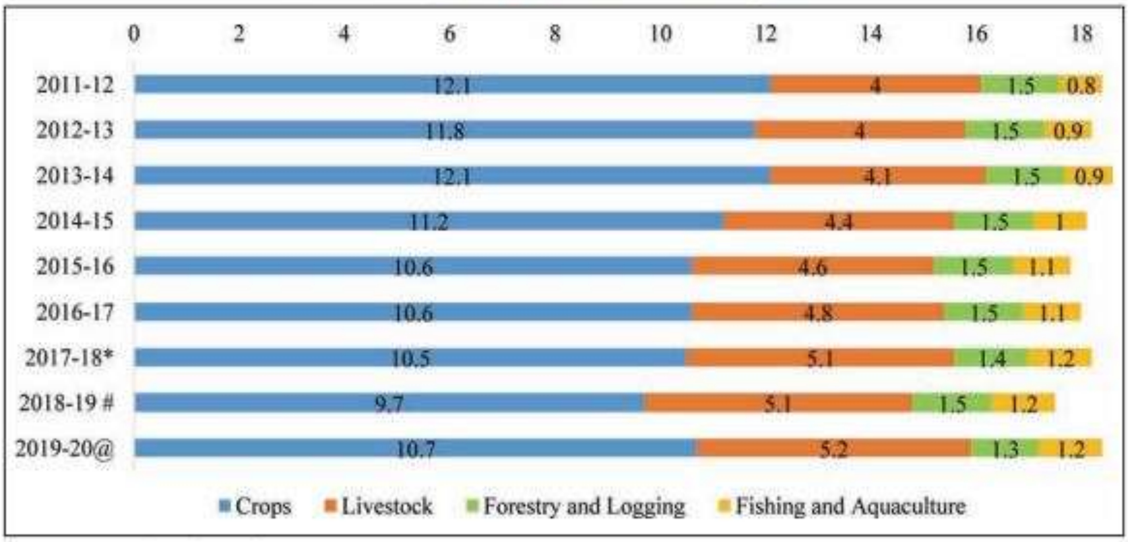
Figure 3: Percentage Share of GVA of Agriculture & Allied Sector to Total GVA (at current prices)



Source: Based on data of DAFW.
*As per 1st Advance Estimates of National Income, 2021-22.

- In the 2019–20 year, the proportion of livestock, fishing and aquaculture in the overall agricultural GVA increased. Recognising the increasing importance of allied sectors, the Committee on Doubling Farmers' Income (DFI, 2018) considers dairying, livestock, poultry, fisheries and horticulture as engines of high growth and has recommended a focused policy with a concomitant support system.
- The total food grain production of India was 297.50 MT in 2019-20 and was estimated to be 308.65 MT in 2020-21 (Agricultural Statistics at a Glance 2021).
- Total Horticulture production in 2020-21 was estimated to be 331.04 MT (Agricultural Statistics at a Glance 2021).
- As per fourth advance estimates, the estimated production of rice is 122.27 MT, Wheat is 109.52 MT & Nutri/Coarse Cereals is 51.15 MT for the year 2020-21 (Agricultural Statistics at a Glance 2021).

Figure 4: Percentage Share of GVA of Crop & Allied Sectors in Total Agriculture GVA (at current prices)



Source: Based on data of DAFW.

- The total agricultural export was 308830 crore during the year 2020-21 which shares 14.30% share in total national export whereas the agricultural import was 154510.72 crore in the same year sharing 5.30 percent share in total national import (Directorate General of Commercial Intelligence and Statistics, Department of Commerce).
- The CAGR for pulses, oilseeds and cotton has been 7.9, 6.1 and 2.8%, respectively during the same period.
- Exports of Rice (Basmati and other rice) values at 45426.65 crore in 2019-20. The export of other cereals was 501.12 thousand tonnes in 2019-20 (Directorate General of Commercial Intelligence and Statistics, Department of Commerce).
- India ranks 1st in milk production and contributes 23% to global milk production growing at a CAGR of about 6.2% to reach 209.96 MT in 2020-21. The all India per capita availability of milk was 406 grams per day in 2019-20 and 427 grams per day in 2020-21 (provisional) (Economic Survey 2020-21, Ministry of Finance, GoI)
- India ranks 3rd in global egg production and produced at least 122.11 billion nos. in 2020-21 with per capita availability of egg at 86 eggs per annum in 2019-20 and 91 eggs per annum in 2020-21(provisional) (Economic Survey 2020-21, Ministry of Finance, GoI).
- India is the 2nd largest fish-producing country in the world and accounts for 7.56% of the global production. The total fish production during FY 20-21 is estimated at 14.73 MMT.
- Sugar exports from India stood at 8.6 MT until May of the ongoing 2021-22 marketing year ending September.
- Online grocery retail in India has seen a CAGR of over 50% and projected to grow to $10 Bn to 12 Bn by 2025.
- The marine products exports from India touched $7,740 mn during 2021-22 despite the heavy odds faced by the sector. It observed 30% higher growth as compared to 2020-

21. The USA, China, and Japan are the top three favorite destinations of Indian marine exports. Exports to these three countries contributed 63% of exports. India ranks 8th in meat production in the world. Meat production in the country has increased from 6.69 MT in 2014-15 to 8.80 MT in 2020-21 (Provisional) (Economic Survey 2020-21, Ministry of Finance, GoI).

- The total consumption of fertilizer in India was 325.36 lakh tonnes in 2020-21 and the production was 184.54 lakh tonnes. The country imported 108.46 lakhs tonnes of fertilizers from other countries during the same year (Agricultural Statistics at a Glance-2021).
- India produced 91.16 thousand quintal of breeder seeds, 24.12 lakh quintals of foundation seeds and distributed 421.09 lakh quintal of certified and quality seeds in 2020-21 (Agricultural Statistics at a Glance-2021, MoA&FW).
- During the last 5 years ending 2019-20, Food Processing sector has been growing at an Average Annual Growth Rate (AAGR) of around 11.18 per cent as compared to around 4.19 per cent in Agriculture (at 2011-12 prices).
- As per latest Annual Survey of Industries (ASI) 2018-19, the total output in food processing sector was Rs.12,76,995 crores, which contributed 12.83% of total output in the registered manufacturing sector in India.
- The Gross Value added (GVA) in the food processing sector was Rs.2.24 lakh crore in 2019-20 contributing 1.69% of the total GVA in the country. The GVA in food processing sector was 9.87% of GVA in Manufacturing and 11.38% of GVA in Agriculture, Forestry and Fishing sectors respectively in 2019-20.

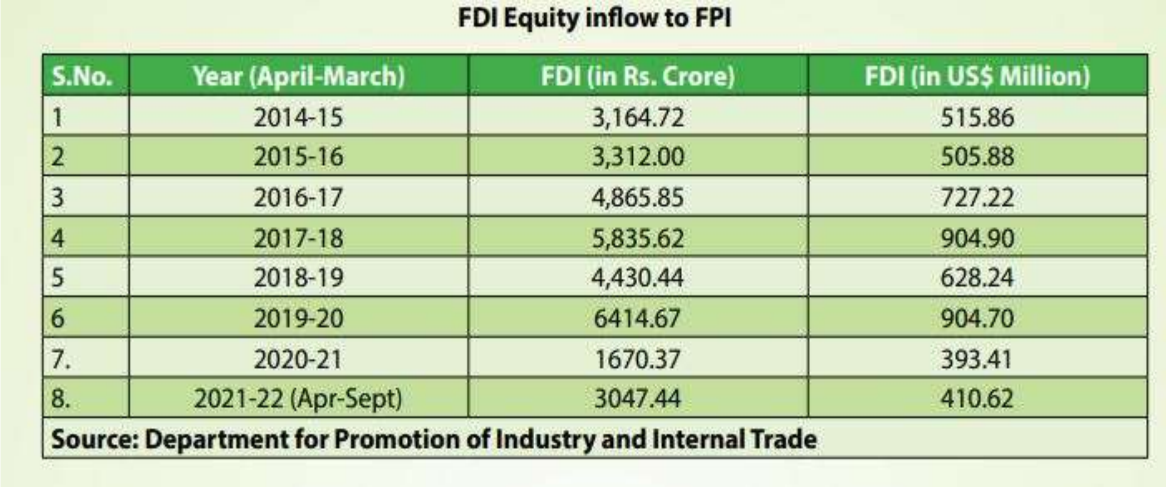
India's Share in Global Food Trade

Value in US$ million

	2016	2017	2018	2019	2020
World food export	1324404.3	1432272.3	1493758.6	1488060.0	1525621.1
World food import	1342585.9	1449095.6	1524012.3	1521161.4	1553119.4
India's food export to world	29196.3	34418.9	34070.2	33617.8	35200.7
India's food import from world	21938.0	25090.3	19603.5	19183.7	20365.6
% Share of India's food export in world	2.20%	2.40%	2.28%	2.26%	2.31%
% Share of India's food import in world	1.63%	1.73%	1.29%	1.26%	1.31%
Source: ITC trade Map (2021)					

- The value of agri-food exports including processed food exports during 2020- 21 was of the order of US $ 38.32 Billion accounting for about 13.2 per cent of India's total exports (total exports US $ 291.17 Billion).
- The value of import of agri-food items including processed food during 2020- 21 was US $ 20.99 Billion, which was 5.3 per cent of India's total, imports (total imports US $ 393.61 Billion).

- The share of India’s agri-food exports in the world was 2.31% in 2020 and the share of India’s agri-food imports in the world was 1.31% in 2020 (Annual Report 2020-21, Ministry of Food Processing Industries)
- Hundred percent FDI was permitted under the automatic route in food processing industries. Hundred percent FDI was allowed through Government approval route for trading, including through e-commerce in respect of food products manufactured and/or produced in India. The sector has witnessed FDI equity inflow of USD 4.99 billion during April 2014 to September 2021.



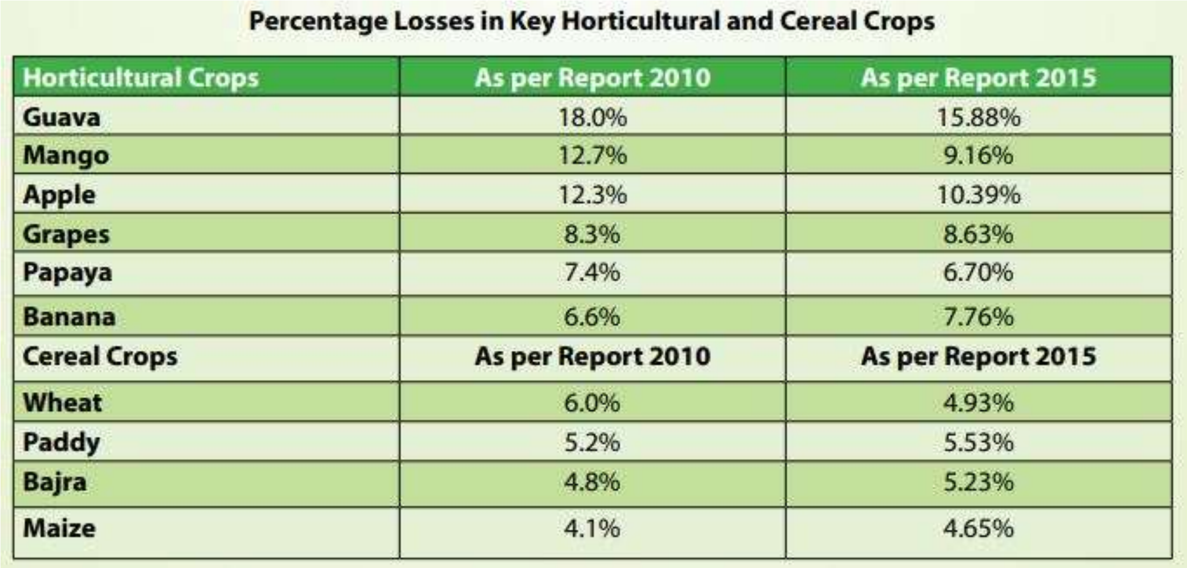
FDI Equity inflow to FPI

S.No.	Year (April-March)	FDI (in Rs. Crore)	FDI (in US$ Million)
1	2014-15	3,164.72	515.86
2	2015-16	3,312.00	505.88
3	2016-17	4,865.85	727.22
4	2017-18	5,835.62	904.90
5	2018-19	4,430.44	628.24
6	2019-20	6414.67	904.70
7.	2020-21	1670.37	393.41
8.	2021-22 (Apr-Sept)	3047.44	410.62
Source: Department for Promotion of Industry and Internal Trade			

- The study conducted by CIPHET in 2015 has estimated that annual value of harvest and post-harvest losses of major agricultural produces at national level was 92,651 crore rupees.

Percentage Loss of Major Agricultural Produce in India

Crops	Cumulative wastage (percent)	
	as per report 2010	as per report 2015
Cereals	3.9– 6.0	4.65– 5.99
Pulses	4.3– 6.1	6.36– 8.41
Oil seeds	2.8– 10.1	3.08– 9.96
Fruits &Vegetables	5.8– 18.0	4.58– 15.88
Milk	0.8	0.92
Fisheries (Inland)	6.9	5.23
Fisheries (Marine)	2.9	10.52
Meat	2.3	2.71
Poultry	3.7	6.74



Percentage Losses in Key Horticultural and Cereal Crops

Horticultural Crops	As per Report 2010	As per Report 2015
Guava	18.0%	15.88%
Mango	12.7%	9.16%
Apple	12.3%	10.39%
Grapes	8.3%	8.63%
Papaya	7.4%	6.70%
Banana	6.6%	7.76%
Cereal Crops	**As per Report 2010**	**As per Report 2015**
Wheat	6.0%	4.93%
Paddy	5.2%	5.53%
Bajra	4.8%	5.23%
Maize	4.1%	4.65%

Government initiatives for agribusiness

- The government declared in October 2020 that it was establishing a nationwide shared data infrastructure for farmers. Through the use of a shared database, information about land records will be merged with the Pradhan Mantri Fasal Bima Yojana (PMFBY), PM-Kisan, and the Soil Health Card.
- In September 2020, the government introduced all the PM Matsya Sampada Yojana, the e-Gopala App, and several programmes in agricultural, dairy, animal husbandry, and fisheries production. In accordance with this plan, 21 states will get investments totaling 20,000 crore rupees ($2.7 billion) during the next 4–5 years.
- To increase agricultural exports, the Indian government introduced the Transport and Marketing Assistance (TMA) initiative, which offers financial support for the marketing and transportation of agricultural products.
- **Entrepreneurial Training institutes**: There are three institutes engaged in training of small-scale entrepreneurs. These are National Institute for Entrepreneurship and Small Business Development (NIESBUD), New Delhi, Guwahati, National Institute of Small Industry Extension Training (NISIET), Hyderabad and Indian Institute of Entrepreneurship (IIE).
- **Fragrance & Flavour Development Centre (FFDC), Kannauj**: The Government of India established The Fragrance & Flavour Development Centre (FFDC) in 1991 with the aid of UNDP/UNIDO, and the Government of Uttar Pradesh/UNDP/UNIDO provided technical expertise and imported equipments. The government of Uttar Pradesh donated the land and the building, while the government of India paid for the indigenous equipment and ongoing expenses. The Center's primary goals are to support, uphold, and improve the position of farmers and businesses involved in the cultivation and processing of aromatic plants in order to increase their competitiveness on the domestic and international markets.

- **Export Processing Zones**: The purpose of the export zones (EPZ) established as enclaves, fiscally isolated from the Domestic Tariff Areas, is to offer a competitive duty-free environment for export production. At Noida (Uttar Pradesh), Chennai (Tamil Nadu), Palta (West Bengal), and Vishakhapatnam (Andhra Pradesh), the government has established four EPZs.
- **Special Economic Zones**: The government unveiled a new plan for creating Special Economic Zones (SEZs) in the nation on March 31, 2000, under the Export and Import Policy. The policy authorised the establishment of SEZs in the public, private, joint, or state government sectors. Additionally, it was revealed that several of the current Export Processing Zones would become SEZs. In light of this, the government announced on November 1st, 2000, that the existing Export Processing Zones at Kandla (Gujarat), Santa Cruz (Maharashtra), and Cochin (Kerala) will be converted into SEZs. On the promoters' request, notification has also been granted for the conversion of the Surat (Gujarat) private sector EPZ into the SEZ.
- **Export Oriented Units (EOU)**: In the early 1981, introduction of the export-oriented units (EOU) programme is an addition to the EPZ programme. It uses the same production regime but provides a variety of options for locations based on things like the availability of technological capabilities, source of material, the existence of an industrial base, ports of export and the requirement for a sizable land area for the project. As of March 2001, 1,536 units were running under the EPU system. Textiles and yarn, food processing, electronics, chemicals, plastics, granites, and minerals/ores are the key industries where EOUs are concentrated. Majority of units are located in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Gujarat.
- **Export Promotion Industrial Park (EPIP) Scheme:** In order to include the State Governments in the development of infrastructure facilities for export-oriented industry, a centrally supported "Export Promotion Industrial Park" (EPIP) Scheme was created in 1993–1994. The plan stipulates that a central grant to the State Governments will cover 75% of the capital investment needed to create these facilities, which is typically limited to 10 crores of rupees in each case.
- **New Anna Marumalarchi Thittam:** The State Government of Tamil Nadu has introduced the New Anna Marumalarchi Thittam in April 2002 to set up agribusiness units with a minimum investment of 35 lakh rupees at the rate of one unit in each block. This scheme provides scope for setting 385 agribusiness units in Tamil Nadu.
- **Agri-Clinic and Agribusiness Centres**: Small Farmers Agribusiness Consortium in co-operation with MANAGE has drawn plans to provide training on management capacity building for those willing to set up Agri-clinics and Agribusiness Centres either as individual or a group five (four agricultural and allied graduates and one management graduate) with a maximum loan assistance of 10 lakh rupees for individuals and 50 lakh rupees for a group of five entrepreneurs.

- **e-NAM:** National Agriculture Market (e-NAM) is a pan-India electronic trading portal which networks the existing APMC mandis to create a unified national market for agricultural commodities**.**
- **National Mission for Sustainable Agriculture (NMSA):** It has been formulated for enhancing agricultural productivity especially in rainfed areas focusing on integrated farming, water use efficiency, soil health management and synergizing resource conservation.
- As part of Aatmanirbhar Bharat Abhiyan, Ministry of Food Processing Industries (MoFPI) has launched an all India centrally sponsored "PM Formalisation of Micro food processing Enterprises (PMFME) Scheme" for providing financial, technical and business support for upgradation of existing micro food processing enterprises. The Scheme adopts One District One Product (ODOP) approach.
- The NDA government in 2015 launched the Paramparagat Krishi Vikas Yojana (PKVY), an initiative to promote organic farming in the country.
- Pradhan Mantri Fasal Bima Yojana (PMFBY) is the government sponsored crop insurance scheme that integrates multiple stakeholders on a single platform.
- **Mega Food Park:** It is a scheme of the Ministry of Food Processing (part of the Government of India) with the aim of establishing a "direct linkage from farm to processing and then to consumer markets" through a network of collection centres and primary processing centres. The Ministry of food processing industry out of which 22 mega food parks are operational has sanctioned 42 Mega Food Parks so far.
- **Scheme for Cold chain and value addition:** In order to minimize the post-harvest losses and enhance value addition in the agricultural produce, Ministry of Food Processing Industries has been implementing the Scheme for Integrated Cold Chain and Value Addition Infrastructure since 2008. Scheme provides for promoting integrated and complete cold chain facilities without any break from the farm gate to the consumer, end to end, to reduce losses by improving efficiency in collection of farmer produce, storage, transportation and minimal processing. Both horticultural and non-horticultural produce are eligible for support under this scheme.

Legal regulations

- Decisions are strongly affected by laws pertaining to competition, price setting, distribution arrangements, advertising, etc. It is necessary for a manager to understand the legal environment of the country and the jurisdiction of its courts. The following laws affecting business in India are important.
- Indian Contract Act, 1872
- Factories Act, 1948
- Minimum Wages Act, 1948
- Securities contracts Regulation Act, 1956 (Now replaced by SEBI Act)
- The Companies Act, 1956

- Trade and merchandise Marks Act, 1958
- Monopolies and Restrictive Trade Practices Act, 1969
- The water (Prevention and Control of Pollution) Act, 1974
- The Air (Prevention and Control of pollution) Act, 1981
- Sick Industrial Companies (Special provision) act, 1985
- Environment protection Act, 1986
- Consumer protection Act, 1986
- Securities and Exchange Board of India Act, 1992
- Taxation laws covering Corporate tax, indirect taxes like Excise, Customs, Sales tax and Wealth tax)

Entrepreneurial opportunities in modern agriculture

Farming (on farm)	Product marketing	Inputs marketing	Processing	Facilitative
Crop	Wholesale	Fertilizer	Milk	R&D
Dairy/Poultry/ Goat	Retail	Agrl. chemicals	Fruits	Mktg. Info
Fish	Commission Agent	Seeds	Vegetables	Quality control
Rabbit	Transport	Machineries	Paddy	Insurance
Vegetables	Export	Animal feed	Sugarcane	Energy
Flowers	Finance	Poultry hatchery	Cashew	
Ornamental flowers	Storage	Vetmedicines	Coir	
Palmrosa	Consultancy	Landscaping	Poultry	
Fodder		Agrl.credit	Cattle	
Sericulture		Custom service	tannery	
Agro-forestry		Bio-control units	Brewery	
Beekeeping		Bio-tech units		
Mushroom				

Key trends expected in future

- Increases in food production
- Changing Consumption Pattern:
- Land Consolidation
- Increase in Demand for Processed Food
- Increase in Competitiveness
- Agricultural Labour will move to more productive jobs
- Crop Diversification

- The National Policy on Biofuels in 2018 targets a 5% blending of biodiesel in diesel by 2030
- Use of Biotechnology
- Prudent Use of Land and New Growing Medium
- Hydroponic farming
- Precision farming
- Use of Drones in Agriculture
- Use Nano-Technology
- Use of digital technology to integrate agricultural production from the paddock to the consumer.
- Niche Marketing
- Improved Storage and Supply-Chain Facilities
- Digitisation of Retail outlets
- Automation in Agriculture
- Organic Farming will prosper
- Gene Editing Boom for Climate Change in Agriculture
- Insured Farming
- Smart farming
- Zero budget farming

The key driver of exponential growth in coming years: *Cost, quality and reliability*

- **Labour is becoming costly** and inaccessible, and so, is being replaced by technology.
- **Inputs are becoming prohibitively expensive**, necessitating more use that is efficient.
- **Precision technology** is becoming cheaper and more powerful
- The **"shared economy"** is disrupting expensive outright ownership models for farm tech

Conclusion:

- Increasing population, increasing average income and globalisation effects in India will increase demand for quantity, quality and nutritious food, and variety of food. Therefore, pressure on decreasing available cultivable land to produce more quantity, variety and quality of food will keep on increasing.
- Although the constraints in agriculture make the productivity and return complex but still a high-untapped potential is there in India's agriculture sector. Efforts are being made to convert all the challenges in agriculture into opportunities and this process is the future of agriculture and agribusiness.
- The understanding of agricultural business models helps to explain how agricultural organizations increasingly collaborate with customers and suppliers to cope with the demands of changes in the technological landscape, driving innovation and growth. Several socioeconomic and technological trends influenced also by environmental concerns delineate possible pathways for the consolidation of various types of business models in Europe.

- The large-scale agricultural enterprise model is associated with a rapid adoption of novel technology to improve operational efficiency and is based on the reduction of fixed costs allocated to unit products through economies of scale and the increase of yields in the production of food commodities.
- The organic farming model, precision farming, zero budget farming, smart agriculture constitutes a kind of differentiation tentative from the large-scale firms and it is characterized by the focus on sustainable products and processes. The adoption of these practices seems to be unrelated to farm size and a quest for innovation to increase agricultural yields is foreseeable.
- Family farming emerges in a context characterized by small possibility of achieving scale economies. This model is associated to labor-intensive crops such as fruit, vegetables, and perennial crops.
- Government initiates also play a vital role in increasing the agribusiness by providing the financial and technical aids in agriculture sector.
- The use of latest technologies like artificial intelligence, nanotechnology, e-trading, digitalization etc. we're making a new path for the bright future of agriculture sector.

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VERTICAL FARMING APPROACH TOWARDS MODERN AND SUSTAINABLE AGRICULTURE

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Abstract:

Maximizing food production per unit cultivable area is necessary because a growing world population is placing pressure on available agricultural land. The building industry will be required to develop billions of new dwelling units inside urban centers by 2050, when there will be an additional 3 billion people on the planet. Food being one of the basic needs, the agriculture industry also needs to adapt to the expanding population. This has led to the development of substitute methods of food production, including urban farming and, in particular, vertical hydroponic farming, in which food is grown indoors in a controlled environment with artificial lighting, with a minimal amount of water, and without pesticides. The integration of vertical farming to traditional agricultural methods would enhance the sustainability of food production for the expanding global population under a more severe environment.

Keywords: Hydroponics, aquaponics, aeroponics, urban farming and indoor farming.

Introduction:

In order to address the main issues of population expansion, climate change, and resource depletion, as well as calamities brought on by pandemics and conflicts, current agrifood systems are being called into question. One of the most significant anthropogenic activities causing climate change is the food system. By 2050, it is predicted that we will need to produce 60% more food than is currently produced. In order to safeguard these resources, it is crucial to implement more efficient and effective solutions (Banerjee and Adenaeuer, 2014). Thus, the UN's 2030 Agenda for Sustainable Development places a strong emphasis on the problems of food insecurity and malnutrition. The Covid-19 problem has brought to light the need for local and circular food supply networks in urban settings as well as the vulnerability of access to food. One of the largest issues facing the globe today is how to meet the demand for food both now and in the future. Despite the fact that there is a favorable association between urban food demand and food production, urban food systems are still independent and unincorporated. Due to the restricted availability of land for farming, it is necessary to continue farming operations in order to expand the supply of food.

Many factors put pressure on the food industry and processing, including: population growth and its correspondingly growing needs; reduction of natural resources due to expanding cities; earth erosion; various forms of contamination; the advent of biofuels; and restrictions placed on food production techniques by consumers and rule-makers that demand better quality, less chemical use, and many useful environmental attempts ‘from farm to fork’ (Albajes *et al.* 2013).

The use of vertical farming has been suggested as a potential answer to these problems. The importance of space is only increasing as mankind expands. As a result, things like homes, interior design, and even gardens, are getting taller. However, we are beginning to have larger versions of farms and gardens. This option keeps it while the field and greenhouse take their place. Nowadays, indoor vertical farming is becoming prevalent in big cities, and artificial intelligence is being used to remotely control the vegetation.

Vertical Farming (VF)

According to Sharath *et al.* (2020)

"A multilayer indoor plant production system in which all growth factors, including light, temperature, humidity, carbon dioxide concentration, water, and nutrients, are precisely controlled to produce large amounts of fresh produce of the highest quality throughout the year, completely independent of solar light and other outdoor conditions."

A more general definition of vertical farming is a type of commercial farming in which living things are artificially stacked vertically on top of one another in order to develop them for use as food, fuel, fiber or other goods or services (Garg and Balodi 2014).

Need for Vertical Farming:

(a) Solution to Food Security

An increasingly critical concern is food security. Demographers predict that in the future decades, the population of cities will grow significantly. Agronomists, ecologists, and other land experts warn of a growing shortage of farmland at the same time (Thomaier *et al.* 2015). Due to these factors, there may be a global famine if food demand grows exponentially faster than supply. By 2050, the population of the globe is expected to exceed 9 billion people, according to UN estimates. By this time, 80% of the world's population, according to the UN, will live in cities. Additionally, it projects that by 2050, we would require 70% more food to meet the needs of an additional 3 billion people on the planet. To address this enormous global problem, we urgently need innovative answers (Muller *et al.* 2017).

Produce more food on less land is the fundamental premise of vertical farming. The vertical farm's proponents assert that it would develop compact, self-sufficient ecosystems that serve a variety of purposes, from waste management to food production. In addition to enabling efficient and ecological food production, vertical farming has the potential to improve the economy, reduce pollution, provide new job opportunities, rebuild ecosystems, and increase access to wholesome foods. Indoor farming has the potential to produce higher yields and eternal income because it is year-round and weather-independent. Additionally, indoor farming offers a low-impact approach that can drastically cut down on travel expenses and GHG emissions by shortening trip distances between far-off farms and the neighborhood market. (Katz and Bradley 2013).

(b) Climate Change

The loss of arable land is a result of climate change. The loss of important agricultural land due to flooding, hurricanes, storms, and drought has had a negative impact on the global economy (Kalantari *et al.* 2017). Large expanses of agricultural land will be desecrated as a result of these occurrences, making them unusable for farming. In comparison to conventional agriculture, vertical farming may produce food while using less land and water and perhaps emitting zero pesticides and fertilizers.

(c) Urban Density

According to Despommier (2010), vertical farming has advantages over "horizontal" urban farming since it frees up space for more urban activities (i.e., more housing, services, and amenities). According to research, converting urban space to farmland results in a decline in population density and lengthier commutes. Living in a lower density area requires more energy and produces more air and water pollution. According to the National Highway Travel Survey (NHTS), households would need to buy an extra 100 gallons of petrol a year if urban density were to be reduced by 50%.

(d) Health

Conventional agricultural methods frequently place a high priority on profit and commercial benefit while paying insufficient attention to the harm they cause to the environment and to human health (Touliatos *et al.* 2016). These methods consistently pollute the soil, induce erosion, and produce an excessive amount of water waste. According to the World Health Organization, more than half of all farms still use raw animal manure as fertilizer, which may attract flies and contain weed seeds or diseases that can spread to plants. This practice is harmful to human health. Consequently, consuming such food has a negative impact on people's health.

In addition, growing crops indoors would have the advantage of decreasing the overuse of pesticides and herbicides, which results in polluted agricultural runoff. A high concentration of nutrients is produced (known as eutrophication) when too much fertilizers is washed into water bodies (such as rivers, streams, and oceans), which could upset the natural balance.

Furthermore, by providing precise irrigation and effective scheduling, indoor vertical farming uses cutting-edge growing techniques that utilize less water (approximately 1/10th of that used in traditional farming). As the urban population grows, there may be a large ameliorative effect as a result of this. More than two thirds of the fresh water in the globe is used for agricultural purposes, and farmers are struggling to find enough water for their crops.

(e) The Ecosystem

Since ancient times, traditional agriculture has been intruding on natural habitats. "Farming has upset more ecological processes than anything else—it is the most destructive process on earth," claims Dickson Despommier (2013). According to Despommier, the destruction of these historic ecosystems is accelerating climate change. By restoring biodiversity and mitigating the detrimental effects of climate change, indoor vertical farming can lessen the agricultural impact on the world's ecosystems. Cities might lower their CO2 emissions enough to create better technical advancements for the long-term improvement of the biosphere if they used vertical farms to produce even 10% of the ground area they consume.

(f) Economics

The vertical farm's proponents also claim that it will offer affordable food prices. The cost difference is rapidly closing due to traditional farming's escalating costs. For instance, it would be able to sell product directly to the consumer if vertical farms were strategically placed in metropolitan areas. This would cut transportation costs by eliminating the middleman, which can account for up to 60% of expenditures (Al-Kodmany 2016). Advanced farming techniques and intense farming practices are also used in vertical farms to dramatically enhance output. Additionally, vertical farming offers a chance to boost the regional economy. In urban areas with a shortage of fresh produce, abandoned buildings can be transformed into vertical farms to supply communities with wholesome food.

General Structure and process of Vertical Farming:

Understanding the operation of vertical farming involves four key areas:

1. **Physical layout**- Increasing food production per square meter is the main objective of vertical farming. Crops are raised in a tower living structure in tiers to achieve this purpose.

- ✓ Selection of wall
- ✓ Preparation of framework
- ✓ Use of building materials such as PVC pipe, plastic sheets and fabric material
- ✓ Installation of irrigation and fertigation system
- ✓ Selection and insertion of plants

2. **Lighting**- Any indoor garden's lighting setup, which gives plants the energy they require for photosynthesis, is its beating heart. Beginner indoor gardeners on the correct track to building an effective, profitable garden will already understand the concept of setting up a lighting system and will be able to do the necessary calculations. To keep the room's lighting at the ideal level, a precise blend of natural and artificial light is used. Lighting efficiency is increased by using tools like rotating beds. It is intended for the vertical farm to use only artificial light, or that both artificial and natural light should be considered. There are two possibilities. HPS (high-pressure sodium) or LED (light emitting diode).

3. **Growing medium**- Growing media such as aeroponic, aquaponic, or hydroponic systems are utilized in place of soil. Both inorganic and organic plant-growing media are employed, and the majority of them are blends of different components such peat, coir pith, wood fiber, compost bark, green waste compost, perlite, sand, and mineral wool (Carlile *et al.* 2015).

4. **Sustainability features**- To reduce the energy cost of farming, the vertical farming technique makes use of a number of sustainability aspects. Actually, 95% less water is used in vertical farming.

Plants suitable for vertical garden:

The location and climate should be taken into consideration when choosing plants. Plants should grow compactly so that they can create a thick, dense layer of cover. Plants with a short growth habit should have a long life cycle and a shallow fibrous root structure. Depending on the region, plants should be able to tolerate either full sun or full shade. The most typical plants utilized in vertical gardens are:

- **Green Façades:** *Hedera helix, Parthenocissus* spp., *Hydrangea petiolaris, Lonicera*s pp., *Clematis* spp. *Aristolochia* spp., *Jasminumofficinale, Passifloracaerulea,* etc.
- **Living Wall:** *Dracaena, Phalaenopsis* spp, *Asparagus sprengeri, Kalanchoe, Cordylin*spp., *Chlorophytum* spp., *Haworthia* spp., *Tradescantia* spp., *Fittonia* spp., *Nephrolepsis, Clematis, Gardenia* spp., *Aspleniumnidus, Maranta* spp., *Cotoneaster, Euonymus fortune, Hedera, Hydrangea, Lonicera, Parthenocissus, Polygonum, Pyracantha, Selaginella, Wisteria, Rose, Petunia, Nasturtiums* and even some vegetables like tomato, chilli, cucumber, peas and lettuce *etc*.
- **Exterior Wall:** *Lavendula*, *Thymus*, *Salvia* for full sunlight and *Begonia*, *Arum*, *Davallia*, *Asplenium,* and *Fuchsia* for shady locations.
- **Interior Wall:** *Philodendron*, *Epipremnum*, *Aeschynanthus*, *Columnea*, *Saintpaulia*, *Begonia* and different ferns like *Nephrolepis*, *Pteris* and many species of *Peperomia*.

Systems of vertical farming:

(a) Hydroponics

In order to grow food without utilizing soil, hydroponics uses mineral nutrient solutions in water. Hydroponics is described as "the cultivation of plants in nutrient-enriched water, with or without the mechanical support of an inert medium such as sand or gravel" in Encyclopedia Britannica. It is now accepted that hydroponics is a practical way to grow decorative crops like herbs, roses, freesia, and foliage plants as well as vegetables. Hydroponics, which is the most common growth method utilized in vertical farms, involves growing plants in nutrient solutions rather than actual soil. The nutrient solution, which is regularly checked for proper chemical composition and circulated, is submerged with the plant roots. This method results in more uniform and better yields the optimum combination of nutrients can be provided to all plants.

In industrial agriculture nowadays, hydroponics is frequently used and offers a number of benefits over conventional soil-based farming. This method's potential to remove or at least significantly lessen soil-related cultivation issues, such as the insects, fungus, and bacteria that thrive in soil, is one of its main benefits. Insofar as weeding, tilling, kneeling, and dirt removal are not difficulties, the hydroponic approach is likewise reasonably low-maintenance. The hydroponic technique also offers a less time-consuming alternative to handle greater production areas. Furthermore, because no animal excrement is utilised, it might provide a cleaner procedure. The hydroponic method also makes it simpler to manage pH balance and fertilizers levels. As soil-fixed nutrients are being dissolved in water through erosion and mineralization, a variety of elements in the soil, including temperature, oxygen content, moisture, and microbes, affect how accessible the nutrients are to plants. As a result, the hydroponic method may generate more uniform [product] and higher yields since all plants can receive the ideal combination of nutrients.

(b) Aeroponics

Technologically speaking, aeroponic is advancement above conventional hydroponics. An enclosed ecosystem of air, water, and nutrients, known as an aeroponic system, promotes rapid plant development while using little water, direct sunlight, and no soil or media. The primary distinction between hydroponic and aeroponic systems is the use of water in the former as the growing medium while none is present in the latter. Aeroponic does not need trays or containers to hold water because it uses mist or nutrient solutions instead of water. It is a successful and efficient method of cultivating plants since it uses little water (95 percent less water than conventional farming techniques) and little land. Plant boxes can be piled in practically any environment, including a warehouse or basement.

Plants can easily grow upward and downward because the stacking arrangement of the plant boxes is designed to sustain the top and bottom of the plants in the air. A fine mist of a nutrient-rich, water-mix solution feeds the plants. The fertilizers mix is completely recycled because the system is enclosed, which results in significant water savings. Therefore, this technique is especially useful in areas with a lack of water. The aeroponic approach also has the benefit of not using pesticides or fertilizers. Additionally, studies have shown that this high-density planting technique yields more and facilitates harvesting.

(c) Aquaponics

Aquaponics is a bio-system that combines hydroponic vegetable, flower, and herb production with recirculate aquaculture (fish farming) to foster symbiotic connections between the plants and the fish. In order to "fertigate" hydroponic production beds, it uses the nutrient-rich waste from fish tanks. In turn, the hydroponic beds serve as bio-filters that purge the water of gases, acids, and substances like ammonia, nitrates, and phosphates. In addition, the gravel beds serve as nitrifying bacteria's homes, which improve the nutrient cycle and water filtration. As a result, the fish tanks can receive a fresh infusion of cleaned water.

Status and potential of vertical farming in India:

India is one of the countries that produce the most fruits, vegetables, and other agricultural products. Vertical farming has been adopted in India. In soil-less settings, ICAR specialists are developing the idea of "vertical farming," in which food crops can be produced even on multistory buildings in major metropolitan cities without the use of soil or pesticides. The productive effectiveness of vertical farming has been put to the test in Punjab, where researchers have had some initial success cultivating fruits, vegetables, and potato tubers in a controlled setting without soil. Even though India's agriculture produces enough food to feed its population, a fourth of the world's hungry people reside there. The excessive use of water, fertilizers, and pesticides in Indian agriculture makes horizontal farming a resource-intensive practice. Land shortage is a problem because the nation is also undergoing desertification and land degradation. Numerous of these problems that the Indian agriculture sector is presently experiencing can be effectively and permanently resolved by vertical farming.

Conclusion and future prescriptive:

A growing worldwide population is putting pressure on agricultural land, necessitating the maximization of food output per cultivable area. Due to the technology's promise to address one of the most important issues—food security—vertical farming has experienced enormous growth in several nations throughout the world. These vertical farms might be set up in densely populated locations where they could provide millions of people with year-round access to fresh, wholesome food regardless of the weather.

For a variety of crops, new high-tech cultivation techniques including hydroponics, aeroponics, and aquaponics are mainly challenging the requirement for soil-based farming. In the near future, improvements in greenhouse technology and its enabling technologies including multi-racking automated systems, recycling systems, LED lighting, solar, wind, and storage batteries—as well as in computing power, software applications, databases, and the Internet of Things—are likely to come together to form effective production systems. The government would need to take the initiative and organize awareness-raising and skill-development programmes in order to make this new style of farming feasible for India. The government institutions can implement skill development programmes to create skilled workers and manufacturers.

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SUSTAINABLE WATER MANAGEMENT IN AGRICULTURE: IRRIGATION TECHNIQUES AND WATER CONSERVATION

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Abstract:

This book chapter explores the critical issue of sustainable water management in agriculture, focusing on irrigation techniques and water conservation strategies. With the growing global population and increasing water scarcity, finding innovative and efficient approaches to irrigate crops while minimizing water consumption is of paramount importance. The chapter begins by providing an overview of the current challenges and trends in water availability for agriculture. It then delves into various irrigation techniques, such as drip irrigation, sprinkler systems, and precision agriculture, highlighting their advantages and limitations. The discussion encompasses topics such as water distribution uniformity, energy requirements, and the potential for automation and remote sensing technologies in optimizing irrigation practices. Furthermore, the chapter addresses the significance of water conservation methods, including rainwater harvesting, soil moisture monitoring, and crop selection. It explores the benefits of implementing water-saving practices, such as crop rotation, mulching, and deficit irrigation, to enhance water use efficiency. Ultimately, this chapter offers valuable insights and recommendations for sustainable water management in agriculture, promoting the preservation of water resources and the development of resilient farming systems in the face of increasing water scarcity.

Keywords: Agriculture, irrigation techniques, sustainable water management, water conservation and water scarcity.

Introduction:

Water is an essential resource for sustaining life and supporting various economic activities, with agriculture being one of the largest consumers of water globally. As the world's population continues to grow and climate change impacts become more pronounced, ensuring sustainable water management in agriculture has become a pressing concern. This necessitates the adoption of effective irrigation techniques and water conservation practices to address the challenges of water scarcity and environmental degradation.

Importance of water management in agriculture:

Water management in agriculture is of paramount importance due to several reasons. Firstly, agriculture is heavily dependent on water for crop production, livestock farming, and aquaculture. Insufficient water supply or inefficient water usage can lead to reduced crop yields, compromised livestock health, and decreased food production, which can have severe consequences on food security and the global economy. Secondly, water scarcity is a growing concern in many regions around the world. Climate change-induced droughts, overexploitation of water resources, and competing demands from various sectors pose significant challenges to water availability for agriculture. Without proper water management strategies, the agricultural sector may face water shortages, which can exacerbate food insecurity and socio-economic disparities. Thirdly, water management in agriculture is closely linked to environmental sustainability. Excessive water extraction from rivers, lakes, and underground aquifers can deplete water sources and lead to ecological imbalances. Moreover, inefficient irrigation practices, such as flooding or over-irrigation, can contribute to waterlogging, soil erosion, and the contamination of water bodies with agricultural runoff, including fertilizers and pesticides. These negative environmental impacts further emphasize the need for sustainable water management practices in agriculture.

Significance of sustainable practices for water conservation:

Sustainable practices for water conservation are crucial for ensuring the long-term viability of agriculture and protecting the environment. Adopting sustainable techniques and strategies can help optimize water use, reduce wastage, and preserve water resources for future generations. Here are some key reasons highlighting the significance of sustainable practices:

- **Water efficiency:** Sustainable irrigation techniques, such as drip irrigation, micro-sprinklers, and precision farming, enable precise water delivery to plants, minimizing water loss through evaporation or runoff. By improving water use efficiency, farmers can maximize crop productivity while minimizing water consumption.
- **Soil health and productivity:** Proper water management practices, such as regulated irrigation schedules and soil moisture monitoring, promote healthier soil conditions. Maintaining optimal soil moisture levels helps prevent water stress in plants, enhances nutrient uptake, and fosters robust root systems. Healthy soils, in turn, contribute to improved crop yields and long-term agricultural sustainability.
- **Water quality preservation:** Sustainable water management practices focus not only on efficient water use but also on preventing water pollution. Implementing measures like integrated pest management, proper waste disposal, and erosion control can minimize the negative impacts of agricultural activities on water quality. This protects aquatic ecosystems, preserves biodiversity, and ensures safe water supplies for both agriculture and communities.
- **Climate change resilience:** Climate change brings uncertain weather patterns, including more frequent and intense droughts and floods. Sustainable water management practices help build resilience against these climate-related challenges. By adopting water-saving technologies, implementing water storage and harvesting systems, and diversifying water sources, farmers can mitigate the impacts of water scarcity and extreme weather events on agricultural production.

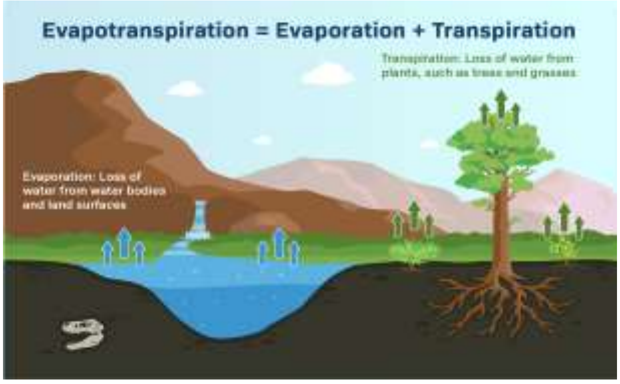
Sustainable water management in agriculture is essential to address the challenges of water scarcity, environmental degradation, and food security. By implementing efficient irrigation techniques and adopting water conservation practices, farmers can optimize water use, protect ecosystems, and build resilience to climate change. Collaboration between governments, agricultural stakeholders, and researchers is crucial to promote and support the widespread adoption of sustainable water management strategies in agriculture.

Water use in agriculture

1. Overview of water requirements for crop production:

Water is essential for agriculture and plays a crucial role in crop production. The amount of water required for crop cultivation varies depending on factors such as crop type, climate, soil conditions, and farming practices. In general, crops require water for various purposes, including seed germination, photosynthesis, nutrient uptake, and transportation of minerals within the plant.

- **Irrigation:** Irrigation is the primary source of water for crop production, especially in areas with limited rainfall or unreliable water availability. Different irrigation methods are used, including flood irrigation, sprinkler irrigation, and drip irrigation, each with varying levels of water efficiency.
- **Evapotranspiration:** Evapotranspiration refers to the combined process of evaporation from the soil surface and transpiration from the plant's leaves. It represents the amount of water lost to the atmosphere during plant growth. Evapotranspiration rates vary depending on factors such as temperature, humidity, wind speed, and plant characteristics.



- **Crop Water Requirements:** The water requirements of crops are often expressed as crop evapotranspiration (ETc) or crop coefficient (Kc). ETc represents the total amount of water needed to meet the crop's water demands, while Kc is a factor that relates the actual crop water requirements to reference evapotranspiration (ETo) calculated from weather data.

2. Challenges and issues associated with water scarcity in agriculture:

Water scarcity poses significant challenges to agriculture, affecting crop production, food security, and livelihoods. Several issues arise due to water scarcity in agriculture:

- **Increased Competition:** As water resources become scarcer, there is increased competition among various sectors, including agriculture, industry, and domestic use. Agriculture often faces tough competition for water, as it requires substantial amounts to sustain crop growth.

- **Crop Yield Reduction:** Water scarcity directly impacts crop yields, leading to reduced agricultural productivity. Insufficient water supply during critical growth stages can stunt crop growth, reduce crop quality, and even lead to crop failure.
- **Depletion of Groundwater:** In regions heavily reliant on groundwater for irrigation, water scarcity can result in over-pumping, leading to the depletion of aquifers. Once aquifers are depleted, it becomes challenging to replenish them, further exacerbating the water scarcity problem.
- **Increased Costs:** When water becomes scarce, its price tends to rise, increasing the cost of irrigation for farmers. This additional financial burden can have a detrimental impact on small-scale farmers who may struggle to afford the necessary water for their crops.
- **Socioeconomic Impacts:** Water scarcity in agriculture can have profound socioeconomic implications, particularly in rural areas where agriculture is a primary source of income. Farmers may experience reduced incomes, unemployment, and migration as a result of crop failures and reduced agricultural activities.

3. Environmental impacts of inefficient water use in farming:

Inefficient water use in agriculture can have several negative environmental consequences, impacting ecosystems and natural resources:

- **Water Pollution:** Excessive or improper use of water, such as over-irrigation or inefficient irrigation systems, can lead to water runoff. This runoff carries fertilizers, pesticides, and other agrochemicals into nearby water bodies, causing pollution and ecological imbalances.
- **Soil Degradation:** Over-irrigation can lead to waterlogging and soil salinization, where excessive salts accumulate in the soil. These conditions degrade soil fertility and render land unsuitable for crop cultivation.
- **Biodiversity Loss:** Inefficient water use can result in the depletion of water bodies and wetlands, negatively impacting aquatic ecosystems and the biodiversity they support. Reduced water availability can disrupt habitats and lead to the loss of species that depend on these ecosystems.
- **Energy Consumption:** Inefficient irrigation practices, such as flood irrigation, require significant amounts of water and energy. Pumping and transporting water for irrigation purposes contribute to increased energy consumption and greenhouse gas emissions, exacerbating climate change.
- **Climate Change Impact:** Inefficient water use contributes to the depletion of water resources, exacerbating the impacts of climate change on water availability. As global temperatures rise and weather patterns become more unpredictable, efficient water management becomes increasingly crucial in mitigating the effects of climate change on agriculture.

Efforts to promote sustainable water use in agriculture include the adoption of water-efficient irrigation techniques, precision farming practices, and the development of drought-tolerant crop varieties. By addressing water scarcity challenges and improving water use efficiency, the agricultural sector can mitigate environmental impacts and ensure long-term food security.

Irrigation techniques for water efficiency:

1. Overview of traditional irrigation methods and their limitations:

Traditional irrigation methods have been widely used for centuries to supply water to agricultural fields. However, these methods often suffer from limitations that result in inefficient water usage. Some of the common traditional irrigation techniques include flood irrigation, furrow irrigation, and overhead sprinklers.

- **Flood irrigation:** This method involves flooding the entire field with water, allowing it to spread across the surface. While flood irrigation is simple and inexpensive, it has several drawbacks. One major limitation is the significant water loss due to evaporation and runoff. The water may also accumulate in certain areas, leading to waterlogging and soil erosion. Additionally, uniform water distribution is challenging, which can result in uneven plant growth and yield.
- **Furrow irrigation:** Furrow irrigation involves creating small channels or furrows along the rows of plants and allowing water to flow through them. While it improves water distribution compared to flood irrigation, it still suffers from similar limitations. There is still a risk of water loss through evaporation and runoff, and water distribution may not be uniform. Soil erosion can also occur if the flow of water is not properly controlled.
- **Overhead sprinklers:** This method involves using sprinklers mounted on above-ground pipes or risers to distribute water over the field. While it provides better water distribution than flood or furrow irrigation, it has its own set of limitations. Overhead sprinklers are prone to significant water loss due to evaporation and wind drift. They may also result in uneven water distribution, leading to overwatering in some areas and underwatering in others. Additionally, certain crops may be susceptible to diseases caused by excessive leaf wetness.

2. Introduction to modern irrigation techniques for water conservation:

To address the limitations of traditional irrigation methods and improve water efficiency, modern irrigation techniques have been developed. These techniques focus on delivering water directly to the plant roots, minimizing water loss, and optimizing water distribution. Here are some of the key modern irrigation techniques:

i. **Drip irrigation:** Drip irrigation is a precise and efficient method that delivers water directly to the plant roots in small, frequent doses. It involves a network of tubes or pipes with emitters placed near each plant or along the crop rows. The emitters release water slowly, allowing it to soak into the soil and minimize evaporation and runoff. Drip irrigation offers several benefits, including reduced water usage, improved water distribution, and minimized weed growth. It also enables the application of fertilizers directly to the root zone, enhancing nutrient efficiency.

ii. **Sprinkler irrigation:** Sprinkler irrigation has evolved from traditional overhead sprinklers to more advanced systems that maximize water distribution efficiency. Modern sprinkler systems use various types of nozzles, including low-pressure, high-efficiency sprinkler heads, and rotating sprinklers. These nozzles help minimize water loss through evaporation and wind drift. Additionally, advanced technologies, such as weather-based controllers and soil moisture sensors, can optimize irrigation scheduling based on actual plant needs and weather conditions. This allows for precise water application and reduces water waste.

iii. **Micro-irrigation systems:** Micro-irrigation systems, including micro-sprinklers and micro-sprayers, provide precision watering to individual plants or small areas. They deliver water in a controlled manner, minimizing runoff and ensuring efficient water uptake by the plants. These systems are particularly suitable for orchards, vineyards, and other specialty crops where targeted irrigation is crucial. Micro-irrigation systems also enable the application of fertilizers and other inputs directly to the root zone, improving nutrient efficiency and reducing environmental impact.

iv. **Subsurface irrigation:** Subsurface irrigation involves delivering water directly to the root zone through buried pipes or tubes. This method minimizes water loss through evaporation and surface runoff. By placing the water source close to the roots, subsurface irrigation maximizes water uptake by the plants and reduces the risk of weed growth. It is especially effective in arid or sandy soil conditions where surface evaporation rates are high. Subsurface irrigation systems can be installed at various depths, depending on the specific crop requirements.

Modern irrigation techniques offer significant improvements in water efficiency compared to traditional methods. Drip irrigation, sprinkler irrigation, micro-irrigation systems, and subsurface irrigation all contribute to minimizing water loss, optimizing water distribution, and enhancing plant growth. Implementing these techniques can help conserve water resources, increase agricultural productivity, and promote sustainable farming practices.

Water conservation strategies in agriculture

1. Soil moisture management and water retention techniques:

Soil moisture management plays a crucial role in water conservation in agriculture. By implementing effective techniques, farmers can optimize water use and minimize waste. Some strategies for soil moisture management include:

- **Irrigation scheduling:** Farmers can use advanced tools and technologies to schedule irrigation based on soil moisture levels, weather conditions, and crop water requirements. This approach ensures that water is applied only when necessary, reducing wastage.
- **Drip irrigation:** Drip irrigation is a highly efficient method that delivers water directly to the plant's root zone. It minimizes water loss through evaporation or runoff and allows precise control over the amount of water provided to each plant.
- **Rainwater harvesting:** Farmers can collect and store rainwater in reservoirs or tanks to supplement irrigation needs during dry periods. This practice helps reduce dependence on groundwater or surface water sources.
- **Contour plowing and terracing:** By contour plowing, farmers create ridges and furrows that follow the contour lines of the land. This technique helps retain water, allowing it to

infiltrate into the soil rather than running off. Terracing involves constructing leveled platforms on slopes, reducing water runoff and soil erosion.

2. Crop selection and rotation for reduced water demand:

Crop selection and rotation are essential factors in water conservation. Some crops have higher water demands than others, and by choosing crops that are better suited to the local climate and water availability, farmers can minimize water usage. Additionally, rotating crops can improve soil health and reduce the risk of diseases and pests, optimizing water use. Some strategies include:

- **Drought-tolerant crop varieties:** Farmers can select crop varieties that are naturally adapted to the local climate and require less water to thrive. These varieties can withstand periods of limited water availability without compromising yield or quality.
- **Crop diversification:** Planting a diverse range of crops can help optimize water usage. Different crops have varying water demands, rooting depths, and growth cycles, which can minimize overall water requirements and maximize water utilization.
- **Cover crops:** Cover crops are grown between main crop seasons to protect and improve the soil. They help retain moisture, reduce soil erosion, and enhance soil structure, ultimately benefiting subsequent crops by reducing water stress.

3. Mulching: Benefits in reducing evaporation and soil moisture retention:

Mulching involves covering the soil surface around plants with a layer of organic or synthetic materials. It offers several benefits for water conservation in agriculture:

- **Reduces evaporation:** Mulch acts as a protective barrier, reducing evaporation by shielding the soil from direct sunlight and wind exposure. This helps retain soil moisture and reduces the need for frequent irrigation.
- **Suppresses weed growth:** Mulch inhibits the growth of weeds, which compete with crops for water and nutrients. By reducing weed pressure, mulching ensures that water resources are utilized by crops more efficiently.
- **Improves soil moisture retention:** Mulch helps maintain soil moisture levels by slowing down water evaporation from the soil surface. It also aids in preventing soil compaction and crusting, which can impede water infiltration.

4. Cover cropping and intercropping: Maximizing water use efficiency:

Cover cropping and intercropping are techniques that involve growing multiple crops together in a specific pattern. These practices offer several advantages for water conservation:

- **Increased water use efficiency:** Cover crops and intercropping systems optimize water use by creating a microclimate that reduces water evaporation from the soil surface. The additional plant canopy helps shade the soil, retaining moisture and reducing water loss.
- **Nutrient cycling and soil improvement:** Cover crops add organic matter to the soil when incorporated, improving its water-holding capacity and nutrient availability. Intercropping systems can also enhance nutrient cycling and reduce nutrient leaching, thereby minimizing water pollution.

- **Pest and disease management:** By diversifying crops and incorporating cover crops, farmers can disrupt pest and disease cycles. This reduces the need for chemical interventions, minimizing potential water contamination and reducing water demand for pest control measures.

5. Water-saving practices in livestock farming:

Water conservation in livestock farming is essential to minimize water usage and maintain sustainable agricultural practices. Some strategies to save water include:

- **Efficient watering systems:** Implementing technologies like automatic drinkers or nipple waterers ensures that animals have access to clean water without excessive wastage. These systems reduce spillage, evaporation, and contamination, conserving water resources.
- **Proper waste management:** Efficient handling and management of animal waste can reduce water pollution and conserve water. Properly designed systems for waste storage, treatment, and recycling can minimize water usage in cleaning and processing waste.
- **Improved animal health and nutrition:** Ensuring optimal animal health and nutrition reduces water wastage indirectly. Healthy animals use water more efficiently and produce less waste, minimizing overall water demand in livestock operations.
- **Rainwater collection for livestock watering:** Collecting rainwater from roofs or catchment areas can provide an additional source of water for livestock. Proper storage and treatment systems should be in place to ensure water quality and availability during dry periods.

By implementing these water conservation strategies in agriculture, farmers can enhance their sustainability, reduce water usage, and mitigate the impacts of water scarcity and climate change on food production. These practices contribute to the overall resilience and long-term viability of agricultural systems.

Precision water management technologies

Precision Water Management Technologies aim to optimize water usage in agricultural practices by employing various advanced techniques and tools. This comprehensive approach incorporates remote sensing, real-time data collection and analysis, sensor-based irrigation systems, and decision support tools to ensure efficient water management. Let's explore each component in detail:

1. Remote sensing and satellite imagery for water monitoring:

Remote sensing involves the use of satellites and aerial platforms to gather information about the Earth's surface. In the context of water management, remote sensing technologies provide valuable data on soil moisture, crop health, and water availability. Satellite imagery allows for large-scale monitoring, offering insights into water distribution, evapotranspiration rates, and drought conditions. These observations help farmers and water managers make informed decisions regarding irrigation planning and water allocation.

2. Real-time data collection and analysis for optimal irrigation scheduling:

Real-time data collection systems, such as weather stations and soil moisture sensors, provide continuous updates on environmental conditions and soil moisture levels. These sensors are strategically placed in fields to capture crucial information for irrigation scheduling. By monitoring variables like rainfall, temperature, humidity, and soil moisture content, farmers can determine the optimal timing and duration of irrigation, ensuring that crops receive the necessary amount of water without wastage. Advanced analytics and algorithms help process and interpret this data, facilitating precise irrigation scheduling.

3. Sensor-based irrigation systems for precise water application:

Sensor-based irrigation systems employ various sensors, such as soil moisture sensors, plant water status sensors, and weather sensors, to monitor and regulate water application. These sensors provide real-time feedback on soil moisture levels, plant water needs, and environmental conditions. With this information, automated irrigation systems can adjust water delivery to match the precise requirements of each crop and field zone. By avoiding over- or under-irrigation, these systems reduce water waste, improve crop yield and quality, and conserve water resources.

4. Decision support tools for water management in agriculture:

Decision support tools (DSTs) utilize advanced algorithms and models to assist farmers and water managers in making informed decisions regarding water management. These tools integrate data from various sources, including remote sensing, real-time monitoring, and historical records, to generate insights and recommendations. DSTs can predict crop water requirements, optimize irrigation scheduling, and evaluate the impacts of different management scenarios. By providing actionable information, DSTs enable stakeholders to enhance water-use efficiency, conserve resources, and mitigate the risks associated with water scarcity.

Precision Water Management Technologies combine remote sensing, real-time data collection and analysis, sensor-based irrigation systems, and decision support tools to optimize water usage in agriculture. By leveraging these technologies, farmers and water managers can enhance irrigation efficiency, conserve water resources, and promote sustainable agricultural practices.

Policy and economic perspectives

1. Government policies and regulations promoting sustainable water management:

Government policies and regulations play a crucial role in promoting sustainable water management practices. Recognizing the importance of water as a finite and essential resource, many governments worldwide have implemented various measures to ensure its efficient use and conservation. These policies aim to strike a balance between meeting the growing water demands of a nation while preserving the environment and protecting water resources for future generations.

- **Water allocation and pricing:** Governments can implement policies that allocate water resources efficiently and ensure fair distribution. This can involve establishing water rights systems, setting up water markets, or implementing water allocation plans based on priority and equity. Additionally, governments can introduce pricing mechanisms that reflect the true value of water, encouraging its conservation and discouraging wasteful practices.

- **Water use efficiency standards:** Governments can establish regulations and standards that promote water-efficient technologies and practices across different sectors. For example, in agriculture, governments can set benchmarks for irrigation efficiency, encourage the use of precision irrigation techniques, and promote the adoption of modern irrigation systems that minimize water losses. These standards can also apply to industrial and domestic sectors, encouraging the adoption of water-saving technologies and practices.
- **Water conservation programs and incentives:** Governments can design and implement water conservation programs that incentivize individuals, businesses, and communities to adopt sustainable water management practices. This can involve offering financial incentives, subsidies, or tax benefits to those who invest in water-efficient technologies or implement water conservation measures. Governments can also support research and development in water-saving technologies and provide grants or funding opportunities for innovative projects.
- **Integrated water resources management (IWRM):** Governments can adopt an integrated approach to water management, considering social, economic, and environmental factors holistically. IWRM emphasizes collaboration among various stakeholders, such as government agencies, water users, and local communities, to develop comprehensive water management plans. These plans can address issues like water allocation, pollution control, watershed management, and the protection of ecosystems.

2. Economic incentives for farmers to adopt water-efficient practices:

Farmers play a vital role in water conservation efforts, as agriculture is one of the largest consumers of freshwater globally. Governments and organizations can provide economic incentives to encourage farmers to adopt water-efficient practices, thereby reducing water use and improving sustainability in agriculture. Some of these incentives include:

- **Financial support and grants:** Governments can offer financial support to farmers in the form of grants, subsidies, or low-interest loans to invest in water-efficient technologies and infrastructure. This assistance can help farmers upgrade their irrigation systems, install efficient water pumps, or adopt precision agriculture techniques that optimize water use.
- **Water pricing mechanisms:** Governments can implement pricing mechanisms that provide economic incentives for farmers to conserve water. This can involve tiered pricing structures, where the cost of water increases as usage exceeds certain thresholds. Higher prices for excessive water use can motivate farmers to adopt water-saving practices and technologies.
- **Research and extension services:** Governments can invest in research and extension services to provide farmers with information, training, and technical support on water-efficient practices. This can include conducting research on crop varieties that require less water, promoting soil moisture monitoring techniques, or offering guidance on optimal irrigation scheduling. Access to such knowledge can empower farmers to make informed decisions and adopt sustainable water management practices.
- **Market-based incentives:** Governments can establish market mechanisms that reward farmers for sustainable practices. For example, certification programs can be introduced,

where farmers adhering to certain water management standards receive premium prices for their produce. Additionally, governments can collaborate with private sector entities or certification bodies to create market opportunities for sustainably produced agricultural products.

3. Collaborative efforts and partnerships for water conservation in agriculture:

Water conservation in agriculture requires collaborative efforts among multiple stakeholders, including government agencies, farmers, researchers, NGOs, and industry players. Partnerships and collaborations enhance knowledge sharing, coordination, and the implementation of effective strategies. Here are some examples:

- **Public-private partnerships:** Governments can form partnerships with private sector entities, such as agricultural companies, technology providers, and financial institutions. These collaborations can leverage the expertise and resources of the private sector to promote sustainable water management practices in agriculture. For instance, companies can offer technical assistance, access to innovative technologies, or financial support for water conservation projects.
- **Farmer organizations and cooperatives:** Supporting and strengthening farmer organizations and cooperatives can facilitate collective action towards water conservation. These organizations can provide a platform for sharing experiences, best practices, and knowledge among farmers. They can also negotiate with policymakers and engage in dialogue to advocate for supportive policies and programs.
- **Research institutions and universities:** Collaboration between research institutions, universities, and farmers is crucial for developing and disseminating water-efficient agricultural practices. Joint research projects can focus on improving crop varieties, optimizing irrigation techniques, and developing innovative water-saving technologies. Additionally, universities can provide education and training programs that equip farmers with the skills and knowledge needed for sustainable water management.
- **Awareness campaigns and community engagement:** Governments, NGOs, and community-based organizations can collaborate to raise awareness about the importance of water conservation in agriculture. Community engagement initiatives can involve workshops, field demonstrations, and capacity-building programs to educate farmers about water-efficient practices. Additionally, campaigns can target consumers to promote responsible water use and support sustainably produced agricultural products.

By combining policy measures, economic incentives, and collaborative efforts, governments can foster sustainable water management practices in agriculture. These comprehensive approaches are essential to address the challenges posed by water scarcity, climate change, and the increasing global demand for food.

Case studies and success stories

1. Examples of successful implementation of sustainable water management practices:

- **The Sujalam Sufalam Jal Sanchay Abhiyan (SSJSA) in Gujarat:** This water management initiative was launched by the Government of Gujarat in 2018. The aim was to conserve rainwater and enhance groundwater levels in the state. Through the construction of check dams, farm ponds, and recharge wells, the initiative successfully increased water availability for irrigation and drinking purposes. As a result, farmers experienced improved crop yields, and water scarcity issues were mitigated.

- **The Bhungroo System in Gujarat:** Developed by Naireeta Services, the Bhungroo system tackles water scarcity by harvesting and storing rainwater. This innovative technology allows farmers to access groundwater during periods of low rainfall. The system involves drilling a well with a perforated pipe, which is filled with layers of sand, gravel, and charcoal. During the monsoon season, excess rainwater is collected and stored in the system, replenishing groundwater. Farmers in Gujarat have reported significant increases in crop productivity and reduced dependence on rainfall.
- **The Hirakud Dam in Odisha:** The Hirakud Dam, built across the Mahanadi River, is a noteworthy example of sustainable water management. Completed in 1957, it serves multiple purposes, including irrigation, flood control, and hydroelectric power generation. The dam has significantly contributed to agricultural development in the region by providing a reliable water supply for irrigation. Additionally, the reservoir created by the dam supports fisheries, tourism, and recreational activities, leading to socio-economic benefits for local communities.

2. Lessons learned and best practices from various regions and agricultural systems:

- **Drip Irrigation in Maharashtra:** Maharashtra has successfully implemented drip irrigation techniques, especially in water-scarce regions like Marathwada. Drip irrigation delivers water directly to the plant roots, minimizing water wastage through evaporation and ensuring efficient water usage. The adoption of drip irrigation has resulted in improved crop yields, reduced water consumption, and enhanced farmer incomes. This practice serves as a valuable lesson for other states facing similar water challenges.
- **Community-Based Water Management in Rajasthan:** Rajasthan has effectively implemented community-based water management practices, such as community-led water harvesting structures called "johads" and traditional water management systems like "khadins" and "talabs." These practices involve local communities actively participating in the planning, construction, and maintenance of water infrastructure. By empowering communities to manage their water resources, Rajasthan has achieved sustainable water management, leading to improved water availability for agriculture and domestic use.
- **System of Rice Intensification (SRI) in Tamil Nadu:** The System of Rice Intensification (SRI) is a sustainable agricultural technique that promotes water-efficient paddy cultivation. By modifying planting techniques, transplanting younger seedlings, and adopting alternate wetting and drying practices, SRI reduces water requirements while improving crop productivity. Tamil Nadu has successfully implemented SRI, resulting in reduced water consumption, increased rice yields, and enhanced farmer livelihoods. This approach has the potential to address water scarcity issues in other rice-growing regions across India.

India has witnessed several successful case studies and implementation of sustainable water management practices. These examples highlight the importance of innovative technologies, community participation, and adaptive agricultural techniques in addressing water challenges. By adopting these lessons learned and best practices, India can continue to achieve sustainable water management, ensuring water availability for various sectors and improving the livelihoods of its people.

Future directions and research priorities

1. Emerging technologies and innovations in water management for agriculture:

Water management is crucial for sustainable agriculture, and as we look towards the future, emerging technologies and innovations are expected to play a significant role in addressing water scarcity and improving water management practices. Some of the key emerging technologies and innovations in this field include:

- **Precision Agriculture:** Precision agriculture utilizes advanced technologies such as remote sensing, geographic information systems (GIS), and global positioning systems (GPS) to optimize water usage in agriculture. By precisely analyzing crop needs and soil conditions, farmers can apply water resources more efficiently and reduce wastage.
- **Sensor Technologies:** Sensors can provide real-time data on soil moisture, temperature, and other important parameters. These sensors can be integrated with automated irrigation systems, enabling farmers to irrigate their fields based on actual crop water requirements. This helps in avoiding over-irrigation and ensures that plants receive adequate water.
- **Drip Irrigation and Micro-Irrigation:** Drip irrigation and micro-irrigation systems deliver water directly to the root zone of plants, minimizing evaporation and reducing water loss. These systems can be coupled with sensors and automation technologies to optimize water delivery based on crop needs.
- **Desalination and Water Purification:** With freshwater resources becoming increasingly scarce, desalination technologies are gaining prominence. Desalination removes salt and impurities from seawater or brackish water, making it suitable for irrigation. Additionally, water purification technologies can help in treating wastewater and making it reusable for agricultural purposes.
- **Hydroponics and Aeroponics:** Hydroponics and aeroponics are soilless cultivation techniques that involve growing plants in nutrient-rich water or mist environments. These systems can significantly reduce water consumption compared to traditional soil-based farming methods.

2. Areas of further research and development:

While significant progress has been made in water management for agriculture, there are still several areas that require further research and development to ensure sustainable and efficient water usage. Some of the key areas for future research include:

- **Crop-Specific Water Requirements:** Understanding the water needs of different crops and developing crop-specific water management strategies can optimize water usage in agriculture. Further research is needed to determine the precise water requirements of various crops under different environmental conditions.
- **Water-Efficient Irrigation Techniques:** Developing and improving irrigation techniques that minimize water loss and maximize water use efficiency is crucial. This includes

further research on improving the performance of drip irrigation, micro-irrigation, and other water-saving irrigation systems.

- **Water Storage and Rainwater Harvesting:** Research on innovative methods of water storage and rainwater harvesting can help mitigate water scarcity during dry periods. This includes investigating the feasibility of underground water storage, large-scale rainwater harvesting systems, and improved water storage technologies.
- **Integrated Water Management:** Integrating water management practices with other agricultural systems, such as nutrient management and crop rotation, can lead to more efficient water use. Further research is needed to explore the synergistic effects of integrating different agricultural practices to optimize water usage.
- **Social and Economic Considerations:** Effective water management in agriculture involves addressing social and economic aspects. Research is required to understand the socioeconomic impacts of water scarcity and develop policies and frameworks that promote equitable access to water resources while incentivizing sustainable water management practices.

3. The role of climate change adaptation in water management strategies:

Climate change poses significant challenges to water management in agriculture. Changing precipitation patterns, increased frequency of extreme weather events, and rising temperatures have direct impacts on water availability and agricultural productivity. Adapting water management strategies to the changing climate is essential for the sustainability of agricultural systems. Here are some key considerations:

- **Water Resource Assessment:** Understanding the impacts of climate change on water resources is crucial for developing adaptation strategies. This involves assessing changes in precipitation patterns, river flows, groundwater availability, and the vulnerability of water supply systems to climate change.
- **Integrated Water Resources Management:** Implementing integrated water resources management approaches that consider climate change projections can help optimize water allocation, storage, and distribution. This includes developing robust water allocation plans that account for changing water availability and demand.
- **Climate-Smart Agriculture:** Climate-smart agricultural practices focus on sustainable intensification while considering climate change impacts. Water management strategies should integrate climate-smart agriculture techniques such as conservation tillage, agroforestry, and the use of drought-tolerant crop varieties to reduce water demand and enhance resilience.
- **Water Governance and Policy:** Strengthening water governance frameworks and policies to account for climate change is crucial. This includes developing mechanisms for water rights and allocation that consider changing water availability patterns and promote adaptive water management practices.
- **Research on Climate Change Impacts:** Continued research on the specific impacts of climate change on water resources and agriculture is necessary. This research can help in identifying vulnerabilities, assessing adaptation options, and informing policymakers and

stakeholders about effective strategies to mitigate the impacts of climate change on water management in agriculture.

Conclusion:

In conclusion, sustainable water management in agriculture is crucial for ensuring long-term food security, preserving natural resources, and mitigating the impacts of climate change. This paper has explored various irrigation techniques and water conservation practices that can contribute to sustainable water use in agriculture. Efficient irrigation techniques such as drip irrigation, micro-sprinklers, and precision irrigation systems have demonstrated significant water savings while maintaining crop productivity. These techniques minimize water loss due to evaporation, runoff, and deep percolation, thereby maximizing water-use efficiency. Additionally, implementing smart irrigation technologies that utilize sensors and data analysis can optimize irrigation scheduling based on real-time weather conditions and plant water requirements. Water conservation practices play a pivotal role in sustainable water management. Measures such as rainwater harvesting, water recycling, and water storage can supplement water supplies and reduce reliance on freshwater sources. Implementing proper soil management practices, including mulching and cover cropping, can enhance water infiltration and reduce soil erosion, thereby improving water availability and quality.

Furthermore, raising awareness among farmers and promoting education and training programs on sustainable water management practices is essential for widespread adoption. Government policies and regulations can provide incentives and support for farmers to implement water-saving techniques and invest in sustainable infrastructure. It is crucial to acknowledge that sustainable water management in agriculture requires a multidisciplinary approach involving farmers, policymakers, researchers, and communities. Collaboration and knowledge sharing among stakeholders are crucial for implementing effective strategies and addressing regional and local water challenges. By adopting efficient irrigation techniques, implementing water conservation practices, and fostering collaboration, the agricultural sector can contribute to sustainable water management, protect ecosystems, and ensure a resilient and food-secure future. Embracing sustainable water practices in agriculture is not only environmentally responsible but also economically beneficial, creating a more resilient and prosperous agricultural sector for generations to come.

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ADOPTION OF MILLETS IN INDIAN DIETS FOR IMPROVED HEALTH: CURRENT STATUS AND PHYSIOLOGICAL ROLE

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Introduction:

Millets, a group of small-seeded grains, have been a traditional staple in India for centuries. However, with the advent of modernization and changing dietary patterns, the consumption of millets has declined. They belong to the Poaceae family and are characterized by their resilience, adaptability, and ability to grow in diverse agro-climatic conditions (Wilson and VanBuren, 2022). Millets have gained considerable attention in recent years due to their nutritional richness, health benefits, and potential for sustainable agriculture. The United Nations General Assembly at its 75th session in March 2021 declared 2023 the International Year of Millets (IYM, 2023).

There are several types of millets, each with its own unique characteristics and culinary uses.

1. Pearl millet (*Pennisetum glaucum*): Popularly known as Bajra, Pearl Millet is one of the most widely cultivated millets in India. Grains are small and round, with a characteristic pale yellow or whitish color. It is rich in protein, fiber, and minerals and is commonly used in porridge, bread, and traditional flatbreads.

2. Finger millet (*Eleusine coracana*): Also known as Ragi or African Millet, Finger Millet is popular in India and Africa. Ragi is regarded as the nutrient powerhouse, providing substantial amounts of dietary fiber, protein, calcium, iron, and antioxidants (Anitha *et al.*, 2021) and is used to make porridge, pancakes, and baked goods.

3. Foxtail millet (*Setaria italica*): Foxtail millet gets its name due to the resemblance of its seedheads to bushy fox tails, is native to China but is now cultivated in many parts of the world. It is gluten-free and used in various dishes such as pilaff, porridge, and desserts. When cooked, foxtail millet exhibits a mild, nutty flavor and a texture similar to rice, used as a substitute for rice in many dishes.

4. Proso millet (*Panicum miliaceum*): Proso Millet, also known as Common Millet or White Millet. With its small, round grain, proso millet is a versatile millet that offers a mildly sweet flavor, primarily grown for bird feed but is also consumed by humans. It is used in the preparation of porridge, soups, and baked goods.

5. Barnyard millet (*Echinochloa esculenta*): Barnyard Millet is a fast-growing millet that is commonly consumed in India and China. It is gluten-free (Bhatt *et al.*, 2022) and used in the preparation of dosa, upma, porridges, and rice dishes.

6. Kodo millet (*Paspalum scrobiculatum*): Kodo Millet is a drought-resistant millet that is mainly grown in India. It is used in the preparation of porridges, pulao (rice dish), and fermented foods.

7. Little millet (*Panicum sumatrense*): Little Millet is a small-grained millet that is widely grown in India and parts of Africa. It is used in the preparation of porridges, upma, and as a substitute for rice in various dishes.

Current status of millet consumption in India:

1. Decline in millet consumption: Over the years, there has been a significant decline in millet consumption in India, primarily due to factors such as urbanization, changing dietary preferences, and limited availability and promotion of millet-based products. This decline has had adverse effects on the overall health and nutrition of the population.

2. Regional variances: Millet consumption varies across different regions of India. Population in some states, such as Karnataka and Andhra Pradesh, have maintained a higher millet consumption level in than others. However, there is a need to promote millet consumption uniformly throughout the country.

Health benefits and physiological role of millets:

1. Nutritional composition:

Millets are abundant in dietary fiber, proteins, vitamins, minerals, and antioxidants making them a nutritious choice (Nithiyanantham *et al.* 2019). Unlike refined grains, millets maintain their bran and germ, qualifying them as whole grains with a high fiber content. The presence of this fiber assists in digestion, regulates blood sugar levels, and reduces the likelihood of cardiovascular diseases. Furthermore, millets are gluten-free, serving as an excellent substitute for individuals with gluten sensitivities or celiac disease.

2. Digestive health:

The high fiber content in millets promotes healthy digestion, prevents constipation, and supports gut health. The presence of resistant starch in millets acts as a prebiotic, nourishing beneficial gut bacteria and contributing to overall gastrointestinal well-being.

3. Diabetes management:

With the rising prevalence of diabetes, adopting a diet that stabilizes blood sugar levels is crucial. Millets, with their low glycemic index, are digested and absorbed slowly, preventing sudden spikes in blood sugar (Anitha *et al.* 2021)). This makes millets an ideal grain for individuals with diabetes or those at risk. Additionally, the complex carbohydrates in millets provide sustained energy, promoting satiety and preventing overeating.

4. Cardiovascular health:

Millets are rich in antioxidants and micronutrients, such as magnesium and potassium, which are beneficial for heart health. Their consumption has been associated with lower blood pressure, reduced risk of heart disease, and improved lipid profiles. Further, their antioxidant constituents combat oxidative stress and reduce inflammation, thereby promoting cardiovascular health.

5. Weight management:

Obesity has become a global health concern, and maintaining a healthy weight is essential for overall well-being. In this context, millets have emerged as a valuable component of a weight management diet. One of the key factors contributing to their effectiveness is their high fiber content, which promotes satiety and reduces calorie consumption. Moreover, millets offer a combination of essential nutrients and low-fat content, making them an ideal choice for maintaining a balanced diet while supporting weight loss or weight maintenance endeavors.

6. Boosts immunity:

A strong immune system is crucial for defending the body against infections and diseases. Millets are rich in various vitamins and minerals like zinc, iron, and vitamin C, which are essential for bolstering the immune system. These nutrients play a crucial role in the production and function of immune cells, enabling the body to effectively combat pathogens. Including millets in one's diet can help strengthen the immune response and promote overall health.

Promoting millet consumption in India:

1. Awareness and education: Creating awareness about the nutritional benefits of millets through nutrition education campaigns and public outreach programs is essential. Informing consumers about easy and innovative ways to incorporate millet into their daily meals can encourage adoption.

2. Product development and diversification: Developing a range of millet-based products, such as millet flours, breakfast cereals, snacks, and bakery items, can increase their accessibility and appeal. Collaboration between food manufacturers, researchers, and the government is crucial in promoting product diversification.

3. Policy support and market linkages: Formulating supportive policies that incentivize farmers to cultivate millets, promoting millet value chains, and creating market linkages.

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SIGNIFICANT ADVANCEMENTS IN AGRICULTURE SCIENCE

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Abstract:

The field of agriculture science has witnessed significant advancements in recent years, driven by the growing need for sustainable food production, resource conservation, and climate change mitigation. One prominent research trend in agriculture science is the integration of precision agriculture techniques. Precision agriculture utilizes advanced technologies such as remote sensing, geographic information systems (GIS), and global positioning systems (GPS) to optimize crop management practices. This approach enables farmers to precisely apply fertilizers, pesticides, and water, leading to increased productivity, reduced environmental impacts, and improved resource efficiency. Another key research area is the development of genetically modified organisms (GMOs) and biotechnology in agriculture. Researchers are exploring genetic engineering techniques to develop crop varieties with enhanced resistance to pests, diseases, and environmental stresses. GMOs offer potential solutions to address food security challenges by improving crop yield and nutritional content, while also reducing the need for chemical inputs. Sustainable agriculture practices are gaining significant attention in current research efforts. Scientists are investigating agro ecological approaches, such as organic farming, agro forestry, and crop rotation, to minimize the use of synthetic inputs and enhance ecosystem services. This research aims to improve soil health, conserve biodiversity, and promote sustainable farming systems that ensure long-term productivity and environmental stewardship. This includes the development of climate-resilient crop varieties, improved irrigation methods, and the promotion of climate-smart agricultural practices that enhance both productivity and climate resilience. Lastly, data-driven and digital technologies are revolutionizing agriculture research. The utilization of big data, machine learning, and Internet of Things (IoT) devices enables real-time monitoring and analysis of agricultural systems. This data-driven approach facilitates decision-making processes, such as precision farming, disease detection, and yield prediction, leading to improved resource management and increased farm efficiency. These research efforts strive to address the challenges faced by the agricultural sector and contribute to the development of sustainable and resilient food systems that can meet the demands of a growing global population while preserving the environment.

Keywords: GIS, GPS, GMOs, IoT, big data, machine learning, Precision agriculture.

Introduction:

In recent years, several research trends have emerged in the field of agricultural science. These trends are driven by the need to address various challenges such as climate change, population growth, food security, and sustainable farming practices. Here are some prominent research trends in agriculture science:

Climate-smart agriculture:

With climate change posing significant threats to agricultural productivity, there is a growing focus on developing climate-smart agricultural practices. This includes the development of drought-tolerant crops, precision agriculture techniques, and the use of remote sensing and data analytics for climate monitoring and prediction.

1. **Climate adaptation:** CSA focuses on building the resilience of agricultural systems to climate change impacts such as droughts, floods, and extreme weather events. It involves the development and adoption of climate-resilient crop varieties, diversification of crops and livestock, and improved water management techniques to cope with changing climate conditions.
2. **Climate mitigation:** CSA seeks to reduce greenhouse gas emissions from agricultural activities. It promotes the adoption of practices that sequester carbon in soils and vegetation, such as agro forestry, conservation agriculture, and cover cropping. Additionally, it encourages the efficient use of resources, including energy and water, to minimize emissions.
3. **Sustainable intensification:** CSA emphasizes the need to increase agricultural productivity sustainably. It promotes the use of precision agriculture technologies, efficient irrigation systems, and optimized nutrient management practices to enhance yields while minimizing resource use and environmental impacts.
4. **Resilient farming systems:** CSA recognizes the importance of integrated farming systems that are resilient to climate variability. It encourages the integration of crops, livestock, and trees to diversify production, enhance ecosystem services, and provide multiple sources of income. This can include practices like agro forestry, silvopastoral systems, and integrated pest management.
5. **Climate information and advisory services:** CSA emphasizes the importance of climate information and advisory services to enable farmers to make informed decisions. Access to timely and accurate weather forecasts, climate projections, and agronomic advice helps farmers adapt their practices and make the most effective use of resources.
6. **Policy and institutional support:** CSA requires supportive policies, institutional frameworks, and financing mechanisms to facilitate its adoption and implementation. Governments, international organizations, and stakeholders need to collaborate in creating enabling environments, providing incentives, and supporting research and extension services.
7. **Knowledge sharing and capacity building:** CSA emphasizes the need for knowledge sharing and capacity building among farmers, researchers, policymakers, and other stakeholders. Training programs, farmer field schools, and knowledge exchange platforms play a crucial role in disseminating best practices, innovations, and lessons learned in climate-smart agriculture.

Climate-smart agriculture represents a holistic and integrated approach to addressing climate change challenges in the agricultural sector. By combining adaptation, mitigation, and sustainable intensification strategies, it aims to enhance the resilience, productivity, and sustainability of farming systems in the face of a changing climate.

Sustainable and organic farming:

There is a strong emphasis on sustainable and organic farming practices that minimize environmental impacts and promote soil health. Researchers are studying agro ecology, integrated pest management, crop rotation, and other practices that reduce the reliance on synthetic fertilizers and pesticides.

1. **Soil health and fertility:** Sustainable and organic farming places a strong emphasis on maintaining and improving soil health. It involves practices such as crop rotation, cover cropping, and the use of organic amendments to enhance soil fertility, structure, and microbial activity. These practices help to reduce soil erosion, increase water holding capacity, and promote long-term sustainability.
2. **Elimination of synthetic inputs:** Organic farming strictly prohibits the use of synthetic pesticides, herbicides, and fertilizers. Instead, it relies on natural methods of pest and weed control, such as crop rotation, biological control, and the use of compost, manure, and other organic fertilizers. This reduces chemical pollution, protects biodiversity, and minimizes the risk of harmful residues in food.
3. **Water conservation and management:** Sustainable and organic farming emphasizes efficient water use and management. Techniques such as drip irrigation, mulching, and agro forestry help to minimize water loss through evaporation and runoff. Additionally, conservation practices such as contour plowing and terracing can help reduce soil erosion and protect water quality.
4. **Animal welfare:** Organic farming standards typically include specific guidelines for the welfare of livestock. These guidelines ensure that animals are raised in humane conditions, have access to outdoor areas, and are fed organic feed. Animal welfare in sustainable and organic farming focuses on providing appropriate living conditions and minimizing stress.
5. **Certification and labeling:** Organic farming is often regulated and requires certification to ensure compliance with specific standards. Certification bodies assess farms and food processors to ensure that they meet the criteria for organic production. This allows consumers to make informed choices and ensures the integrity of organic products in the market.
6. **Local and community-oriented agriculture:** Sustainable and organic farming often promotes local and community-oriented agriculture systems. This involves connecting farmers directly with consumers through farmers' markets, community-supported agriculture (CSA) programs, and farm-to-table initiatives. These systems foster a sense of community, reduce food miles, and support local economies.

Sustainable and organic farming practices strive to minimize environmental impacts, promote biodiversity, and produce healthy and nutritious food. They offer an alternative approach to conventional agriculture by focusing on holistic systems that prioritize long-term sustainability and the well-being of ecosystems, farmers, and consumers (Islam *et, al.*, 2007).

Genetic engineering and biotechnology:

Advances in genetic engineering and biotechnology are being leveraged to improve crop yields, enhance disease and pest resistance, and develop genetically modified organisms (GMOs) with improved traits. Techniques such as gene editing using CRISPR/Cas9 are being explored for precise genetic modifications.

1. **Genetic modification of crops:** Genetic engineering allows scientists to introduce specific genes into the DNA of crop plants to confer desired traits. This includes traits such as improved yield, enhanced nutritional content, resistance to pests, diseases, or herbicides, and tolerance to environmental stresses like drought or salinity. Genetically modified (GM) crops, also known as genetically engineered (GE) crops, have been developed for various purposes, such as insect resistance (e.g., Bt crops) and herbicide tolerance (e.g., glyphosate-resistant crops).
2. **Precision breeding:** Genetic engineering techniques enable precise and targeted modifications in the genetic makeup of crops, speeding up the breeding process compared to traditional methods. Techniques like gene editing, using tools like CRISPR-Cas9, allow researchers to make specific changes in the DNA sequence of a plant without introducing genes from other organisms. This precise breeding approach can help accelerate the development of new crop varieties with desired traits.
3. **Disease and pest resistance:** Genetic engineering has played a crucial role in developing crops with enhanced resistance to pests and diseases. For example, genetic modifications have been introduced in crops to produce toxins that are toxic to specific pests, reducing the need for synthetic pesticides. This approach, seen in BT crops, has demonstrated effective pest control while minimizing environmental harm.
4. **Improved nutritional content:** Biotechnology has been employed to enhance the nutritional value of crops, addressing deficiencies in essential nutrients in certain regions. This includes biofortification, where crops are genetically modified to have increased levels of vitamins, minerals, or other essential nutrients, helping to combat nutrient deficiencies and improve human health.
5. **Livestock improvement:** Genetic engineering techniques have been applied to livestock breeding as well. This includes the development of transgenic animals with desirable traits, such as increased disease resistance, improved growth rates, or enhanced milk production. Additionally, biotechnology is used in assisted reproductive technologies, such as embryo transfer and in vitro fertilization, to improve breeding efficiency and preserve valuable genetic traits.
6. **Biopharmaceutical production:** Genetic engineering allows for the production of valuable pharmaceutical and industrial compounds in plants or animals. This approach, known as molecular farming or biopharming, utilizes genetically modified organisms to

produce proteins, vaccines, antibodies, and other high-value products. Plants like tobacco and crops like corn have been used to produce pharmaceutical proteins.

7. **Environmental sustainability:** Genetic engineering and biotechnology can contribute to environmental sustainability in agriculture. By developing crops with increased resistance to pests and diseases, farmers can reduce the reliance on synthetic pesticides and fungicides, leading to reduced chemical inputs and minimized environmental impacts. Additionally, genetically modified crops can be engineered to tolerate specific herbicides, allowing for more targeted and efficient weed control.
8. **Regulatory frameworks:** The use of genetic engineering and biotechnology in agriculture is subject to strict regulations and oversight in many countries. Regulatory frameworks assess the safety, environmental impact, and potential risks associated with genetically modified organisms (GMOs) and ensure that they meet established criteria before commercial release.

Genetic engineering and biotechnology have transformed agriculture by providing tools for precise and targeted crop improvement, enhancing crop productivity, improving nutritional content, and reducing environmental impacts. However, debates surrounding GMOs and their potential effects on human health, ecosystems, and socio-economic factors continue to shape the ongoing discussion about the use and regulation of these technologies in agriculture (Singh *e, al.*, 2006).

Precision agriculture:

Precision agriculture involves the use of technology such as sensors, drones, satellite imagery, and GPS to optimize farming practices. It enables farmers to make data-driven decisions regarding irrigation, fertilization, and crop protection, resulting in improved efficiency and resource management.

1. **Precision planting:** Precision agriculture enables farmers to precisely plant crops at optimal spacing and depth, ensuring uniformity and maximizing yields. GPS-guided planting equipment helps maintain accurate row spacing and seed placement, reducing input wastage and promoting even crop emergence.
2. **Variable rate application:** Precision agriculture allows for variable rate application of fertilizers, pesticides, and irrigation based on site-specific needs. By mapping variations in soil properties, nutrient levels, or pest infestations, farmers can apply inputs at customized rates, optimizing resource use and minimizing environmental impacts.
3. **Remote sensing and imaging:** Remote sensing technologies, such as aerial or satellite imagery can provide valuable information about crop health, water stress, and nutrient deficiencies. By analyzing these images, farmers can detect problem areas in their fields and take corrective actions, such as targeted irrigation or fertilization, thereby improving overall crop performance.
4. **Soil and yield mapping:** Precision agriculture utilizes soil sampling and analysis to create detailed soil maps, identifying variations in soil properties and nutrient levels across a field. Yield monitoring systems coupled with GPS allow farmers to map crop yields,

providing insights into productivity variations and helping optimize management practices for different areas.

5. **Data-driven decision-making:** Precision agriculture relies on data collection and analysis to support decision-making. Farmers can integrate data from multiple sources, such as soil sensors, weather stations, and machinery, to gain a comprehensive understanding of field conditions. Data analytics tools help identify patterns, trends, and correlations, enabling informed decisions regarding planting, irrigation, fertilization, and pest management.
6. **Automated machinery and robotics:** Precision agriculture involves the use of automated machinery and robotics for various tasks. This includes autonomous tractors, robotic weeders, and drones equipped with sensors for data collection. Automation improves efficiency, reduces labor requirements, and allows for precise operations in the field.
7. **Farm management software:** Precision agriculture utilizes farm management software systems that integrate data, facilitate decision-making, and provide real-time monitoring and control. These software platforms enable farmers to manage and analyze data, track resources, plan activities, and optimize inputs for improved productivity and profitability.
8. **Sustainability and resource efficiency:** Precision agriculture promotes sustainable farming practices by optimizing resource use and minimizing waste. By applying inputs only where and when they are needed, farmers can reduce fertilizer and pesticide runoff, limits water usage, and minimizes environmental impacts. This approach enhances resource efficiency and reduces the ecological footprint of agriculture (Kademani *et al.*, 2007).

Big data and analytics:

The agriculture sector is increasingly adopting big data analytics to improve decision-making and optimize farm management. By collecting and analyzing large datasets related to weather patterns, soil conditions, crop growth, and market trends, researchers can develop models and tools that assist farmers in maximizing productivity and profitability.

1. **Data collection:** Agriculture generates a massive amount of data from multiple sources. This includes information on weather patterns, soil conditions, crop health, yield data, machinery performance, and market trends. Advanced technologies, such as sensors, drones, and satellite imagery, enable the collection of real-time and high-resolution data across large areas.
2. **Data integration and management:** Big data in agriculture often comes from heterogeneous sources and in various formats. Integrating and managing this data in a centralized system is essential for effective analysis. Data management tools and platforms help aggregate, organize, and store data, making it accessible for analysis and decision-making.
3. **Predictive analytics:** Big data analytics enables predictive modeling and forecasting in agriculture. By analyzing historical and real-time data, predictive models can be developed to forecast crop yields, identify disease outbreaks, predict weather patterns, optimize

irrigation schedules, and estimate market demands. This helps farmers make informed decisions and plan their operations more efficiently.

4. **Crop monitoring and management:** Big data analytics allows for real-time monitoring of crop conditions and growth. By analyzing sensor data, satellite imagery, and weather information, farmers can detect early signs of stress, diseases, or nutrient deficiencies in crops. This enables timely interventions and targeted management practices, such as precision irrigation and fertilization, to optimize crop health and yields.
5. **Market analysis and decision-making:** Big data analytics helps farmers and agricultural businesses gain insights into market trends, consumer preferences, and supply chain dynamics. By analyzing market data, including pricing, demand patterns, and competition, farmers can make informed decisions about crop selection, production planning, and marketing strategies.
6. **Disease and pest management:** Big data analytics can assist in early detection and management of crop diseases and pests. By analyzing historical and real-time data on pest populations, weather conditions, and crop phenology, predictive models can be developed to identify potential disease outbreaks and optimize the timing of pest control interventions. This can reduce the need for broad-spectrum pesticide applications and minimize environmental impacts.
7. **Farm efficiency and optimization:** Big data analytics helps improve overall farm efficiency and optimization. By analyzing machinery data, such as fuel consumption, equipment performance, and maintenance records, farmers can identify areas for improvement, schedule maintenance tasks proactively, and optimize machinery operations. This leads to cost savings, reduced downtime, and increased productivity.

Big data and analytics offer significant opportunities for data-driven decision-making, increased productivity, and improved sustainability in agriculture. By harnessing the power of data, farmers and agricultural businesses can gain valuable insights, optimize resource allocation, enhance crop management practices, and make informed decisions for more efficient and sustainable agricultural operations.

Vertical farming and urban agriculture:

With urbanization and limited arable land, there is a growing interest in vertical farming and urban agriculture. These approaches involve growing crops in vertically stacked layers or within urban environments using hydroponics, aquaponics, or other controlled environment systems.

1. **Vertical farming systems:** Vertical farming utilizes indoor environments, such as multi-level structures or repurposed buildings, to grow crops vertically. These systems often employ hydroponics, aeroponics, or aquaponics, which are soilless cultivation methods. Artificial lighting, temperature control, and precise nutrient delivery systems are used to create optimal growing conditions. Vertical farming allows for year-round production, independent of climate and weather conditions.

2. **Efficient space utilization:** Vertical farming maximizes land use by utilizing vertical space, making it suitable for urban areas with limited available land. By growing crops in vertical layers, the production capacity per unit area can be significantly increased compared to traditional horizontal farming methods. This enables higher yields and the potential for local food production in densely populated cities.
3. **Resource efficiency:** Vertical farming systems are designed to optimize resource efficiency. Water usage is minimized through recycling and recalculating irrigation systems. Controlled environments reduce the need for pesticides and herbicides, and precise nutrient delivery systems minimize fertilizer use. Additionally, vertical farming systems can be designed to utilize energy-efficient LED lighting and advanced climate control technologies, reducing energy consumption.
4. **Local food production:** Urban agriculture, including vertical farming, promotes local food production, reducing the need for long-distance transportation and associated carbon emissions. By growing food closer to consumers, urban agriculture can enhance food security, improve freshness, and support local economies.
5. **Food safety and traceability:** Vertical farming systems offer enhanced food safety and traceability. With controlled environments and reduced exposure to external contaminants, the risk of crop contamination from pathogens or chemicals is minimized. Additionally, the controlled and monitored production process allows for better traceability of food from farm to table.
6. **Community engagement and education:** Urban agriculture projects, including vertical farming, often engage local communities, providing opportunities for education, skills development, and community involvement. They can serve as platforms for urban gardening initiatives, school programs, and social enterprises that promote food literacy and sustainability.
7. **Green building integration:** Vertical farming can be integrated with green building design principles, utilizing underutilized spaces or incorporating living walls and rooftop gardens. This integration enhances building aesthetics, improves indoor air quality, and provides additional ecosystem services such as urban heat island reduction and storm water management.
8. **Potential challenges:** Vertical farming and urban agriculture face challenges such as high initial investment costs, energy requirements for artificial lighting and climate control, and technical expertise for efficient operation. Additionally, crop selection and optimization, pest management, and achieving economic viability are areas that require careful consideration and ongoing research.

Vertical farming and urban agriculture hold promise for sustainable food production in urban areas. By maximizing space utilization, resource efficiency, and community engagement, these approaches contribute to local food resilience, reduce environmental impacts, and promote a closer connection between urban dwellers and their food sources.

Agro forestry and sustainable land management:

Agro forestry integrates trees and shrubs into agricultural landscapes to provide multiple benefits, such as improving soil fertility, enhancing biodiversity, and sequestering carbon. Research in this area focuses on identifying suitable agro forestry systems and their impact on ecosystem services.

1. **Multiple benefits:** Agro forestry systems offer a range of benefits compared to conventional agriculture or monoculture forestry. These systems provide multiple products and services, such as food, fuel wood, timber, fiber, fodder, and ecosystem services like soil conservation, water regulation, biodiversity conservation, and climate change mitigation.
2. **Soil conservation and improvement:** Agro forestry practices help prevent soil erosion by providing vegetative cover and reducing the impact of wind and water. Tree roots stabilize the soil, preventing nutrient leaching and improving soil structure. The leaf litter from trees contributes organic matter, enhancing soil fertility and moisture retention.
3. **Biodiversity conservation:** Agro forestry systems promote biodiversity by creating habitats for a variety of plant and animal species. The diverse vegetation structure and plant species composition in agro forestry systems provide niches for a wide range of organisms, including pollinators, birds, beneficial insects, and soil microorganisms.
4. **Climate change mitigation:** Agro forestry plays a role in mitigating climate change by sequestering carbon dioxide (CO2) from the atmosphere. Trees in agro forestry systems absorb and store carbon, reducing greenhouse gas emissions and contributing to carbon sinks. Additionally, the presence of trees can modify microclimates, reducing temperature extremes and wind speeds, and thus improving crop productivity.
5. **Water management:** Agro forestry systems help manage water resources by reducing water runoff and improving water infiltration. Trees intercept rainfall, reducing soil erosion and surface runoff. Their deep root systems facilitate water absorption and increase water storage capacity in the soil, contributing to improved water availability for crops and reducing the risk of drought.
6. **Economic diversification and resilience:** Agro forestry systems provide economic diversification by integrating multiple products and income streams. Farmers can benefit from selling timber, fruits, nuts, and other tree products, in addition to agricultural crops or livestock. The combination of multiple income sources enhances the resilience of farming systems to market fluctuations and environmental stresses.
7. **Nutrient cycling and agro ecosystem productivity:** Agro forestry systems promote nutrient cycling and enhance overall productivity. Trees with deep root systems can access nutrients from deeper soil layers, making them available to crops. The diverse plant species in agro forestry systems contribute to nutrient cycling through symbiotic nitrogen fixation, nutrient uptake, and cycling processes.

Agro forestry and sustainable land management offer a holistic approach to land use, integrating trees, crops, and livestock to achieve multiple benefits. These systems contribute to environmental sustainability, biodiversity conservation, climate change mitigation, and socio-economic resilience. They provide a pathway towards more resilient and productive agricultural systems that support both human livelihoods and the health of ecosystems (Mondal *et al.,* 2004).

Digital agriculture and farm automation:

Digital technologies are transforming agriculture through automation, robotics, and artificial intelligence. Researchers are exploring the development of smart farming systems, autonomous machinery, and farm management software to streamline operations, reduce labor requirements, and enhance productivity.

1. **Precision farming:** Digital agriculture enables precision farming practices, where farmers can make data-driven decisions based on detailed information about soil conditions, weather patterns, and crop health. Sensors and remote sensing technologies provide real-time data on variables such as soil moisture, nutrient levels, and pest infestations. This information helps optimize the application of inputs like fertilizers, pesticides, and water, reducing waste and maximizing yields.
2. **Internet of Things (IoT) and sensors:** IoT devices and sensors are deployed across farms to collect and transmit data from various sources, including soil, plants, and machinery. These sensors provide information on temperature, humidity, light intensity, plant growth, equipment performance, and more. The data is sent to a central system for analysis, allowing farmers to monitor and manage farm operations remotely and in real-time.
3. **Data analytics and farm management software:** Digital agriculture relies on data analytics and farm management software to process and analyze the vast amounts of data collected from sensors and other sources. Advanced analytics tools and algorithms help identify patterns, trends, and correlations in the data, enabling farmers to make informed decisions about crop management, resource allocation, and risk assessment.
4. **Farm automation and robotics:** Robotics and automation technologies are increasingly being used in agriculture to streamline labor-intensive tasks. Robots can perform activities like planting, harvesting, pruning, and weed control with high precision and efficiency. Automated systems can also manage irrigation, monitor livestock, and control environmental conditions in livestock or greenhouse operations. This reduces labor requirements, improves productivity, and enhances operational efficiency.
5. **Drones and aerial imaging:** Drones equipped with cameras or sensors provide aerial imaging and data collection capabilities. They can capture high-resolution imagery of crops, identify problem areas, and monitor crop health. Drones enable rapid and cost-effective field assessments, allowing farmers to detect issues such as nutrient deficiencies, disease outbreaks, or irrigation problems early on.
6. **Smart farming equipment:** Digital agriculture incorporates smart farming equipment that utilizes technology for improved efficiency and accuracy. This includes GPS-guided tractors and implements, which enable precise positioning, mapping, and variable rate application of inputs. Smart equipment can optimize fuel consumption, reduce overlap, and enhance overall operational efficiency. **(Rajput T.B.S, *et,al.,* 2006)**

7. **Connectivity and cloud computing:** Digital agriculture relies on reliable connectivity and cloud computing infrastructure to transmit and store data securely. Cloud-based platforms allow farmers to access and manage data, collaborate with experts, and integrate various technologies and software systems. This connectivity facilitates real-time decision-making and enables remote monitoring and control of farm operations.
8. **Sustainability and resource optimization:** Digital agriculture contributes to sustainability by optimizing resource use and reducing environmental impacts. By employing precision farming techniques and automation, farmers can minimize the use of water, fertilizers, and pesticides, reducing waste and runoff. Data-driven decision-making enables more efficient use of resources, improving productivity while minimizing inputs and environmental harm.

Digital agriculture and farm automation offer significant potential for increasing efficiency, productivity, and sustainability in agriculture. By leveraging technology and data-driven insights, farmers can optimize their operations, reduce costs, and enhance environmental stewardship. These approaches enable the development of smarter and more resilient farming systems to meet the challenges of food security and sustainability in the future (Kaur *et al.*, 2014).

Food safety and traceability:

Ensuring food safety and traceability is crucial for consumer confidence. Research efforts are directed towards developing technologies and systems that enable real-time monitoring, rapid detection of contaminants, and accurate traceability of food products throughout the supply chain.

1. **Hazard identification and risk assessment:** Food safety begins with identifying and assessing potential hazards that can occur at various stages of the food production process, including production, processing, storage, distribution, and handling. Hazards may include biological contaminants (such as bacteria or viruses), chemical residues, allergens, or physical contaminants. Conducting risk assessments helps prioritize actions to mitigate these hazards.
2. **Good Agricultural Practices (GAPs):** Good Agricultural Practices encompass a set of guidelines and practices that promote safe and sustainable crop production. This includes appropriate use of fertilizers and pesticides, proper irrigation and water management, hygiene practices, and preventive measures to minimize microbial contamination. GAPs aim to ensure the safety and quality of agricultural products from the earliest stages of production.
3. **Good Manufacturing Practices (GMPs):** Good Manufacturing Practices focus on ensuring the safety and quality of processed food products. They involve proper hygiene practices, employee training, sanitation procedures, facility design, equipment maintenance, and process control to minimize risks of contamination, cross-contamination, and adulteration during processing and packaging.
4. **Hazard Analysis and Critical Control Points (HACCP):** HACCP is a systematic approach used in the food industry to identify and control hazards at critical points in the production process. It involves identifying critical control points, establishing critical

limits, monitoring procedures, corrective actions, and verification to ensure that potential hazards are effectively controlled. HACCP is widely recognized as an effective preventive approach for ensuring food safety.

5. **Quality control and testing:** Quality control measures involve regular testing and monitoring of food products to ensure compliance with safety and quality standards. This includes microbiological testing, chemical analysis, and sensory evaluation to detect potential contaminants, adulterants, or quality deviations. Testing helps identify issues early on and enables appropriate actions to be taken to prevent unsafe or substandard products from reaching consumers.
6. **Food labeling and product information:** Accurate and informative food labeling is essential for consumer awareness and choice. Proper labeling provides information on ingredients, allergens, nutritional content, country of origin, and storage instructions. It also includes the use of appropriate labeling standards and regulatory requirements to prevent misrepresentation, mislabeling, or fraudulent activities.
7. **Traceability systems:** Traceability involves the ability to track the movement of food products and their ingredients throughout the supply chain. It enables the identification of the origin, production, processing, and distribution history of a particular food item. Traceability systems utilize various tools, such as batch numbers, barcodes, QR codes, or RFID tags, to record and track information. This enables rapid and accurate tracing of food products in the event of a safety or quality issue, facilitating timely recalls and preventing potential harm to consumers.
8. **Regulatory compliance and certification:** Food safety regulations and certifications play a crucial role in ensuring compliance with standards and best practices. Governments establish regulatory frameworks and enforce standards to protect consumer health and safety. Certifications, such as Global Food Safety Initiative (GFSI) recognized schemes, provide independent verification of compliance with specific food safety standards, enhancing consumer confidence and market access.

Food safety and traceability are essential components of a robust food system that prioritize consumer health and confidence. By implementing comprehensive food safety management systems, adhering to best practices, and ensuring effective traceability, stakeholders throughout the food supply chain can mitigate risks, prevent food borne illnesses, and maintain the integrity of food products from farm to fork (Sagar *et al.,* 2009).

Agricultural waste management:

Proper management of agricultural waste is essential for environmental sustainability. Research is focused on finding innovative ways to convert agricultural residues into biofuels, bioplastics, and other value-added products, as well as developing efficient waste management practices to minimize environmental pollution.

These research trends reflect the growing need for sustainable, efficient, and resilient agricultural systems in the face of evolving global challenges. By leveraging scientific advancements and interdisciplinary approaches, researchers aim to enhance food production while minimizing the environmental footprint of agriculture.

1. **Waste reduction and prevention:** The first step in agricultural waste management is to focus on waste reduction and prevention. This can be achieved through improved farm management practices, such as precision farming techniques, efficient use of fertilizers and pesticides, and proper inventory management of agricultural inputs. By minimizing waste generation at the source, the need for subsequent waste management and disposal is reduced.
2. **Composting:** Composting is a widely used technique for managing organic agricultural waste, such as crop residues and animal manure. It involves the controlled decomposition of organic materials under aerobic conditions to produce compost, a nutrient-rich soil amendment. Composting not only reduces waste volumes but also produces a valuable product that can enhance soil fertility, improve water retention, and promote sustainable crop production.
3. **Anaerobic digestion:** Anaerobic digestion is a process that converts organic waste, such as animal manure, into biogas and dig estate. Biogas, primarily composed of methane, can be used as a renewable energy source for heating, electricity generation, or fuel. The dig estate, a by-product of the process, can be used as a nutrient-rich fertilizer. Anaerobic digestion helps reduce greenhouse gas emissions from waste decomposition and provides an alternative energy source.
4. **Recycling and reuse:** Agricultural waste materials can often be recycled or reused in various ways. For example, crop residues can be used as animal feed, bedding, or mulch. Packaging materials can be recycled or repurposed. Agrochemical containers can be cleaned, recycled, or disposed of properly to prevent environmental contamination. Finding innovative ways to reuse or recycle agricultural waste can reduce the need for disposal and conserve resources.
5. **Biomass utilization:** Agricultural waste, particularly crop residues, can be utilized as biomass for energy generation. Biomass can be converted into solid biofuels, such as pellets or briquettes, which can be used for heating or cooking. It can also be used in bio energy production processes, such as bio ethanol or biogas production. Biomass utilization provides an alternative to fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable energy sources.
6. **Waste-to-value approaches:** Agricultural waste management can involve exploring waste-to-value approaches, where waste materials are transformed into valuable products. For example, crop residues can be processed into bio-based materials, such as bio-plastics or bio-composites, for various applications. By extracting value from waste, these approaches contribute to a circular economy and promote sustainability.
7. **Regulatory compliance and best practices:** Agricultural waste management should comply with relevant regulations and best practices to protect human health and the environment. Governments may establish guidelines and standards for waste handling,

storage, transportation, and disposal. Adhering to these regulations ensures safe and responsible waste management practices, preventing environmental contamination and potential health risks.

8. **Education and awareness:** Promoting education and awareness among farmers, agricultural workers, and the public is crucial for effective agricultural waste management. Training programs and outreach activities can raise awareness about proper waste management practices, promote the adoption of sustainable waste management technologies, and encourage behavioral changes. Enhancing knowledge and understanding of agricultural waste management fosters a culture of environmental stewardship in the agricultural community.

Proper agricultural waste management is essential for sustainable agriculture, environmental protection, and resource conservation. By implementing effective waste reduction strategies, utilizing waste as a resource, and adopting appropriate waste management technologies, the agricultural sector can contribute to a more circular and sustainable economy (Anonymous. GIS 2002).

Conclusion:

In conclusion, the field of agriculture science is witnessing dynamic research trends that are aimed at addressing the challenges faced by the agricultural sector and promoting sustainable food production systems. Key conclusions drawn from the research trends include:

1. Precision agriculture techniques are playing a vital role in optimizing crop management practices, improving resource efficiency, and minimizing environmental impacts.
2. Genetically modified organisms (GMOs) and biotechnology offer potential solutions to enhance crop productivity, improve nutritional content, and mitigate the impact of pests, diseases, and environmental stresses.
3. Sustainable agriculture practices, such as organic farming and agro ecology, are gaining recognition for their ability to conserve natural resources, promote biodiversity, and ensure long-term productivity while minimizing the use of synthetic inputs.
4. Climate change mitigation and adaptation strategies are crucial in developing climate-resilient agricultural systems. Efforts are focused on developing climate-smart practices, resilient crop varieties, and innovative irrigation methods to address the challenges posed by a changing climate.
5. The integration of data-driven and digital technologies, such as big data, machine learning, and IoT devices, is revolutionizing agriculture research and enabling real-time monitoring, decision-making, and resource management for increased farm efficiency.

Overall, these research trends in agriculture science demonstrate a strong emphasis on sustainable practices, resource optimization, resilience to climate change, and the application of cutting-edge technologies. These efforts are vital for ensuring food security, environmental sustainability, and the well-being of farmers and consumers in an ever-evolving agricultural landscape.

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SYSTEMIC ACQUIRED RESISTANCE

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Introduction:

In 1901, Beauverie and Ray independently realized that plants previously infected by a pathogen could better resist further infection. Over the 30 years that followed these reports, many studies suggested the existence of various induced disease resistance phenomena in plants. These have been summarized by Chester in 1933. One prominent induced resistance phenomenon is nowadays known as systemic acquired resistance (SAR). SAR refers to a distinct signal transduction pathway that plays an important role in the ability of plants to defend themselves against pathogens. SAR is induced by most pathogens that cause tissue necrosis, either as a part of a hypersensitive response (HR) or as a symptom of disease. One characteristic of SAR is the development of the enhanced resistance in the distal, uninoculated plant organs. Another hallmark of SAR is its activity against a broad and distinctive spectrum of pathogens which includes viruses, bacteria, oomycetes, and fungi. It can be induced by plant pathogens, chemicals and bio-agents and not induced after the onset of flowering & fruiting in host plant. In addition, SAR confers a long-lasting protection against a broad spectrum of microorganisms that can last for weeks to month, and sometimes throughout an entire season. SAR requires the signal molecule salicylic acid (SA) and is associated with accumulation of pathogenesis-related proteins, which are thought to contribute to resistance. SA is apparently not the translocated signal but is involved in transducing the signal in target tissues.

Mechanism involved in systemic acquired resistance

1. Lignifications and other structural barriers
2. Pathogenesis Related proteins
3. Conditioning

1. Lignifications and other structural barriers

Deposition of lignin in cell wall is called as lignification. It observed in many plants. It is an important mechanism for disease resistance. Lignin incorporation strengthen plant mechanically. Lignified cell starved the pathogen and act as pre cursors may might exert toxic effect. Mycelia of *Colletotrichum lagenarium* become lignified *in vitro*. Glycine rich proteins accumulate systemically in cell wall of tobacco plants infected with TMV and virus infected rice plants.

2. Pathogenesis related proteins

Pathogenesis related protein (PRs) were first described in 1970 in tobacco leaves infected with TMV. PRs proteins have been defined as plant proteins that accumulate after pathogen attack or related situation. PRs proteins are assigned an important role in plant defense against pathogenic constraints and in general adaptation to stressful environment. These proteins are accumulated 7-10 days after infection and indicate the attainment of SAR. It is accumulated in the intercellular spaces (first line of defence) and vacuole (second line of defence by lytic enzyme).

Biochemical and structural characteristics of PR Proteins

- It is a low-molecular proteins (5-75 kDa).
- It stable at low pH (< 3).
- It is thermostable & Highly resistant to proteases.
- It contains four α-helices and β-strands arranged antiparallel between helices.
- It established in all plant organs – leaves, stems, roots, flowers.
- Feature: Antifungal, Antibacterial, Insecticidal & Antiviral action.

Classification and properties of families of PR proteins

Family	Properties	Targeted Pathogen Site
PR-1	Antifungal	Active against Oomycetes
PR-2	β-1,3-Glucanase	Cell wall Glucan of fungi
PR-3	Chitinase (class I,II, IV,V,VI,VI)	Cell wall Chitin of fungi
PR-4	Chitinase class I,II	Cell wall Chitin of fungi
PR-5	Thaumatin-like,	Active against Oomycetes
PR-6	Proteinase-inhibitor	Active on Nematodes + Insect
PR-7	Endoproteinase	Microbial cell wall dissolution
PR-8	Chitinase class III	Cell wall Chitin of fungi + Mucopeptide wall of bacteria
PR-9	Peroxidase	Antimicrobial activity by catalyzing oxidative cross-linking protein and phenolic in cell wall leading to reinforcement of physical barrier
PR-10	Ribonuclease activity	Viral-RNA
PR-11	Chitinase class I	Cell wall chitin of fungi
PR-12	Defensin	Antifungal and Antibacterial
PR-13	Thionin	Antifungal and Antibacterial
PR-14	Lipid-transfer protein	Antifungal and Antibacterial
PR-15	Oxalate oxidase	Produce H_2O_2 that inhibite microbes and also stimulates host defense
PR-16	Oxalate oxidase-like	Produce H_2O_2 that inhibite microbes and also stimulates host defense
PR-17	Uncharacterized	Unknown

3. Conditioning

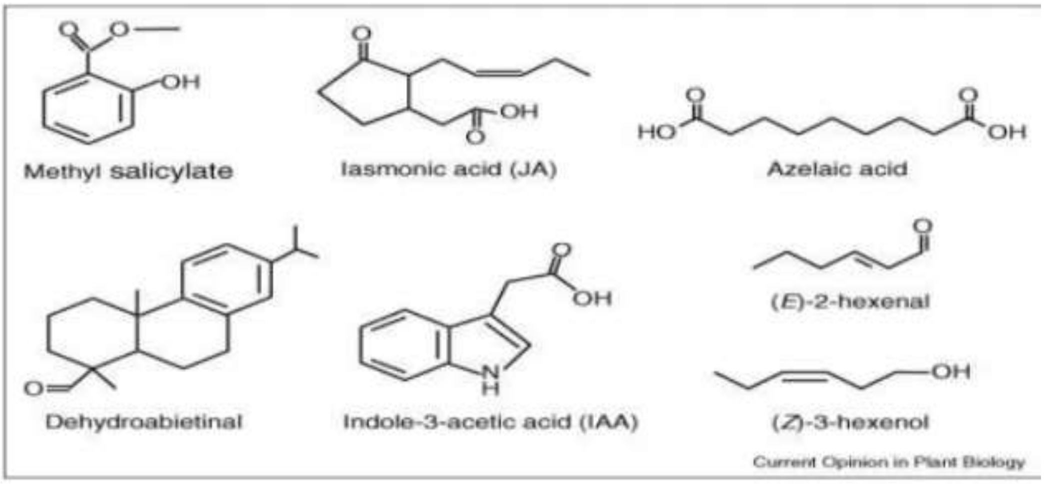
When plants are pretreated with necrotizing pathogen or a synthetic inducer of SAR, the systemically protected leaves react more rapidly and more efficiently to challenge infection with a virulent pathogen. This phenomenon is known as conditioning or sensitizing. Skipp and Daverall (1973) induced resistance in bean hypocotyls though localized HR caused by *Colletotrichum lindemathianum*.

Signal transduction in SAR

A primary local infection can trigger not only effector-triggered immunity (ETI), which is often associated with programmed cell death (PCD) of the infected cells, but also production of the immune signal salicylic acid (SA) in chloroplasts through the activity of isochorismate synthase ICS1. Mobile immune signals are also produced, including azelaic acid (AzA), glycerol-3-phosphate (G3P), methyl salicylic acid (MeSA), and dehydroabietinal amines (DA). AzA regulates the expression of *AZI1*, which encodes a predicted secreted protease-inhibitor/seed-storage/lipid-transfer family protein, and AzA, G3P, and DA all require DIR1, a putative lipid- transfer protein, for their functions. Accumulation of SA affects the cellular redox and the NPR1 nuclear translocation through S-nitrosoglutathione (GSNO) and thioredoxins (TRXs). The nuclear NPR1 concentration is controlled by SA levels through the SA receptor proteins NPR3 and NPR4. A high concentration of SA in the local infection site promotes NPR1-NPR3 interaction and NPR1 degradation to allow PCD and ETI to occur, whereas in the neighboring cells, the intermediate level of SA disrupts NPR1-NPR4 interaction, resulting in the accumulation of NPR1. NPR1 can interact with transcription factors (TFs) to activate the expression of *ER* genes to facilitate protein secretion; the expression of antimicrobial PR proteins such as PR1, PR2, and PR5; and resistance to secondary infection.

The SAR primed state is associated with acetylation (Ac) of H3K9 and methylation (Me) of H3K4 at SAR-associated gene promoters. DNA methylation and proteins affecting chromatin architecture (e.g., SNI1) and DNA repair (e.g., RAD51 and BRCA2) may function in priming plant defense genes and protecting genome stability not only in the current generation but also in the progeny. An avirulent pathogen not only triggers defense responses locally but also induces the production of signals such as salicylic acid (SA), methyl salicylic acid (MeSA), azelaic acid (AzA), glycerol-3-phosphate (G3P), and abietane diterpenoid dehydroabietinal (DA). These signals then lead to systemic expression of the antimicrobial *PR* (*pathogenesis-related*) genes in the un inoculated distal tissue to protect the rest of the plant from secondary infection. This phenomenon is called systemic acquired resistance (SAR). SAR can also be induced by exogenous application of the defense hormone SA or its synthetic analogs 2,6-dichloroisonicotinic acid (INA) and benzothiadiazole S- methyl ester (BTH) . In contrast to ETI, SAR is not associated with PCD, and instead promotes cell survival. The onset of SAR is associated with massive transcriptional reprogramming, which is dependent on the transcription cofactor NPR1 (nonexpresser of *PR* genes 1) and its associated transcription factors (TFs) such as TGAs . SAR is believed to be conferred by a battery of coordinately induced antimicrobial PR proteins whose secretion requires significant enhancement of endoplasmic reticulum (ER) function.

Systemic signals in SAR for plant defense



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These mobile signals help in activation of SAR. Mostly metabolites function as systemic signal, contributing to long distance signaling in plant defense.

Methyl Salicylate (MeSA)

It is a mobile signal, moves systemically, found in phloem exudates of infected leaves, and is required for SAR. SAR requires SABP2's MeSA esterase activity in the systemic tissue to convert biologically inactive MeSA to active SA. (SABP2'S = Receptor in systemic tissue)

Nicotiana tabaccum contains N resistance gene that governs gene –for – gene type resistance to TMV, MeSA functions as enhance the resistance to subsequent infection by TMV.

Jasmonic acid

Jasmonic acid activates gene encoding protease inhibitor which protect plants against insect attack. Oxylipns, synthesized from polyunsaturated fatty acid. Methyl jasmonate (MJ) function as volatile signal and also translocated through the vasculature. Treatment of potato with jasmonate increase resistance to *Phytophthora infestans.*

Azelaic acid

It is a nine–carbon dicaboxylic acid. Pathogen infection induces the release of free carbon 18 fatty acids (C18 FA) from membrane lipids, these results in azelaic acid (AzA) production. *AZI1 (AZELAIC ACID INDUCED1)* gene, which is expressed at elevated level in azelaic acid-treated plant, was required for defence priming by azelaic acid.

Salicylic acid (SA)

SA/ orthohydroxy benzoic acid group of phenolics. SAR- endogenous signal produced by infected leaf and translocate in the phloem to other plant parts. Vascular mobile signal that moves throughout the plant after initial infection. It is reported in several plant species *i.e.*, Tomato, Potato, Rice, Sugarcane, Okra, Wheat, Carrot, Tobacco, Bean and Papaya. Salicylate regulated defenses more active against biotropic pathogens. Salicylic acid is part of signaling pathway involved in transmission of the defense response throughout the plant to produce SAR. SA reported as the endogenously as well as exogenously signal of SAR. SA play role in elicitation of Pathogenesis-Related proteins.

The mode of action of SA

The search for a SA-binding protein has led to catalase and ascorbate peroxidase. The binding of SA to such enzymes might lead to the formation of a phenolic radical that in turn is involved in lipid peroxidation. The products of lipid peroxidation can activate defense gene expression. Whether such radicals form sufficient lipid peroxides at the right time and place for the defense response to be induced remains to be shown. SA-binding proteins (SAPs) different from catalase were identified that show a higher affinity for SA and related functional analogues. The biological importance of these SAPs remains to be determined, but they certainly offer exciting perspectives toward an understanding of SA. The induction of gene transcription by SA was also followed closely.

SA- and pathogen-inducible protein kinase (SIPK) belonging to the MAP kinase family was identified in tobacco. A number of studies have concentrated on the upstream regulatory sequences (URS) of the PR- 1 gene promoter, one of the culminating responses in SAR. A consensus sequence (TGACG) in the URS of PR-1 is recognized specifically by TGA transcription factors of the bZIP protein family. TGAs were also found to interact with the NPR1 protein, providing a direct link between NPR1 and SA-induced PR-1 expression. SNI1, a negative regulator of SAR represses *PR* gene expression, presumably by direct binding to a specific DNA sequence or via a transcription. Other reports have identified a SA- and pathogen-inducible WRKY DNA-binding factor. This factor specifically recognizes the elicitor response element of the tobacco class I chitinase promoter. Protein phosphorylation is important for the activity of WRKY DNA-binding factors; this emphasizes the role played by kinases in SA-signaling.

Salicylic acid biosynthesis

Genetic studies in Arabidopsis have shown that SA is synthesized mainly through the pathway involving ICS1. Biochemically, SA can also be synthesized from cinnamate produced by phenylalanine ammonia lyase (PAL) but this pathway seems to play a minor role in SAR-associated SA synthesis. The chorismate pathway has similarities to the bacterial SA-biosynthesis pathway:

1. ICS1 converts chorismate to isochorismate
2. SA is generated from isochorismate catalyzed by isochorismate pyruvate lyase (IPL) .

Proteins whose roles in SA synthesis have been proposed but not specifically confirmed:

EDS5 (enhanced disease susceptibility 5)- hypothesized to be involved in transporting SA or a precursor of SA . PBS3 (avrPphB susceptible 3)- belongs to the GH3 acyl adenylase family of enzymes. The related JAR1protein is known to adenylate JA, leading to the conjugation of isoleucine to JA to form the bioactive. EPS1 (enhanced *Pseudomonas* susceptibility 1)- provide the enzymatic activity that is equivalent to IPL found in bacteria. The *rabidopsis* NPR1 (nonexpresser of *PR* genes 1) protein is a master regulator of SAR. Recent study has shown tha salicylic acid directly binds to the NPR1 adaptor proteins NPR3 and NPR4, regulates their interactions with NPR1, and controls NPR1 protein stability.

Conclusion:

SAR is a widely observed phenomenon in plants and priming for potentiated activation of defense responses has emerged as an important part of it. SAR is effective against a broad range of pathogens and parasites, including fungi, bacteria and viruses. Salicylic acid is not a translocated signal responsible for inducing SAR but is required in signal transduction. Methyl salicylic acid, azelaic acid, glycerol-3-phosphate, and abietane diterpenoid dehydroabietinal have been identified as mobile signals for SAR. Azelaic acid, glycerol-3-phosphate, and all require DIR1, a lipid transport protein, for their functions. NPR1, as a transcription coactivator, is a master regulator of plant defense required for *ER* and *PR* gene induction, local defense, and SAR. Besides inducing SAR, SA is known to inhibit the hypersensitive response during ETI and trigger thermogenesis in plants and inhibit plant growth, chloroplast development, and photosynthesis.

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ROLE OF INSECTS IN PRODUCTION OF BIOFUEL

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Abstract:

Biofuels are among the most promising replacement for non-renewable fossil fuel energy and are derived from living organisms or from metabolic by-products. Biomass (organic material) can be converted directly into burnable fuel which becomes biofuel. Biofuel can be liquids or gases (Sugars, starch, vegetable oil or animal fats) or solid (wood, sawdust, grass cuttings, domestic refuse, charcoal, agricultural waste, dried manure etc.). The two most widely used biofuels are ethanol and biodiesel. In line with the requirements for sustainable economies and clean environments, insect-based biofuels have recently received tremendous attention both in industry and academic communities worldwide. Alternative and renewable fuels derived from insects offer the potential to reduce our dependence on fossil fuels and mitigate global climate change. Biodiesel is one promising approach to reduce the consumption of petroleum. Insect fat has the great potential for biodiesel production. Insect could convert organic waste into insect fat which was further extracted as a novel feedstock for biodiesel production. Insects belonging to the order Coleoptera—such as the yellow meal worm (YMW) and *Tenebrio molitor* L., and Diptera—such as the black soldier fly (BSF) and *Hermetia illucens* L. can efficiently degrade organic matters, transforming wastes into larval biomass. Insect enzymes which are present in the gut play an important role in biofuel production. Lignocellulose can serve as a precursor for a number of biorefinery processes such as cellulose/ hemicellulose hydrolysis, pyrolysis, and gasification. For example: In grasshoppers, termites and cutworm caterpillars a variety of enzymes and symbionts are present in the gut which have the ability to break down plant materials are linked to what the insects eat. These enzymes could be used in the biofuel industry. The crane fly, *Tipula abdominalis* gut are recognized as a natural biorefinery model.

Keywords: Biofuel, Insects, Biodiesel, Coleoptera, Diptera, Biorefinery

1. Introduction:

A biofuel is a fuel that is produced through contemporary biological processes, such as agriculture and anaerobic digestion, rather than a fuel produced by geological processes such as those involved in the formation of fossil fuels, such as coal and petroleum, from prehistoric biological matter.

Biofuels can be derived directly from plants (*i.e.* energy crops), or indirectly from agricultural, commercial, domestic, and/or industrial wastes. Renewable biofuels generally involve contemporary carbon fixation, such as those that occur in plants or microalgae through the process of photosynthesis. Other renewable biofuels are made through the use or conversion of biomass (referring to recently living organisms, most often referring to plants or plant-derived materials). This biomass can be converted to convenient energy-containing substances in three different ways: thermal conversion, chemical conversion, and biochemical conversion. This biomass conversion can result in fuel in solid, liquid, or gas form. This new biomass can also be used directly for biofuels.

Biofuels are in theory carbon-neutral because the carbon dioxide that is absorbed by the plants is equal to the carbon dioxide that is released when the fuel is burned.

2. History of biofuel:

Biofuels in the solid form has been in use ever since man discovered fire. Wood was the first form of biofuel that was used even by the ancient people for cooking and heating. With the discovery of electricity, man discovered another way of utilizing the biofuel. Biofuel had been used since a very long time to produce electricity. This form of fuel was discovered even before the discovery of the fossil fuels, but with the exploration of the fossil fuel like gas, coal, and oil the production and use of biofuel suffered a severe impact. With the advantages placed by the fossil fuels they gained a lot of popularity especially in the developed countries. Liquid biofuel has been used in the automotive industry since its inception.

One of the first inventors to convince the people of the use of ethanol was a German named Nikolaus August Otto. Rudolf Diesel is the German inventor of the diesel engine. He designed his diesel engine to run in peanut oil and later Henry Ford designed the Model T car which was produced from 1903 to 1926. This car was completely designed to use hemp derived biofuel as fuel. However, with the exploration of huge supplies of crude oil some of the parts of Texas and Pennsylvania petroleum became very cheap and thus lead to the reduction of the use of biofuels. Most of the vehicles like trucks and cars began using this form of fuel which was much cheaper and efficient.

In the period of World War II, the high demand of biofuels was due to the increased use as an alternative for imported fuel. In this period, Germany was one of the countries that underwent a serious shortage of fuel. It was during this period that various other inventions took place like the use of gasoline along with alcohol that was derived from potatoes. Britain was the second country which came up with the concept of grain alcohol mixed with petrol. The wars frames were the periods when the various major technological changes took place but, during the period of peace, cheap oil from the gulf countries as well as the Middle East again eased off the pressure.

With the increased supply the geopolitical and economic interest in biofuel faded away. A serious fuel crisis again hit the various countries during the period of 1973 and 1979, because of the geopolitical conflict. Thus (OPEC), organization of the petroleum Exporting countries made a heavy cut in exports especially to the non-OPEC nations. The constant shortage of fuel attracted the attention of the various academics and governments to the issues of energy crisis and the use of biofuels. The twentieth century came with the attention of the people towards the use of biofuels. Some of the main reasons for the people shifting their interest to biofuels were the rising prices of oil, emission of the greenhouse gases and interest like rural development.

3. Generations of biofuels

First-generation biofuels

First-generation or conventional biofuels are biofuels made from food crops grown on arable land. With this biofuel production generation, food crops are thus explicitly grown for fuel production. The sugar, starch, or vegetable oil obtained from the crops is converted into biodiesel or ethanol, using transesterification, or yeast fermentation.

Second-generation biofuels

Second generation biofuels are fuels manufactured from various types of biomasses. Biomass is a wide-ranging term meaning any source of organic carbon that is renewed rapidly as part of the carbon cycle. Biomass is derived from plant materials, but can also include animal materials.

Whereas first generation biofuels are made from the sugars and vegetable oils found in arable crops, second generation biofuels are made from lignocellulosic biomass or woody crops, agricultural residues, or waste plant material (from food crops that have already fulfilled their food purpose). The feedstock used to generate second-generation biofuels thus either grows on arable lands, but are just byproducts of the actual harvest (main crop) or they are grown on lands which cannot be used to effectively grow food crops and, in some cases, neither extra water or fertilizer is applied to them. Non-human food second generation feedstock sources include grasses, jatropha and other seed crops, waste vegetable oil, municipal solid waste and so forth.

Third-generation biofuels

From 1978 to 1996, the US NREL experimented with using algae as a biofuels source in the "Aquatic Species Program". A self-published article by Michael Briggs, at the UNH Biofuels Group, offers estimates for the realistic replacement of all vehicular fuel with biofuels by using algae that have a natural oil content greater than 50%, which Briggs suggests can be grown on algae ponds at wastewater treatment plants. This oil-rich alga can then be extracted from the system and processed into biofuels, with the dried remainder further reprocessed to create ethanol. The production of algae to harvest oil for biofuels has not yet been undertaken on a commercial scale, but feasibility studies have been conducted to arrive at the above yield estimate. In addition to its projected high yield, alga culture – unlike crop-based biofuels – does not entail a decrease in food production, since it requires neither farmland nor fresh water. Many companies are pursuing algae bioreactors for various purposes, including scaling up biofuels production to commercial levels.

Fourth-generation biofuels

Similarly, to third-generation biofuels, fourth-generation biofuels are made using non-arable land. However, unlike third-generation biofuels, they do not require the destruction of biomass. This class of biofuels includes electrofuels and photobiological solar fuels. Some of these fuels are carbon-neutral. The conversion of crude oil from the plant seeds into useful fuels is called transesterification.

4. Types of biofuels

Biofuels may be solid, liquid or gaseous in nature.

1. **Solid**-Wood, dried plant material, and manure
2. **Liquid:** Bioethanol and Biodiesel
3. **Gaseous**: Biogas

The two most widely used biofuels are ethanol and biodiesel. Others include butane, methanol, Fischer-Tropsch diesel and gasoline.

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane, or sweet sorghum. Cellulosic biomass, derived from non-food sources, such as trees and grasses, is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form (E100), but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the United States and in Brazil.

At this plant the production of bioethanol from starch-containing cereals takes place in five steps:

1. Milling, *i.e.* the mechanical crushing of the cereal grains to release the starch components
2. Heating and addition of water and enzymes for conversion into fermentable sugar
3. Fermentation of the mash using yeast, whereby the sugar is converted into bioethanol and CO_2
4. Distillation and rectification, *i.e.* concentration and cleaning the ethanol produced by distillation
5. Drying (dehydration) of the bioethanol

Apart from fermentation Ethanol is also produced by the process called hydrolysis, where material such as lignocelluloses which are found in tissues of plant or other organic material are used.

Biodiesel is made from algae, animal fats or vegetable oils or recycled cooking grease. The process used to convert these oils to biodiesel is called transesterification.

There are three basic routes to biodiesel production from oils and fats:

- Base catalysed transesterification of the oil.
- Direct acid catalysed transesterification of the oil.
- Conversion of the oil to its fatty acids and then to biodiesel.

Almost all biodiesel is produced using base catalyzed transesterification as it is the most economical process requiring only low temperatures and pressures and producing a 98% conversion yield.

The transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol. A triglyceride has a glycerine molecule as its base with three long chain fatty acids attached. The characteristics of the fat are determined by the nature of the fatty acids attached to the glycerine. The nature of the fatty acids can in turn affect the characteristics of the biodiesel. During the esterification process, the triglyceride is reacted with alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide. The alcohol reacts with the fatty acids to form the mono-alkyl ester, or biodiesel and crude glycerol. In most production methanol or ethanol is the alcohol used (methanol produces methyl esters, ethanol produces ethyl esters) and is base catalysed by either potassium or sodium hydroxide. Potassium hydroxide has been found to be more suitable for the ethyl ester biodiesel production, either base can be used for the methyl ester. A common product of the transesterification process is Rape Methyl Ester (RME) produced from raw rapeseed oil reacted with methanol.

5. Applications of biofuels

Transportation

Nearly 30% of all energy consumed in the United States is used in transportation. To put this into perspective, residential and commercial uses combined only account for 10%. That means that humans in industrial nations use, on average, three times more energy to get around than they use to cook their food and heat their homes. This number does not include electricity generation, which accounts for 40% of all energy used.

Globally, transportation accounts for 25% of energy demand and nearly 62% of oil consumed. Most of this energy, two-thirds in fact, is burned to operate vehicles with the rest going to maintenance, manufacturing, infrastructure, and raw material harvesting.

Power generation

The generation of electricity is the single largest use of fuel in the world. In 2008, the world produced about 20,261 TWh of electricity. About 41% of that energy came from coal, another 21% came from natural gas, and the rest was covered by hydro, nuclear, and oil at 16%, 13%, and 5% respectively. Of the fuel burned, only 39% went into producing energy and rest was lost as heat. Only 3% of the heat was then used for co-generation. Of the 20,261 TWh produced, 16,430 TWh were delivered to consumers and the rest was used by the plants themselves.

A great deal of energy goes into producing electricity, which is not surprising given that everything humans do in the industrialized world, from running water to surfing the internet, requires electricity. Most estimates suggest that about 40% of all GHG emissions come from the production of electricity, with transportation coming in a very close second. Coal is highly problematic for its production of sulfur dioxide, which produces acid rain. Interestingly, nuclear power is the least damaging in terms of pollutants produced, generating less carbon than any form of power generation other than hydro and including solar (PV panel production uses large amounts of water).

Heat production

The major use of natural gas from fossil fuels is heat, though a good deal of it also goes to energy. In the United States, a boom in hydraulic fracturing (called Fracking) has led to a huge surge in the production of natural gas from shale (a fossil fuel) and to the prediction that this will soon become the predominant form of energy, perhaps as soon as 2040. Of course, natural gas need not come from fossilized plant material, it can also be produced from recently grown plant material.

Of course, the majority of biofuel used in heating is solid. Wood is both an aesthetic and a practical method of heating and may homes use wood burning stoves as supplements to other heating systems like natural gas or electricity. Renewed interest in solid biofuels, in part a response to rising energy prices, as led to a surge in innovation in the industry with research focusing on improved efficiency, reduced emissions, and enhanced convenience. Wood gasification boilers can reach efficiencies as high as 91%.

6. Insects in biofuel production

In line with the requirements for sustainable economies and clean environments, insect-based biofuels have recently received tremendous attention both in industry and academic communities worldwide. Alternative and renewable fuels derived from insects offer the potential to reduce our dependence on fossil fuels and mitigate global climate change. The world, therefore, is on the verge of an unprecedented increase in the production and use of biofuels. However, in industry, breakthrough technologies to overcome barriers to developing cost-effective processes for converting insect biomass to fuels and chemicals are not yet fully realized.

Insects order involved in biofuel production

- Isoptera
- Coleoptera
- Diptera
- Orthoptera
- Thysanura
- Plecoptera
- Dictyoptera
- Hemiptera
- Hymenoptera

Figure 1: Insects under different order

7. Insects in biodiesel production

Biodiesel is one promising approach to reduce the consumption of petroleum. However, biodiesel economy has been hampered by the production of oilseed plants. Therefore, alternative feedstocks are urgently needed to enable biodiesel production from cheaper materials. Insect recourse which is rated as the most diverse animal group is rich and ubiquitous in the world.

Main criteria for selecting insects for biodiesel production

Having seen the great potential for fat content in certain insect species, and the possibility of feeding them in many ways, we are going to mention some criteria for selecting some species over others:

- Fat content (of larvae). As previously mentioned, fat content can be very variable throughout the life cycle of an insect. Particularly in holometabolous insects, large variations can exist not only between different immature stages (larvae vs. pupae) but also throughout the course of the larval development itself.
- Speed of completion of the life cycle. The life cycles of a large majority of insects are very fast, particularly for species that feed from decaying organic matter (saprophagous, necrophagous and
- coprophagous species). This is due to the ephemeral nature of this type of habitat. Even species with other ways of life (e.g. phytophagous species) have very fast growth rates compared, for example, to vertebrates. This is possible because of the combination of their small size and high metabolic rates. Many insects can develop their complete life cycle in just over a week, though at least 30 days are usually necessary to complete the cycle.
- Requirements of space and reproductive capacity. Space requirements of many insect species are also reduced in comparison to other animal groups. Because of their small size, a large number of specimens can be gathered in limited spaces for artificial rearing.

Biodiesel production from insects

The biodiesel production from insects has been described by several authors. In a 100 ml reactor equipped with a reflux condenser, a thermometer, a mechanical stirrer, and a sampling outlet. Biodiesel production was accomplished using a two-step process: acid-catalyzed esterification of free fatty acids (FFA) (to decrease the acidity of the crude fat), and alkaline-catalyzed transesterification (Manzano-Agugliaro *et al.*, 2012).

Acid-catalyzed esterification

The acid-catalyzed esterification step was a pretreatment used to convert free fatty acids in the crude fat into biodiesel, and to decrease the acidity of the crude fat. Specifically, 16 sets of 30 g of crude fat were pretreated to esterify the free fatty acid with methanol using 1% H2SO4 (w/w) as the catalyst at the following conditions: four sets were pretreated (methanol to fat ratio 8:1; time 1 h) at a temperature of 55 ◦C, 65 ◦C, 75 ◦C or 85 ◦C, respectively; four sets were pretreated (temperature 75 ◦C, time 1 h) with a methanol to fat ratio of 6:1, 8:1, 10:1, or 12:1, respectively; four sets were pretreated (methanol to fat ratio 8:1, temperature 75 ◦C) with a reaction time of 30 min, 60 min, 90 min, or 120 min, respectively. During esterification, 3 ml samples were withdrawn periodically to determine the free fatty acid conversion. After pretreatment, the reaction mixture was poured into a funnel, and was allowed to separate by gravity. The upper layer (crude fat and biodiesel) was then transferred to a reactor for alkaline-catalyzed transesterification.

Alkaline-catalyzed transesterification

The upper layer (crude fat and biodiesel) obtained from the above acid-catalyzed esterification was mixed with methanol (methanol to fat ratio of 6:1) and the catalyst NaOH (0.8%, w/w). This mixture was placed in a 65 ◦C water bath for 30 min, with agitation by a magnetic stirrer. After the reaction, the mixture was separated by gravity. The upper biodiesel layer was then separated from the lower layer and purified by distilling at 80 ◦C to remove the residual methanol.

Insect fat has been proposed as a promising resource for biodiesel production or Insect fat has the great potential for biodiesel production. The insects, through the development of their life cycle, can be fed with agricultural, industrial or urban by-products in order to accumulate a large amount of fat with potentially excellent quality (fatty acids C16–18), for conversion into energy through biodiesel production.

Insect could convert organic waste into insect fat which was further extracted as a novel feedstock for biodiesel production.

A more economically feasible and environmentally friendly approach is the use of insect to convert crop residues into biomass and simple organic materials: a concept called biotransformation. Insects belonging to the order Coleoptera—such as the yellow meal worm (YMW) and *Tenebrio molitor* L., and Diptera—such as the black soldier fly (BSF) and *Hermetia illucens* L. can efficiently degrade organic matters, transforming wastes into larval biomass. The YMW larvae were reported to contain 23–47% fat and are an important scavenger of decayed milled cereals and grains under humid and poor conditions (Wang *et al.,* 2017).

YMW fed with decayed vegetable matter and BSFL fed with animal manure, rice straw, restaurant wastes, and corncob are used for biodiesel production. The BSF larvae (BSFL) contain 20–40% fat.

Figure 2: Black fly

Figure 3: Yellow meal worm

Process to turn organic wastes into biodiesel by insect

Over the last ten years, biodiesel was produced from edible oil. It was soon found that this way had many problems because it required oil seeds plants which occupy limited arable lands. A biochemical process to turn organic wastes into biodiesel by BSF had been developed. The research showed that BSF were potentially capable of converting most of the nutrients and energy within organic wastes into BSF biomass. Firstly, BSF would secrete powerful digestive enzymes into the organic waste, the complex organic materials were changed into soluble organic molecules (sugar, amino acids, and fatty acids), and secondly soluble organic molecules were changed into the grease of BSF, and then the grease was extracted for biodiesel production. The bioconversion process was shown in the Figure 4 (Li *et al.*, 2011).

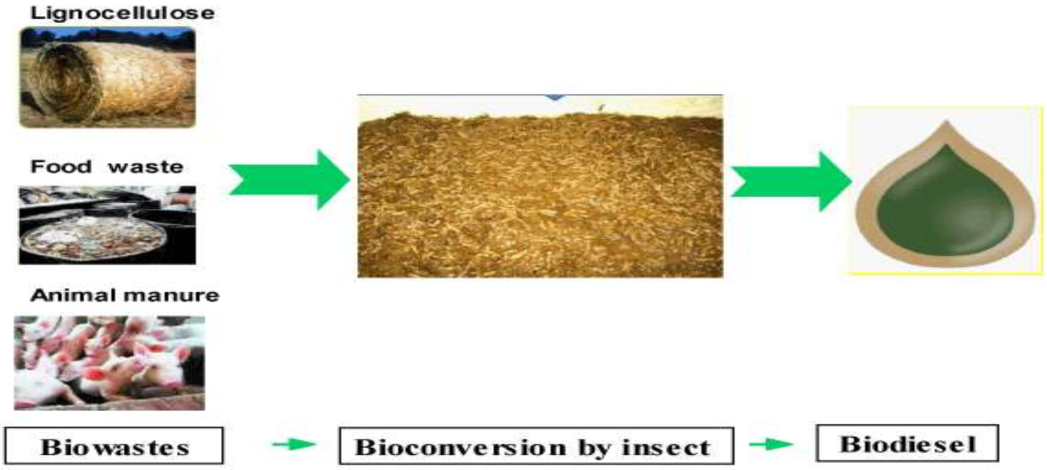

Figure 4: Process to turn organic wastes into biodiesel by insect

There is no creature on the earth capable of disposing of putrescent waste more quickly and efficiently than BSF. On the surface of the disposal unit, there was a 2- to 4-inch layer of actively feeding larvae in several stages of growth. Over 100,000 active larvae can be found in a typical waste disposal unit. In an experiment conducted in Texas over a period of one year, the results showed that BSF larvae could digest 15 kg/m2 restaurant food waste every day at least. BSF had the ability to eat and digest all kinds of biowaste, including meat and dairy products. Enviro-Group had developed and patented a unique BSF bioconversion process without energy, electricity, chemicals, even water. The bioconversion was ideal and easily constructed in the same simple manner. Current business investments are marketing efforts on the promises of producing biodiesel from organic wastes.

Bioconversion of food waste to biodiesel *via* insect farming

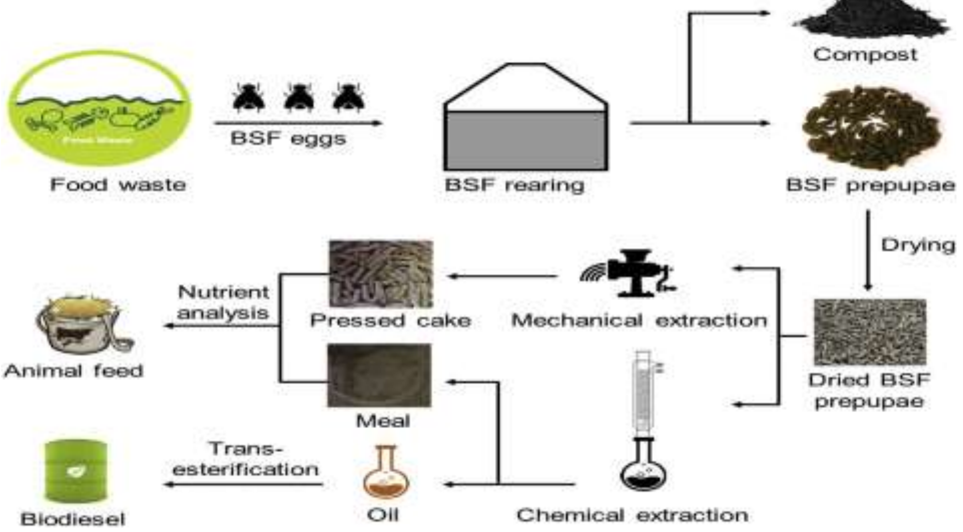

Figure 5: Bioconversion of food waste to biodiesel and animal feed *via* insect farming

Black soldier fly (BSF) was grown in the food wastes by using specially designed reactor for self-harvesting of prepupae. The schematic of bioconversion of food waste to biofuel and animal feed is presented in Fig. 5. Harvested larvae were dried using conveyer oven at 60ºC to the moisture content of around 5.8%. The dried BSF prepupae were fractionated into crude oil using chemical means. The extracted crude oil was collected, centrifuged, and the mass of the supernatant oil was recorded. Then the oil was converted into biodiesel by transesterification process (Surendra *et al.,* 2016).

8. Properties of insect-based biodiesel

The properties of biodiesel are determined by compositions of the various fatty esters, such as cold flow, and viscosity. The viscosity of biodiesel derived from insect fat is high, which is due to saturated fatty acid of insect fat. With the increase of saturated fatty acid, the viscosity of biodiesel would be increasing, such as animal fat, and palm oils. Compared to petro-diesel, biodiesel have a much narrower range of temperatures between the cloud point and the pour point. The cold flow properties of biodiesel are dependent on the feedstock from which they are made. The cold filter plug point can be accomplished by blending biodiesels from several origins with a variety of cold flow properties, or by adding cold filter plug point improvers. Biodiesel help to enhance the ignition quality of the diesel with no negative effect on its cold flow properties when it mixes with diesel.

9. Insect in bioethanol production

The major steps involved in industrial bioethanol production from second-generation feedstocks are outlined as follows (Scharf and Boucias 2010).

Lignocellulose can serve as a precursor for a number of biorefinery processes such as cellulose/ hemicellulose hydrolysis, pyrolysis, and gasification. However, all three processes depend on biomass pre-treatment strategies that use chemicals and/or heat to delignify feedstocks or to release the sugar polymers cellulose and hemicelluloses.

Lignocellulose processing

Biomass feedstock materials are first milled to reduce particle size for subsequent step. Essentially, this processing step is analogous to the mechanical degradation that would occur *via* the action of insect/termite mandibles and the gut proventriculus, in which particle sizes of <50 μ are achieved. Next, in the process known as pretreatment, the processed feedstocks are treated to disrupt lignin and to make hemicellulose/cellulose available for biologic degradation. Pre-treatment can take several forms, including biological, chemical, physical and thermal (Yang &Wyman, 2008 and references therein). After pre-treatment, hydrolysates usually contain hemicelluloses and solids contain cellulose. Hydrolysates are neutralized and conditioned to remove any lignin metabolites, value added by-products, and other materials deleterious to the fermentation process. Next, hemicellulose and/or cellulose are depolymerized into their 5- and 6-carbon monomer sugars, respectively, by enzymes secreted from different biological organisms (Fungi, bacteria, insect etc.)

Current pre-treatment strategies are both chemical and energy-intensive, and they are the costliest component of bioethanol production. Energy and cost inputs into pre-treatments and hydrolysis can be greatly reduced with effective use of insect enzyme.

Insect enzymes which are present in the gut play an important role in biofuel production. Enzymes from lignocellulose-digesting insects and their symbionts, especially termites, are useful for pretreatment and for downstream carbohydrate processing. The digestion efficiency of wood-feeding termites is 74%–99% for cellulose and 65%–87% for hemicellulose which can be achieved by Termite endogenous catalyst systems and catalysts from a variety of gut symbiotic microorganisms, including cellulolytic protozoa and bacteria. The *Reticulitermes flavipes* gut revealed over 175 genes encoding cellulases, hemicellulases, lignases and other potentially relevant digestive enzymes. Two most important groups of *R. flavipes* gut enzymes with potential relevance in industrial lignocelluloses pre-treatment are: lignases and Phenolic acid esterases (Tartar *et al.*, 2009). Insect order involved in cellulose digestion are Thysanura, Plecoptera, Dictyoptera, Orthoptera, Isoptera, Coleoptera, Trichoptera, Hymenoptera, Phasmida and Diptera (Scharf and Boucias, 2010).

The enzymes of termite gut and symbionts are identified and make the synthetic version. This is done by inserting the genes responsible for creating the enzymes into a virus and fed it to caterpillars, which then produced large amounts of the enzymes. Three synthetic enzymes act on different parts of the biomass. Two are responsible for the release of the sugar’s glucose and pentose, while the third breaks down lignin, a complex chemical compound in the walls of plant cells that provides mechanical strength to the cell wall, and by extension the plant as a whole. The synthetic versions of the host termite enzymes were shown to be very effective at breaking down the woody biomass and releasing sugar.

Firebrats belong to a primitive group of insects which were first recorded on land during the Devonian Period, approximately 240 million years ago can thrive on straw, paper and cardboard, all of which contain crystallise cellulose. This forms the fibers that support cell walls and has a high degree of structural order, rendering it tough. Inside their gut, the firebrats had a group of uncharacterized proteins that make up 20 per cent of their carbohydrate digestive enzymes. These proteins proved to be a new class of enzyme, called lytic polysaccharide monooxygenases (LPMOs), which attack crystalline polysaccharides which are responsible for cellulose digestion. These enzymes could be used to break down cellulose in biomass into fermentable sugars to boost the production of renewable, low-carbon biofuels.

Grasshoppers show promise in the hunt for natural catalysts to turn tough plant waste into fuel. Such catalysts may help cutting biofuel production costs and greenhouse gas emissions. For example, grasshoppers might be a good target for biocatalyst discovery because their guts harbor enzymes that can break down cellulose.

Another specific cellulose-consuming insect from the order Diptera is crane fly, *Tipula abdominalis*. The crane fly gut are recognized as a natural biorefinery model. In the hind gut of this insect dense and diverse microbial community are present. A cellulolytic bacterial isolate, 27C64, demonstrated enzymatic activity toward many model plant polymers and also produced a bacterial antibiotic. The bacterial isolate, 27C64 is co-cultured with yeast in fermentation of pine to ethanol, which allowed for a 20% reduction of commercial enzyme (Cook and Peterson, 2010).

10. Advantages of insect-based biofuel

- **Easily available**

  Insects are easily available in nature.

- **Renewable source**

  Most of the fossil fuels will expire and end up in smoke one day. Since insects are renewable and are not likely to run out any time soon, making the use of biofuels efficient in nature. These insect based biofuel will give continuous supply of energy.

- **Reduce our dependence on fossil fuel**

  While locally grown crops have reduced the nation's dependence on fossil fuels, many experts believe that it will take a long time to solve our energy needs. As prices of crude oil is touching sky high, we need some more alternative energy solutions to reduce our dependence on fossil fuels.

- **Energy and economic security**

  Not every country has large reserves of crude oil. For them, having to import the oil puts a huge dent in the economy. If more people start shifting towards biofuels, a country can reduce its dependence on fossil fuels. More jobs will be created with a growing insect based biofuel industry, which will keep our economy secure.

- **Reduce greenhouse gases**

  Because the carbon di oxide that enter the air during combustion of insect based biofuel will have been removed from the air earlier as growing plants engage in photosynthesis and such material is said to be carbon neutral.

- **Lower level of pollution**

Future prospects:

There will be need of development of low-cost enzymatic strategies for delignification and cellulose/ hemicellulose solubilisation. There is a gap between investigations of insect cellulolytic systems and their potential applications for biofuel refinery operations which leads to a lack of integration between insect catalyst systems and advancing current biofuel technology.

Conclusion:

Current world energy needs demand the development of industrial-scale processes for the sustainable production of fuel from renewable biological resources as economic and environmentally sound alternatives to finite fossil fuels. Biodiesel produced from insect biomass (fat) which is converted from organic wastes and lignocellulosic ethanol has been suggested as a desirable biofuel, mostly due to its sustainability, reduced competition as a food resource, net energy production, and reduced input costs related to production process.

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PLANT ANTINUTRITIONAL FACTORS: MECHANISMS AND REMOVAL TECHNIQUES

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Introduction:

Antinutritional factors (ANFs) are naturally occurring compounds found in various plant-based foods that can interfere with nutrient absorption (Samtiya *et al.* 2020), utilization, or overall health in humans and animals. While plants provide essential nutrients, they also contain certain compounds that can have adverse effects on the digestive system or nutrient bioavailability. ANFs can be present in different parts of plants, such as seeds, leaves, stems, or fruits, and their levels can vary depending on factors such as plant species, cultivar, growing conditions, and processing methods. These factors may also influence the effectiveness of ANF removal techniques. The presence of ANFs in food crops, fruits, and vegetables has been a topic of interest due to their potential negative impact on human and animal health. Some ANFs can inhibit the absorption of essential minerals, impair protein digestion, disrupt gut integrity, or induce allergic reactions in susceptible individuals. It is important to note that not all ANFs are harmful in all circumstances. Some ANFs may even possess certain beneficial properties, such as antioxidants (Amarowicz *et al.* 2000) or antimicrobial activity. Therefore, the evaluation of ANFs requires a balanced understanding of their potential risks and benefits. To ensure the optimal nutritional quality and safety of plant-based foods, it is essential to understand the types of ANFs present in different food sources, their mode of action, and effective techniques to minimize or remove them.

Major types of antinutritional factors (ANFs) found in food crops, fruits, and vegetables are described here,

1. Phytic Acid:

Source: Found in cereals, legumes, nuts, and oilseeds.

Mode of Action: Binds to minerals such as iron, zinc, calcium, and magnesium, forming insoluble complexes, and reducing their bioavailability.

Removal Techniques: Soaking, fermentation, germination and enzymatic treatments can help reduce phytic acid levels.

2. Protease Inhibitors:

Source: Found in legumes, such as soybeans.

Mode of Action: competitively inhibits the activity of digestive enzymes, specifically proteases (Cristina Oliveira de Lima *et al.* 2019), leading to incomplete protein digestion and reduced availability of essential amino acids.

Removal Techniques: Thermal processing (e.g., cooking or heat treatment), enzymatic hydrolysis, and specialized processing methods can be employed to reduce protease inhibitor levels.

3. Lectins:

Source: Found in legumes, grains, and some fruits and vegetables.

Mode of Action: Bind to the lining of the gut, disrupting the integrity of the intestinal barrier, and potentially causing inflammation and malabsorption.

Removal Techniques: Soaking, cooking, fermentation, enzymatic hydrolysis, or bioprocessing can be used to reduce lectin content.

4. Oxalates:

Source: Found in leafy greens, such as spinach, and other vegetables.

Mode of Action: Can form insoluble calcium oxalate crystals, leading to the formation of kidney stones and impairing calcium absorption.

Removal Techniques: Boiling or blanching, pressure cooking, or enzymatic treatments can be used to reduce oxalate levels.

5. Tannins:

Source: Found in fruits, nuts, and certain beverages like tea and coffee.

Mode of Action: It binds to proteins and digestive enzymes, inhibiting their activity. Tannins can also reduce the bioavailability of certain nutrients, such as iron and other minerals.

Removal Techniques: Soaking, fermentation, roasting, extraction with solvents or specialized enzymatic treatments can help reduce tannin levels.

6. Saponins:

Source: Found in legumes, chickpeas, lentils, and certain plant foods.

Mode of Action: This can disrupt cell membranes, including those lining the gut, affecting nutrient absorption and causing gastrointestinal disturbances.

Removal Techniques: Soaking, cooking, rinsing, ultrasonication or membrane separation, can be used to reduce saponin levels.

7. Cyanogenic Glycosides:

Source: Found in cassava, bitter almonds, and some stone fruits.

Mode of Action: Can release hydrogen cyanide (HCN) upon hydrolysis, interfering with cellular respiration and potentially causing toxicity.

Removal Techniques: Soaking, thorough cooking, fermentation or enzymatic treatments, can be used to reduce cyanogenic glycosides.

Biotechnology, molecular biology, and genetics offer several techniques to reduce ANFs

1. Genetic Modification: Genetic engineering can be employed to reduce or eliminate antinutritional factors in plants. This involves modifying the plant's DNA to alter the expression of genes responsible for producing antinutritional factors. For example, genes involved in the synthesis of toxic compounds can be suppressed or silenced.

2. Breeding: Traditional breeding techniques can be used to develop new plant varieties with reduced antinutritional factors. By selectively crossing plants with desirable traits, such as low levels of anti-nutritional factors, breeders can gradually reduce their presence in the offspring.

3. Gene Silencing: Techniques like RNA interference (RNAi) can be utilized to silence the expression of genes responsible for producing antinutritional factors (Duraiswamy *et al.* 2023). RNAi involves introducing small RNA molecules that specifically target and degrade the mRNA transcripts of these genes, preventing their translation into proteins.

4. Metabolic Engineering: Metabolic engineering focuses on manipulating the metabolic pathways within plants to reduce the production of anti-nutritional factors. Modifying or introducing enzymes involved in these pathways makes it possible to redirect metabolic flux and reduce the synthesis of undesirable compounds.

5. Tissue Culture Techniques: Somatic embryogenesis or callus culture, can be employed to regenerate plants from individual cells or tissues. This approach allows for the selection and propagation of cells or tissues with reduced antinutritional factors, producing low-antinutritional factor plants.

6. Protein Engineering: Protease inhibitors can be modified or engineered to reduce their inhibitory effects. By altering specific amino acid residues or modifying the protein structure, it is possible to design variants with reduced activity against proteases.

7. Metabolomics and Functional Genomics: Metabolomics and functional genomics can be employed to identify genes and metabolic pathways associated with the production of anti-nutritional factors. This knowledge can then be used to develop targeted strategies for reducing their levels, either through gene editing or the manipulation of relevant metabolic pathways.

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BEAUVERIA BASSIANA AS A POTENTIAL BIOCONTROL AGENT FOR THE MANAGEMENT OF TEA MOSQUITO BUG IN TEA

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Introduction:

Due to its taste, stimulating impact, distinctive flavour, scent, and medicinal or health benefits, tea, *Camellia sinensis* (L.) O. Kuntze, has gained a lot of prominence as the most consumed beverage worldwide. With an output of 1,344.40 million kg in 2021–2022, India ranked second in the world for tea production (Tea Board of India, 2023). Assam, West Bengal, Tamil Nadu, and Kerala are the main producers, accounting for 98 per cent of the total production, and there are currently 54 countries where tea is grown. In India, tea is grown in about 13 states. India is the 2nd largest producer, 2nd largest consumer, 4th largest exporter of tea. India's total tea exports during 2021-22 in quantity were 201 million kg. The total exports during January-April 2022 were 65 million kg and were valued at US$ 215 million, a 9 per cent increase from the same period in 2021 (IBEF, 2023).

Tea provides a stable microclimate and a consistent source of food for the quick accumulation of phytophagous species, which includes insects, mites, and numerous diseases. Tea is a woody perennial with a long lifespan and a monoculture. There are 1034 species of arthropods, 82 species of nematodes, 350 fungal diseases, an algal disease, and tea plants around the world, according to Chen and Chen (1989). Numerous pest species, including the tea mosquito bug, red spider mite, pink mites, thrips, termites, red slug caterpillar, looper, green leaf hopper, etc., have taken over the tea plant in North East India. The infected tea leaves also lessen the flavour of the beverage, which has led to severe yield losses. One of them, the tea mosquito insect, is regarded as one of the most hazardous sucking pests in the major tea-growing countries.

Tea mosquito bug in tea ecosystem

Both the quantity and quality of the tea are severely harmed by the tea mosquito bug on tea farms. The tea mosquito bug nymphs and adults consume the cell sap from sensitive stems, young leaves, and buds, causing the development of reddish brown circular feeding punctures. The actual crop of tea, which consists of buds, shoots, and tender leaves, turns curled, withered, and black with many sucking stains and yields nothing. The inability to harvest (pluck) the injured buds has an impact on the subsequent flush of shoots. The most severely impacted tea plants are stunted and have a darker green colour (Das 1965; Hazarika 2009). Additionally, oviposition results in over-callusing and stem cracking, which also stunts development and causes stem dieback (Das 1965). A tea mosquito insect infestation frequently begins in a tiny part of the tea crop before spreading to nearby plant patches. As a result, the tea field appears to be developing unevenly (Das 1965). In conclusion, the tea mosquito bug causes two different forms of damage: direct loss of the harvestable shoots and severe bush weakness that results in dieback, which delays flushing and lower yields.

Systemic position of tea mosquito bug

Phylum- Arthopoda
Class- Insecta
Order- Hemiptera
Family- Miridae (Capsidae)
Genus- *Helopeltis*
Species- *theivora*

Nature of Damage of tea mosquito bug in tea

Helopeltis theivora embeds eggs one at a time inside the tissues of a succulent stem after tearing them open with its ovipositor. The nymphs and adults of TMB suckle the young leaves, buds, and delicate stems for their sap, injecting poisonous saliva that breaks down the adjacent tissues. Within a few hours of sucking, a ring-shaped patch develops around the feeding spot; it becomes translucent and light brown after 24 hours. Within a few of days, the markings begin to appear as dark brown sunken patches, which then dry up. Curls and other abnormalities appear on the severely injured leaves. Oviposition, which blocks the vascular bundle and alters the physiology, results in the delicate stems becoming cracked and over-callused. Oviposition also sometimes results in stem die-back.

Importance to adopt safer technique for management of tea mosquito bug in tea

Because they have a wide host range, synthetic pesticides are a highly effective tool for managing a variety of insect pests and illnesses in agricultural crops as a whole. But they haven't gotten much attention for their harmful effects on the environment or the sustainability of farming practises in the long run. As a result of the heavy reliance on the use of synthetic chemicals as pesticides and fertilisers, there are a number of unfavourable effects relating to the undecomposed residue of chemicals present in agricultural food for human and animal consumption, affecting both the biotic and abiotic components of the environment.

Chemical pesticides are known to diminish soil fertility, which has a detrimental effect on the native microbial populations already present in the soil, making it unfeasible to manage tea pests with them alone. To control some destructive pest insects in North East Indian tea plantations, the current investigation used new pesticide molecules in low doses along with biological agents (more specifically, microbial biocontrol agents) and the implementation of an Integrated Pest Management (IPM) schedule. Nowadays, numerous multi-locational field tests have been conducted using locally isolated microorganisms such as *Azotobacter, Azospirillum, Bacillus, Pseudomonas, Streptomyces, Trichoderma, etc*. along with crude extracts of numerous botanicals made from *Amphineuron opulentum, Cleome gynandra, Ipomea convolvulus, Polygonum hydropiper, etc*. against dominant tea pests and diseases. Pesticide use has been avoided and alternative approaches to manage tea pests and illnesses have been implemented in an effort to promote sustainable tea cultivation. Microbial biocides have also been widely embraced by tea growers around the region in order to speed the use of these beneficial microorganisms in tea.

Mode of action of *Beauveria bassiana*

An insect disease known as the white muscadine disease is brought on by the fungus *Beauveria bassiana*. This fungus's spores germinate and develop through the cuticle (skin) of its host when they come into touch with the skin of insects that are vulnerable to it. This allows them to infect the host's internal organs. Here, the fungus spreads all throughout the insect's body, creating poisons and depleting it of nutrients until the insect dies. Beauveria and other fungal pathogens infect the insect through touch, as opposed to the bacterial and viral pathogens of insects, which require their host to swallow them in order to infect them. In addition to microbial biocides, which are beneficial bacteria in tea, tea growers all across the region are also generally in favour of them. After killing the host, the fungus returns via the softer parts of the cuticle, covering the insect with a layer of white mould (hence the term white muscadine illness), consuming all of the nutrients, and eventually killing the insect. The environment is exposed to millions of fresh infectious spores produced by this downy mould. The activity of the fungi is favoured by warm, humid conditions. How rapidly an insect dies depends on a number of factors, including the quantity of spores that come into touch with it, the insect's age, susceptibility, and the environment.

Use of *Beauveria bassiana* as potential entomopathogenic fungi

According to Roy *et al.* (2006), entomopathogenic fungi (EPF) are efficient biological control agents for a variety of pests. The most efficient EPFs against different pests have been determined to be *B. bassiana* and *M. anisopliae* (Vilas Boas *et al.* 1996; Lawrence and Khan 2002). An entomopathogenic fungus called *Beauveria bassiana* naturally develops in soils all over the world and parasitizes many species of arthropods. As a biological insecticide, it is employed to get rid of pests like termites, thrips, whiteflies, aphids, and other beetles. As endophytes, *Beauveria bassiana* can colonise a variety of plant hosts without transmitting disease while yet having the ability to infect insects.

Environment for growth and development of *Beauveria bassiana*

Temperature is one of the leading abiotic factors affecting the development of fungi, which in turn significantly affects the virulence of EPF against harmful insects. For instance, Ak (2019) reported that *B. bassiana* caused the highest mortality (93.66%) at 25 °C and the lowest (40.74%) against *Sitophilus oryzae* (Coleoptera: Curculionidae) at 20 °C. Similarly, Vassilakos *et al.* (2006) reported that *B. bassiana* was more effective against *S. oryzae* and *Rhyzopertha dominica* (Coleoptera: Bostrichidae) at 26 °C than at 30 °C. Similar results were obtained by Athanassiou and Steenberg (2007). Therefore, it can be determined that effect of *Beauveria bassiana* will be high in the temperature range of 25 to 30 °C. Higher temperatures can significantly reduce the fungal production efficiency (Noma and Strickler 1999; Ugine 2011). Owing to that it is better to go for application of *Beauveria bassiana* in the early morning and evening hours in the peak growing season of tea when temperature may rise upto 38°C. The relative humidity most suitable for mycelial growth and spore germination is 100%. However, spores of some strains of *B. bassiana* can germinate at a low relative humidity (56.8%).

Effect of *Beauveria bassiana* in tea

Beauveria bassiana 2.5% WP (Cfu count 2x10^8/gm) @ of 3kg/ha (formulation) have been found effective for the control of Tea Mosquito Bug (Plant Protection Code, Version 15). Spraying of the entomopathogen, *Beauveria bassiana* (Bals.- Criv.) Vuill, at 2 kg/ha minimized infestation of the TMB compared with the control under Dooars and Darjeeling field conditions. Fungal isolates consisting of *Beauveria bassiana* extracted from tea soils did not show any phytotoxic effect on the harvestable tea shoots and had acceptable organoleptic attributes among the selected consumers. The formulation was moreover found to be non-pathogenic to non-target insects, *i.e.* natural enemies present in the tea ecosystem (Deka *et al.* 2021). Therefore, it can be concluded that *B. bassiana* can be an effective biocontrol agent that could be used against *H. theivora* and can be a potential component of integrated management of tea mosquito in tea plantations.

Advantages of use of *Beauveria bassiana* against tea pest

- It is an environmentally safe, naturally occurring entomopathogenic fungus and found in all soil types.
- The majority of the economically significant crop pests are successfully controlled by it.
- It is easy and relatively cheap to culture and maintain several *B. bassiana* strains in laboratory conditions compared with the production costs of chemical pesticides.
- Solutions containing *B. bassiana* conidia can easily be applied in field using equipment and application method like those of synthetic insecticides
- It kills both adult and immature stages (eggs, larvae) causing the so-called “white muscardine” disease
- By enhancing crop health and reducing pests, productivity can be increased.
- As the residues are safe for consumers, it can be used up until the day of harvest.

Conditions for safe use of *Beauveria bassiana*

- After mixing with water, *Beauveria* products should be sprayed as soon as possible, as fungal spores die and material loses its viability overnight.
- The foliage should be sprayed until the plants are wet thoroughly, but not to run-off.
- Equipment that gets the material to the undersides of the leaves will result in prolonged activity, as spores are inactivated by sunlight.
- Evening applications may be desirable which will help to avoid high temperature of day as the rate at which *Beauveria* spores kill their host is dependent on temperature.
- Avoid using with other pesticide formulations, especially fungicide formulations

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FALSE SMUT: AN EMERGING RICE DISEASE

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Abstract:

Villosiclava virens, an ascomycete fungal pathogen, is the causal agent of False smut disease in rice. This disease, widely recognized as one of the most significant rice diseases globally, leads to reduced yield and inferior grain quality. Additionally, the pathogen poses a health hazard to both humans and animals due to the production of mycotoxins. Previously regarded as a minor disease due to its sporadic occurrence, False smut disease has now gained considerable importance in the field of rice cultivation. Researchers have been intrigued by this mysterious pathogen for years, because of its distinctive life cycle and infection strategies.

Introduction:

Rice holds a prominent position as a staple food crop across the globe, especially in Asian countries, where approximately 90% of the world's rice is both produced and consumed. India, being the second-largest producer of rice, contributes about 22% of the global production. Despite its significant production output, the productivity of rice in India is relatively low. One of the primary factors contributing to this issue is the prevalence of various diseases caused by pathogens such as fungi, bacteria, and viruses. Among these pathogens, *Villosiclava virens*, the fungal agent responsible for rice false smut, affects millions of tons of rice crops worldwide. The first report of this disease dates back to 1878 when Cooke documented its occurrence in the Tirunelveli district of Tamil Nadu, India. The anamorphic stage of this pathogen is known as *Ustilaginoidea virens* [Cooke] Takahashi. Globally, the yield loss due to false smut has been reported to range from 3% to a staggering 81%. In India, the percentage of false smut-infected tillers varies between 5% to 85%, leading to yield losses ranging from approximately 0.2% to 49%, depending on the severity of the disease and the rice varieties being cultivated. This devastating disease not only reduces the crop yield but also adversely affects the quality of rice grains and straw, as it produces mycotoxins that raise serious concerns regarding food and feed safety. The presence of black chlamydospore masses on healthy rice grains causes further economic losses for farmers, as it lowers the market prices for their produce. Addressing and controlling false smut disease in rice is crucial for sustaining agricultural productivity and ensuring food security.

Classification

Kingdom: Fungi
Phylum: Ascomycota
Class: Ascomycetes

Subclass: Sordariomycetes
Order: Hypocreales
Family: Clavicipitaceae
Genus: *Villosiclava*
Species: *virens*

Symptoms

Symptoms of rice infected by *V. virens* remain latent until after panicles start to flower, at which point the rice grains are replaced by spore balls that burst through the glumes. The pathogen targets individual spikelets, transforming the grains into round to irregularly shaped spore balls composed of densely packed and multiplied hyphae. These spore balls become visible as a white fungal mass protruding from the inner part of a spikelet during the late booting stage. As the infection progresses, the spore balls transition into a yellow-orange hue (see Figure 1.a). Upon maturation, the outer layer of the spore balls becomes entirely covered with chlamydospores, turning them dark green to black (see Figure 1.b). During late autumn, when there are significant temperature fluctuations between day and night, the pathogen forms sclerotia. These structures are black, horseshoe-shaped, irregular oblong, or flat and are believed to act as survival structures, providing inoculum over the winter. In contrast, Wang and Bai (1997) discovered a different type of white false smut fungus, identified as *Ustilaginoidea albicans*, in Liaoning Province, China. Unlike the typical false smut, the spore balls of this white smut on rice remained completely white on the infected grains (see Figure 2).

Figure 1: Typical symptoms of rice false smut disease caused by *Villosiclava virens*

Figure 2: Symptom of White false smut of rice caused by *Ustilaginoidea albicans*

Identification

Chlamydospores, ranging from round to elliptical in shape and measuring approximately 3-5 µm in diameter, feature curved spines on their surface. These spores appear yellowish when young and gradually change color to green or brown as they reach maturity. When exposed to suitable conditions, chlamydospores germinate, giving rise to germ tubes that further develop dissepiments and differentiate into conidiophores. The tips of these conidiophores then produce secondary conidia. As spore balls mature, they generate sclerotia at their center. These sclerotia are firm, dark, irregular, horseshoe-shaped structures, measuring about 2-20 mm. The sexual stage of RFS (Rice False Smut) primarily involves the formation of stroma through sclerotium germination, leading to the development of asci and ascospores.

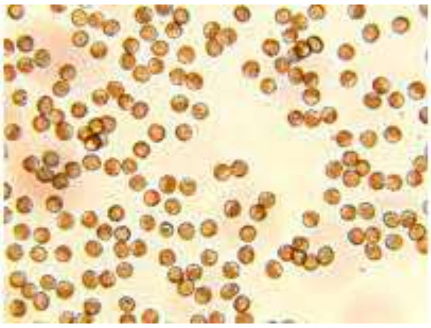

Figure 3: Microscopic view of false smut spores

Factors favoring disease development

False smut symptoms are seen only when the pathogen is favored by following environmental conditions**:**

1. Heavy rainfall and high humidity (>95%)
2. Temperature ranging from 25-35℃.
3. Soil with high nitrogen content
4. Formation of resting structures like sclerotia and chlamydospores to help the fungus overwinter.
5. The optimum pH range for growth is 6.02 to 6.72.

Disease cycle

V. virens is a non-obligate biotrophic fungus, exhibiting both sexual and asexual phases in its life cycle. During the sexual cycle, low temperatures trigger the formation of sclerotia on the surface of rice false smut balls. These sclerotia germinate under appropriate conditions of moisture, light, and temperature, giving rise to ascospores within asci. Primary infections in rice occur through secondary conidia produced by these ascospores. In the asexual cycle, thick-walled chlamydospores are formed on the surfaces of the false smut balls. These chlamydospores act as a significant source of inoculum between seasons and have been reported to infect various weed species associated with paddy fields, including endemic barnyard grass (*Echinochloa crusgalli*) and other common weeds like *Digitaria marginata*, *Panicum trypheron*, and *Imperata cylindrical*.

Although the disease cycle of this fungus-host interaction has not been fully characterized, understanding the pathogen's life history and infection process is vital for disease control efforts. Two proposed models describe the infection pathways in the disease cycle of rice false smut (FS). In the first model, primary infections occur when chlamydospores or airborne ascospores from sclerotia germinate and land on inflorescences during the flowering stage of rice in late summer or early fall. The second model suggests that the fungus survives the winter through spore balls and/or sclerotia. Chlamydospores released from spore balls on seeds or in the soil germinate and then colonize seedlings during germination or shortly thereafter. Subsequently, the fungus colonizes the apical meristematic tissue and then the flowers in the boot stage before the panicle emerges.

Infection strategy

V. virens has undergone evolutionary adaptations to exploit the grain-filling process in rice by mimicking fertilization within the ovaries. These ovaries act as nutrient reservoirs, providing nourishment to the pathogen, thereby facilitating the development of false smut balls. The spores of the fungus germinate, and the hyphae disperse across the outer surface of the spikelets, extending into the inner space through the gap between the lemma and palea. The fungus primarily targets the filaments of stamen located between the lodicules and ovaries, leading to the formation of extensive mycelia that protrude from the spikelets, ultimately resulting in the formation of false smut balls. It is noteworthy that during the infection process, no typical infection structures, such as appressorium and haustorium, can be observed.

The infection progresses relatively slowly, usually taking at least three weeks to develop fully. In the late stage of infection or within a rice false smut (RFS) ball, the stamen filaments are replaced by mycelia, while the ovary and lodicules remain intact, indicating their potential contribution to the formation of the RFS ball. Interestingly, the hyphae of *V. virens* are unable to extend into the pedicles and stems connecting the spikelets, and no anatomical changes are detected in the pedicles during the infection process.

Mycotoxins

The fungus produces a diverse array of secondary metabolites, including mycotoxins like ustiloxins and ustilaginoidins. Ustiloxins are cyclic peptides with antimitotic properties and are water-soluble. Among them, Ustiloxin A and Ustiloxin B are the most commonly found toxins in the middle layer of young false smut balls, which consist of mycelia and immature chlamydospores. On the other hand, ustilaginoidins belong to a family of bis-naphtho-pyrones that readily dissolve in organic solvents. As the false smut balls reach late maturity stages, the chlamydospore layers become enriched in ustilaginoidins.

Management:

Preventive methods

1. Plantation of the crop should be scheduled such that it avoids raining during sensitive stages,
2. Recommended using resistant and tolerant variety.
3. Irrigation channels and field ridges should be kept clean.
4. Alternate wetting and drying of fields.
5. Use of healthy seeds.
6. Seed treatment with carbendazim @ 2.0g/kg of seeds.

Cultural methods

1. To reduce the disease, destruction of plant debris from the field is recommended.
2. Field activities should be avoided when plants are wet.
3. Avoid excess application of nitrogenous fertilizer.

4. Late planting of rice reduces the disease incidence

Chemical methods

1. Preventive spray of copper oxychloride @ 2.5 g/litre or Propiconazole @ 1.0 ml/liter at booting stage or 50% panicle emergence.
2. Spray Trifloxistrobin + Tebuconazole 75 WG at booting or 50% panicle emergence
3. At tillering and pre-flowering stages, spray Hexaconazole @ 1ml/lit or Chlorothalonil @ 2g/lit.

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RNA INTERFERENCE (RNAi) A SIGNIFICANT BREAKTHROUGH OF ENTOMOLOGICAL RESEARCH AND PEST MANAGEMENT

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Introduction:

Insects play a significant role in our ecosystem as pollinators and biocontrol agents, and in some regions of our nation they are served with delicacy. However, if we focus on pests, we see that they have a detrimental effect on agricultural produce, in 2021-22, the FAO (Food & Agriculture organization) claimed that pests were responsible for 30–40% of the damage to agricultural crops. Insects represent a significant threat as competitors for food and fibre, and serve as carriers of some of the most fatal diseases known to humans. The use of chemical pesticides is common practice in agriculture for the purposes of crop protection and mitigating the spread of illnesses transmitted by insects. The frequent usage of insecticides has led to a rise in the occurrences of insecticide resistance, secondary pest outbreak and residue in food commodities to several commonly used insecticides (Sparks and Nauen, 2015). The implementation of novel biotechnological methods, involving the integration of transgenic crops that express Bacillus thuringiensis (Bt) Cry toxin proteins, commonly referred to as insect-resistant transgenic Bt-plants, has resulted in a reduction of pesticide usage in significant crops such as cotton and maize. This has led to notable economic and environmental advantages. New methods of controlling certain agricultural pests are needed because insects are developing resistance this time to the Bt toxins and there are outbreaks of nontarget pests (Bravo and Soberon, 2008; Wu *et al.*, 2008). RNA interference (RNAi) is one technique that shows promise as a safer method of controlling insect pests. RNA interference (RNAi) is a naturally occurring cellular process that silences genes. A molecule with two RNA strands that are not identical to one other is called double-stranded RNA (dsRNA) and may act as a trigger. When dsRNA is injected into a cell, it gives rise to short interfering RNAs (siRNAs), which bind to the genes that they are supposed to silence (Whyard *et al.*, 2009). RNA interference (RNAi) is an endogenous cellular defence mechanism mediated by double-stranded RNA (dsRNA). In the majority of eukaryotes, the presence of long dsRNA within a cell indicates either viral infection or transposon activity, the cell will try to dampen the effects of both (Obbard *et al.*, 2008). It is anticipated that RNA interference (RNAi), a cellular-level gene-silencing process activated by double-stranded RNA (dsRNA), will be the new strategy behind the next generation of insect-resistant transgenic plants. Some research has shown that pest control may be achieved by delivering dsRNA molecules to insects by ingestion, where they are then able to silence the target critical gene, killing or otherwise impairing the survival of the insect (Whyard *et al.*, 2009). Typically, species-specific RNase-III-like enzymes are responsible for processing long dsRNAs, leading to the formation of smaller double-stranded molecules. The shorter RNAs are incorporated into RNA complexes to serve as a guide for identifying target mRNAs. These targets may undergo cleavage or be prevented from translation in posttranscriptional silencing. Alternatively, the shorter RNAs may induce histone modifications as part of a transcriptional silencing response.

The current methods and drawbacks of pest management

A number of strategies are being used today, including cultural, mechanical, biological, chemical and transgenic ones. Among them, cultural, mechanical, and biological measures are traditional approaches followed by farmers through the ages. These methods are beneficial to the environment, sustainable, affordable, accessible, user-friendly, harmless, and can be used in conjunction with other strategies. However, these methods are typically not very fast-acting, require the expertise of specialized personnel, and can only be used in a limited area at a time. Chemical methods of pest control involve the use of toxic substances that interfere with one or more vital pathways in pests by inhibiting enzyme activities. These methods are quicker and more effective than other methods of pest control. However, they have several disadvantages, including their persistence and biomagnification in the environment, which can cause environmental and health problems (Stenersen, 2004). Plant breeding approaches involve the introduction of insect resistance traits into crop varieties. However, this method is limited by the lack of resistance genes in the germplasm for many pests and the potential introgression of undesirable harmful traits from wild varieties through linkage drag (Yencho *et al.*, 2000). Insect pests are a major threat to crop production causing billions of dollars in damage each year. Traditional methods of pest control, such as chemical pesticides are often ineffective, environmentally harmful, and can pose health risks to humans and animals (Christou *et al.*, 2006). Biotechnology offers a promising new approach to pest control. Transgenic crops, which have been genetically modified to express insecticidal proteins, are more specific in their action against insect pests than chemical pesticides. They also produce insecticidal compounds continuously in large amounts, which can help to reduce the number of applications needed. Transgenic crops offer several advantages over traditional methods of pest control. They are more specific in their action, more effective, and more environmentally friendly. They are also considered more economical to farmers, as they can help to increase crop yields and reduce the need for chemical pesticides (Sharma and Sharma, 2013). The use of transgenic crops is a promising new approach to pest control. They offer a number of advantages over traditional methods, and they have the potential to help to reduce the environmental and health risks associated with chemical pesticides. Insect pests are a major threat to crop production, causing billions of dollars in damage each year. Traditional methods of pest control, such as chemical pesticides, are often ineffective, environmentally harmful, and can pose health risks to humans and animals. Transgenic crops offer some advantages over traditional methods. They are more specific in their action against insect pests, and they can produce insecticidal compounds continuously in large amounts. However, they can also be expensive to develop and produce, and they can sometimes harm non-target organisms. The ideal pest control strategy would be economical, environmentally friendly and effective against a wide range of pests. It would also be resistant to the development of pest resistance. There is an urgent need to develop new pest control strategies that meet these criteria. Some promising new approaches include the use of biopesticides, insect-resistant plants, and integrated pest management (IPM) (James, 2014).

RNAI: A promising new approach to pest control

The biological processes that underlie RNA-induced gene silencing (RNAI)

Nature has developed an efficient method for silencing genes using short, double-stranded non-coding RNAs (ncRNAs) that are 21–25 nucleotides long and bind to their target RNAs with a precise sequence. These small RNAs are divided into three primary groups:

- MicroRNAs (miRNAs) are the most abundant type of small RNA. They are generated from longer precursor RNAs by the enzyme Dicer, and they typically base-pair with complementary sequences in mRNA transcripts. When a miRNA binds to its target mRNA, it can either inhibit translation of the mRNA or induce its degradation.
- Small interfering RNAs (siRNAs) are generated from exogenous dsRNA by Dicer. They are similar to miRNAs in structure and function, but they are typically shorter and more abundant in response to infection by viruses or transposons.
- Piwi-interacting RNAs (piRNAs) are a type of small RNA that is found in the germline. They are involved in the silencing of transposons and other mobile genetic elements.

The RNA-induced gene silencing pathway

The RNA interference (RNAi) pathway is a cellular mechanism that uses small RNAs to silence gene expression. The pathway proceeds in several steps:

1. The siRNA or miRNA molecules associate with the RNA-induced silencing complex (RISC). The RISC is a protein complex that is responsible for mediating the effects of RNAi.
2. Within the RISC, the short double-stranded RNA is denatured followed by the degradation of the sense strand. This leaves the antisense strand of the RNA, which is the strand that is complementary to the target mRNA.
3. The RNA/RISC complex becomes fully functional and highly specific by finding mRNA molecules that have a sequence complementary to the antisense RNA present in the RISC. Once the RISC finds a complementary mRNA, it can either cleave the mRNA or repress its translation.
4. If the sequence of the target mRNA is perfectly complementary to antisense RNA in the RISC, then the RISC will cleave the mRNA, which is subsequently degraded by ribonucleases. This prevents the mRNA from being translated into protein.
5. However, if the sequence of the target mRNA is not exactly complementary to that of the antisense RNA within the RISC, then the RISC complex binds to the mRNA, which represses its translation. This prevents the mRNA from being translated into protein, but the mRNA itself is not degraded.

6. RNAi is a powerful biological mechanism for silencing gene expression by either affecting the stability or the translation of mRNA; heterochromatinization of the genome leading to repression of gene transcription. These functions are performed by associating with the RNA-induced initiation of transcription silencing complex (RITS).
7. The antisense RNA strand within the RITS directs the RITS complex to definite gene promoters or to the larger regions of chromatin. The function of RITS is to recruit the chromatin remodeling enzymes to these genomic regions, which in turn methylate histones and DNA, causing heterochromatin formation and subsequent transcriptional silencing.

dsRNA delivery methods in insect

Utilizing an effective delivery technique will result in a positive RNAi response. The three main dsRNA delivery techniques that have been studied thus far in various species are soaking, microinjection, and feeding. These techniques allow for the bulk production of interference compounds that may be utilized as pesticides.

Soaking or incubation: Soaking is a simple and effective method for delivering dsRNA to cells or tissues in culture. This method involves immersing the cells or tissues in a solution of dsRNA for a predetermined amount of time. The dsRNA is then taken up by the cells or tissues, where it can silence gene expression. The effectiveness of soaking can be increased by using transfecting agents. Transfecting agents are molecules that help the dsRNA to enter the cells or tissues. Some common transfecting agents include liposomes, calcium phosphate, and polyethyleneimine. Soaking has been used to study the effects of RNAi in a variety of organisms, including C. elegans (Tabara *et al.,* 1998), nematodes, flatworms, and D. melanogaster (Orii *et al.*, 2003). However, soaking is not a universally applicable method, and it is not always effective in all organisms. For example, soaking is not effective in plants. The narrow range of applications of soaking has limited its use in research. However, soaking is a simple and effective method for delivering dsRNA to cells or tissues in culture, and it may be useful in some specific applications.

Microinjection: Microinjection is a precise and efficient method for delivering dsRNA to target tissues. This method involves inserting a needle directly into the target tissue and injecting the dsRNA. This method is more effective than other methods, such as soaking or feeding, because it ensures that the dsRNA is delivered to the correct cells. Microinjection was first used by (Fire *et al.,* 1998) to study the effects of sense and antisense RNA in C. elegans. Since then, microinjection has been used to study the function of genes in a variety of organisms, including insects, plants, and mammals (Belles *et al.*, 2010). The main advantage of microinjection is that it allows for the precise delivery of dsRNA to the target tissue. This is important because different tissues may respond differently to dsRNA, and the effectiveness of RNAi can be affected by the location of the dsRNA. Microinjection is a more invasive method than other methods, such as soaking or feeding. However, the benefits of microinjection outweigh the risks in many cases Ulrich *et al.*, 2015).

Spraying: Spraying is a method of delivering dsRNA or siRNA to plants that involves synthesizing the dsRNA or siRNA in vitro and then spraying it onto the plant surface. This method was initially thought to be ineffective due to the degradation of siRNAs, but recent studies have shown that it can be an effective delivery method. For example, Miguel and Scott (2016) sprayed dsRNA of the actin gene onto leaves of potato plants to protect them from Colorado potato beetles. They found that the dsRNA-sprayed plants remained protected against pests for 28 days under greenhouse conditions, and that the dsRNAs were stable on the leaves once they dried. A similar method of delivery has also been found effective against fungal pathogens (Koch *et al.,* 2016) and viral pathogens (Konakalla *et al.,* 2016). However, spraying requires the production of dsRNA or siRNA at a large scale, which makes this approach costly. Despite the cost, spraying is a relatively easy way to deliver dsRNA or siRNA to plants, and it does not require any time-consuming procedures. However, it is not effective against pests that feed on internal sap, such as phloem sap feeding and stem borer insects (Li *et al.,* 2015).

Feeding: Oral feeding is a less invasive and simpler method for delivering dsRNA to insects than injection. This method was first demonstrated by Timmons and Fire (1998), and it has since been used successfully in a variety of insect species, including agricultural pests and human parasites. There are several different methods for delivering dsRNA through oral feeding. One method is to feed insects an artificial diet that contains dsRNA or engineered bacteria that express dsRNA. Another method is to use nanoparticles or liposomes to deliver dsRNA to the insect's gut. Finally, dsRNA can also be delivered through transgenic plants that express dsRNA (Joga *et al.,* 2016). The artificial diet-based feeding approach is the most commonly used method for functional genomics studies. In this method, the artificial diet is mixed with dsRNA or engineered bacteria, and the insects are then fed on the diet. This method has been used to study the function of a variety of genes in insects, including the chitinase gene in *Mythimna separate (*Ganbaatar *et al.,* 2017). Bacterial feeding also provides an alternative method for large-scale screening for target candidate genes. In this method, insects are fed on a diet that contains engineered bacteria that express dsRNA targeting a specific gene. If the gene is essential for the insect's survival, then the insect will die or show signs of growth retardation. Liposomes and nanoparticles are two methods for stabilizing dsRNA molecules during delivery and increasing the efficiency of RNAi. Liposomes are formed by conjugation of lipophilic molecules, while nanoparticles are formed by entrapping dsRNAs into chitosan polymer (Taning *et al.,* 2016). Plants have RdRp and SID for amplifying and transporting RNAi signals, while insects do not. This means that plants can amplify the siRNA molecules and transport them through phloem and plasmodesmata to other parts of the plant. Insects can then take processed and unprocessed dsRNAs from plants through feeding and move the dsRNA to other body parts or target sites. Robust and systemic RNAi response has been observed in insects even in the absence of RdRp and SID-1, which may be due to the presence of other genes or pathways required for amplification and systemic response (Zhang *et al.,* 2013).

RNAi-mediated pest control

In addition to its use in studying gene function, the sequence-specific mode of action of RNAi has attracted significant attention in recent years for its potential application in crop protection (Taning *et al.,* 2019). Extensive research has shown that RNAi triggers, such as artificial microRNAs (amiRNAs), hairpin-structured RNAs (hpRNAs), and double-stranded RNAs (dsRNAs), can be specifically designed to target the expression of specific genes or groups of related genes in a target organism. This could potentially allow for the selective targeting of a target species or group of species while sparing non-target species (Bachman *et al.*, 2013). RNA interference (RNAi) has distinct properties of efficacy and selectivity when compared to other conventional agrochemicals. This is because RNAi is sequence-specific and uses a natural molecule as its active component. The deployment of RNAi technology in insect pest management is made possible by the production of genetically modified (GM) crops that express the RNAi trigger against a target species. This approach has been the subject of numerous studies that have highlighted its potential for controlling insect pests (Pintino *et al.*, 2011). Furthermore, more than a dozen countries have authorized the production of the first genetically modified maize crop (MON87411), which expresses double-stranded RNA (dsRNA) that targets the western corn rootworm, *Diabrotica virgifera virgifera.* The genetically modified (GM) RNAi-based strategy faces several challenges, including the inability to genetically modify certain crop species, high capital costs, and public resistance to GM crops. Due to these challenges, researchers are investigating alternative delivery methods that primarily use exogenous double-stranded RNA (dsRNA) to target pests. Examples of such delivery methods include spraying formulated dsRNA alone or with microorganisms, soaking seeds, soaking roots, and injecting trunks. Numerous studies have shown that exogenously delivered dsRNA to plants or directly to the target insect pest can induce RNAi-mediated silencing in the pest (Joga *et al.*, 2016). Numerous studies have demonstrated that exogenously delivered double-stranded RNA (dsRNA) to plants or directly to insect pests can induce RNAi-mediated silencing in the pest (Lu *et al.*, 2020) investigated the viability of significantly reducing the survival of the pest beetle *Enosepilachna vigintioctopunctata* by exposing it to exogenously administered gene-specific dsRNA. They were successful in killing first and third instar larvae as well as adults after 10, 12, and 14 days by topically applying bacterially expressed dsRNA targeting the *Snf7* gene, which encodes a critical cellular component of endosomal sorting complexes required for transport. Similarly, Ullah *et al.* (2020) found that 41% and 48% fewer individuals survived and produced offspring, respectively, in the cotton-melon aphid *Aphis gossypii* after exposure to dsRNA targeting the chitin synthase 1 gene. Recent studies have demonstrated the potential of RNAi-mediated pest control. However, the choice and effectiveness of the delivery strategy will ultimately depend on the specific features of the target insect species, such as the efficiency of the RNAi machinery, host–pathogen interaction mechanisms, and structural characteristics. One important barrier to the efficacy of RNAi for pest control is the stability of dsRNA in the environment and in the insect digestive tract. Giesbrecht *et al.* (2020) provided proof of the impact of digestive nucleases on RNAi efficacy in the mosquito *Aedes aegypti*. Co-delivery of dsRNA targeting two midgut-specific nucleases with dsRNA targeting a reporter gene led to an increase in silencing efficiency compared to mosquitoes that were not fed the nuclease-specific dsRNA. One way to address the dsRNA persistence issue is to apply bacteria that produce insect-specific dsRNA, rather than applying naked dsRNA. The bacteria could potentially lead to a longer persistence of the dsRNA in the environment and in the insect. Zhang *et al.* (2020) provide proof that application of dsRNA-expressing bacteria could be used to target the leaf beetle *Plagiodera versicolora*.

Interactive RNAi response in insect

RNAi technology may be utilized for insect pest management depending on insect's ability to acquire dsRNA via feeding (environmental RNAi). It is important to note, however, that different insect orders respond differently to dsRNA. Coleopterans, in general, are highly sensitive to RNAi, whereas Hemiptera, Orthoptera, Diptera, Hymenoptera, and Lepidoptera are more variable. RNAi efficiency seems to be affected by several mechanisms in different insect species, including: (1) unstable dsRNA before and after entering the insect; (2) insufficient dsRNA internalization; (3) deficient RNAi machinery; (4) impaired systemic spreading; and (5) refractory gene targets. Different species, life stages, tissues, and genes respond differently across orders, as well as within them (Grover *et al.,* 2019). The stability of dsRNA is a critical factor for its efficacy as an insecticide, regardless of the delivery method. In the environment, naked dsRNA can be degraded by UV light, microorganisms, and rain. UV light can break down the dsRNA molecule, while microorganisms can enzymatically degrade it. Rain can hydrate dsRNA, making it more susceptible to degradation by these factors. The efficacy of RNAi in honey bee larvae was reduced when the dsRNA was attached to royal jelly, the primary component of their diet. Additionally, no mortality was observed in *Diabrotica virgifera* adults that were fed an artificial meal prepared with royal jelly that contained a fatal amount of *Diabrotica virgifera* vATPase-A dsRNA (Velez *et al.,* 2016). The stability of double-stranded RNA (dsRNA) in the insect body is influenced by nucleases from the salivary glands, midgut, and hemolymph. Studies have shown that dsRNA is degraded by saliva in hemipterans, such as the tarnished plant bug and the peach aphid. Similarly, dsRNA is degraded in the hemolymph of the tobacco hornworm and the German cockroach after 1 and 24 hours, respectively. Studies have also shown that midgut juices degrade dsRNA in the silkworm, the desert locust, and the Colorado potato beetle. In the silkworm, dsRNA degrades within only ten minutes of exposure to midgut nucleases. The efficiency of nucleases within insect guts can vary from one species to the next. For example, dsRNA disappeared much faster in the desert locust than in the Colorado potato beetle. A comparative study between two weevil species belonging to the genus Cylas indicated that dsRNA degradation in the gut could be a source of variability, even between two very closely related species (Prentice *et al.,* 2019). Once double-stranded RNA (dsRNA) has overcome the initial barriers of degradation in the environment, it must be internalized into the cell in order to be effective. Two mechanisms of dsRNA cellular uptake have been identified in insects: Sid-like transmembrane channels and clathrin-dependent endocytosis. Sid-like transmembrane channels have been shown to play a role in dsRNA uptake in nematodes, but their role in insects has not been directly demonstrated. Clathrin-dependent endocytosis is the primary mechanism of dsRNA uptake in multiple insect species. Other mechanisms of dsRNA uptake, such as caveolar endocytosis and micropinocytosis, have not been studied in insects.

Conclusion:

RNAi is a natural process that cells use to silence genes. This can be done by introducing double-stranded RNA (dsRNA) into the cell. dsRNA is similar to mRNA, which is the molecule that cells use to make proteins. When dsRNA enters the cell, it is cleaved by an enzyme called Dicer. This produces small interfering RNA (siRNA), which binds to mRNA and prevents it from being translated into protein. In insects, RNAi can be used to silence genes that are essential for the insect's survival. This can be done by delivering dsRNA to the insect in a variety of ways. For example, dsRNA can be sprayed onto the insect, ingested by the insect, or injected into the insect. The effectiveness of RNAi depends on how well it can be delivered to the insect and how long it can remain stable in the insect's body. If dsRNA is not delivered effectively, it will be degraded by the insect's immune system before it can reach the target genes. If dsRNA is not stable in the insect's body, it will be broken down before it can have an effect. RNAi is a promising new technology for pest management. It has the potential to be more effective and safer than traditional pesticides. However, more research is needed to understand the full potential of RNAi and to ensure its safe use. Agricultural ecosystems can be protected from negative consequences associated with broad-spectrum insecticides due to the high specificity of insecticides. The presence of beneficial fauna aids in enhancing the pollination process, while natural enemies help to regulate pest populations below economically damaging levels. Enhancing the efficiency of RNA interference (RNAi) can be achieved through the delivery of double-stranded RNA (dsRNA) using chemically modified molecules, polymer nanoparticles, liposomes, viruses, or bacteria. The selection of a suitable delivery method and formulation depends on various factors such as the specific circumstances, target insect species, and underlying causes of impaired RNAi efficiency. For instance, liposomes and polymers may be employed when limited cellular uptake hampers the insect's response to RNAi. Polymer- or liposome-based nanoparticles and bacteria can be utilized when the main issue lies in maintaining dsRNA stability within the insect's body. Insect virus-mediated delivery might be a viable solution for facilitating cellular uptake, degradation, and situations where the insect is challenging to access, as dsRNA would be promptly produced within insect cells infected by the viruses. Transgenic plants expressing dsRNA can serve as an effective approach to selectively suppress insect pests. However, the extensive regulatory process involved in utilizing transgenic plants can be circumvented through non-transformative strategies that achieve comparable efficiency. The Canadian Food Inspection Agency has approved the release of a GM corn event that uses RNAi to control insects. This is the first time that a regulatory agency has approved a GM crop that uses RNAi. However, other regulatory agencies have not yet established clear frameworks for the regulation of RNAi-based pest control. The EPA has published a white paper on the risk assessment of RNAi-based GM crops, and the European Food Safety Authority is currently collecting information on this technology. The EPA suggests that the risk assessment protocols used for Bt PIPs could be applicable to RNAi-based GM crops, but more research is needed to confirm this. The main challenge in regulating RNAi-based pest control is that the field is relatively new and there are many unanswered questions about its safety. For example, it is not yet clear how specific RNAi is, how it affects non-target organisms, and how it degrades in the environment.

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VEGETATIVE METHODS OF PLANT PROPAGATION IN HORTICULTURE CROPS

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Introduction:

Plant propagation refers to the process of multiplying or reproducing plants through various techniques and procedures. It involves both science and art, aiming to achieve objectives such as uniformity in crops, early bearing, increased production, resistance against pests and diseases, and the introduction of desirable traits in new generations. The propagation of plants plays a crucial role in commercial nurseries, maintaining plant stocks, and conserving endangered species (Hartmann *et al.*, 2011).

Plant Propagation Methods Plants can be propagated by sexual and asexual means. Sexual propagation involves the use of seeds, which contain a miniature undeveloped plant (embryo) and food reserves within a protective seed coat. On the other hand, asexual propagation utilizes vegetative parts of plants, such as shoots, leaves, roots, stems, buds, and underground parts, to create new plants. Common asexual propagation methods include cutting, layering, grafting, and budding, each requiring specialized skills and techniques specific to different plant types (Baskin and Baskin, 2014).

Purposes of plant propagation

1. **Conservation of germplasm**: Germplasm conservation is vital for preserving plant species. During crop expeditions, scientists collect plant material samples intended for research and improvement programs, including the development of new plant varieties. As such materials are often scarce, they need to be increased in quantity while maintaining the original characteristics of the plants (Liu *et al.*, 2019).
2. **Crop production**: Plant propagation on a large commercial scale is essential for producing food to feed the population. Whether using seeds, cuttings, or other methods, the goal in commercial production is to increase or replicate the source of plant material. The success of propagation is determined by how closely the progeny or offspring plants resemble their parent plant (Rajasekar *et al.*, 2013).

Types of plant propagation

1. **Sexual propagation**: Sexual propagation involves the union of pollen and egg, combining the genes of two parents to create a new individual. This method relies on the floral parts of a plant, and it results in genetic variation among offspring.

2. **Asexual propagation**: Asexual propagation, also known as vegetative propagation, entails taking a part of a parent plant and causing it to regenerate into a new plant. The resulting plant is genetically identical to its parent, ensuring the preservation of desirable traits. Asexual propagation uses vegetative parts of a plant, such as stems, roots, or leaves.

Methods of vegetative production

Vegetative propagation is a reliable method of reproducing plants using vegetative parts. These organs possess the ability to regenerate, making this method highly successful in horticulture and agriculture.

One of the common techniques of vegetative propagation is cutting. A cutting is a detached vegetative part of a plant that, when separated and planted, has the potential to regenerate and develop into a new plant. This method is cost-effective and rapid, allowing for the production of numerous uniform plants from a few parent plants without requiring specialized skills (Hartmann *et al.*, 2011).

Stem cutting is a type of vegetative propagation that involves four categories based on the age and maturity of the detached shoots:

1. **Hardwood cutting**: Taken from woody plants, mostly deciduous species, such as rose, grapes, and pomegranate. Cuttings are obtained from one-year-old mature branches and planted in a rooting medium to induce root formation (Baskin and Baskin, 2014).

Procedure

- Select branches of one-year old healthy plants, having pencil thickness. Cut the branches into 10–15 cm long cuttings.
- Long cuttings are used to raise rootstocks for fruit trees. Each cutting must have at least 4–5 dormant vegetative buds. Leaves and thorns, if present, are completely removed. This checks transpiration loss.
- A slanting cut is given at the base of the cuttings just below the node and a straight upper cut is given away from the top bud.
- The cut portion will help identify the planting position. Slanting cut at the base is given so that a large area of the cuttings is in contact with the rooting medium for inducing roots.
- The secretion of hormones at the bud near the cut portion induces rooting. Straight cut at upper end reduces transpiration loss, which can be inhibited by the application of wax.
- The cuttings are planted slant-wise in a nursery bed or small poly bags for growing plants. Callus tissues form the cambium layer and rooting takes place in this region. The best season for planting the cuttings is monsoon for evergreen plants and November–February for deciduous plants. Cuttings can be planted in greenhouse or poly-house for better results

2. **Semi-hardwood cutting**: Obtained from 4- to 9-month-old shoots of current season woody plants. Examples include ornamental foliage plants like croton and nerium. Semi-hardwood cuttings are rooted under mist spray or fog (Liu *et al.*, 2019).

Procedure

- Semi-hardwood cuttings are prepared from branches having pencil thickness. The length of these cuttings varies from 7.5 to 15 cm.
- The cuttings must have at least 4–5 dormant vegetative buds. Some leaves are retained as they help in preparing food by photosynthesis. Large leaves are reduced in size by cutting.
- A slant basal cut is given just near the vegetative bud and a straight top cut must be given away from the bud. The slant cut helps to expose more area of the cambium layer, which helps in more water absorption and callus formation.
- The upper straight cut minimises exposure to the atmosphere, which reduces transpiration loss from the cuttings. It is useful to dip the top of the cuttings in wax to check transpiration and infections.
- Dipping the base of the cuttings before planting in IBA @ 5000 ppm induces early rooting.
- The cuttings are planted in slanting position so that their maximum base is in contact with the rooting medium.
- The planting season for semi-hardwood cuttings is monsoon. Commercially, such cuttings are rooted under mist spray or fog.

Hard wood cutting

Semi Hardwood cutting

3. **Softwood cutting**: Taken from herbaceous or succulent plants, such as alternanthera and clerodendrum. Softwood cuttings are prepared from tender but mature branches and rooted in a sandy loam medium (Rajasekar *et al.*, 2013).

Procedure

Softwood cuttings are prepared from tender but mature branches. The length of these cuttings varies from 10–12 cm. Tender shoots do not have sufficient food material. Hence, all leaves present on the shoots are retained for photosynthesis. The cutting material is gathered early in the morning and must be kept moist by keeping them in a wet cloth. Sandy loam medium is the best for planting softwood cuttings.

4. **Herbaceous cutting**: Obtained from herbaceous plants like chrysanthemum and marigold. Herbaceous cuttings are made from tender succulents, particularly the leafy part of the stems, and rooted under mist (Arzani and Ashraf, 2005).

Procedure

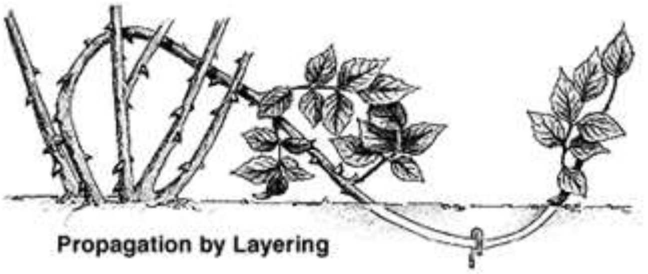
Herbaceous cuttings are made from tender succulents, especially the leafy part of the stems of herbaceous plants. Terminal, measuring 8–12 cm, of a healthy shoot is cut and the basal leaves are removed, leaving the upper leaves undisturbed. The cuttings once detached must not desiccate at the cut and are rooted well under mist. The application of auxins promotes the regeneration of adventitious roots. Sandy loam medium is the best for planting herbaceous cuttings.

Soft wood cutting

Herbaceous cuttings

Layering

Layering is a method of vegetative propagation in which roots are allowed to develop on a covered portion of the stem while it is still attached to the mother plant. Once the roots have emerged and developed, the portion is separated from the mother plant and grows independently as a new plant known as a "layer."



Propagation by Layering

There are different types of layering techniques:

1. **Simple or Tongue layering**: In this method, a partial tongue-like cut is made on a branch. The branch is then bent to the ground, and the treated portion is covered with soil while keeping the top exposed. The layered branches develop roots in a few weeks and can be carefully detached and transplanted to a nursery. Examples include jasmine, ixora, and pyrostegia.

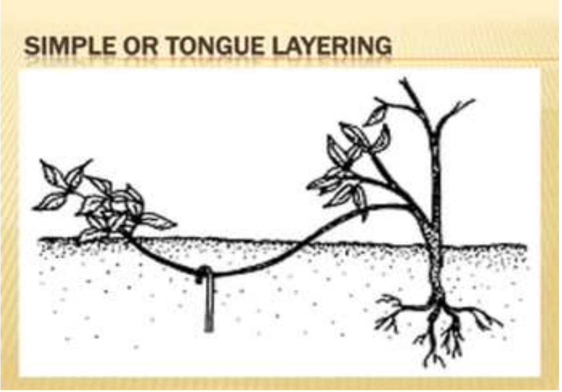
Procedure

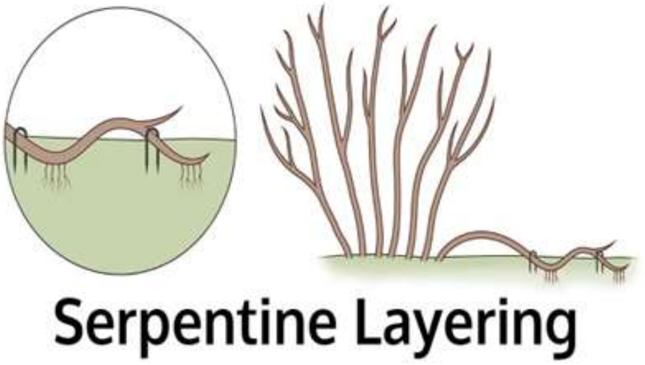
Select one-year old healthy, flexible, long un-branched shoot near the ground level. Remove leaves of the selected shoot, retaining some at the top. The retained leaves prepare food through photosynthesis. Bend down the shoot so that some part of it touches the ground. At that portion, generally, 15−30 cm away from the terminal end, a sharp slanting inward cut of 2−3 cm is given. A small matchstick is inserted in the cut to keep the slit open. Bend down the branch and cover the cut part with soil. Keep some weight or stone over the buried part so that it is not pulled upward, and remains in the same position. A stake is fixed near the layered branch and the branch operated upon is tied with it. Water the layered portion regularly. After 3−4 weeks, rooting starts at the operated portion and this can be indicated by sprouting buds on the shoot. After this, the layer is separated from the mother plant and planted in a new place.

2. **Compound or Serpentine Layering**: Compound layering is similar to simple layering, but the branches are alternately covered and exposed along their length. This method is used in plants like bougainvillea and jasmine.

Procedure

One-year old healthy and flexible long shoot near the ground is selected for compound layering. The selected stem is placed in soil in a way that the nodes at certain distance are covered under the soil and the intermediate internodes are exposed. Remove leaves from the selected branch but retain few leaves at the top. Give two circular cut around the bark about 2.5−4 cm wide. Remove the bark of the operated portion (girdling). Apply rooting hormone to the girdled portion and cover it with soil. The same branch is operated at 3−4 places at certain distance in the same way. The growing shoots, which emerge from the covered portion of the branch, are separated from the mother plant for planting in a nursery.





3. **Mound or Stooling Layering**: This method is suitable for plants with firm branches that are difficult to bend. The selected plant should be in a dormant stage during layering. The upper portion of the plant is cut back, and when new shoots emerge, they are partially buried in loose soil. After a few months, the rooted layers are separated and planted in a nursery. Examples include apple, guava, and pear.

Procedure

Cut back the upper portion of the plant 2.5 cm above the ground level. After few days, new shoots will emerge. When the shoots grow to a height of 7−15 cm and become little sturdy, place loose soil around them so that they are half buried. When the shoots attain a height of

20−25 cm, again add soil around them so that they are half buried. Water the heaped soil regularly. It will take 3−4 months to get the layers. Cut the rooted layers close to the base from the mother plant and plant it in a nursery. Examples are apple, guava, currant, gooseberry, pear, etc.

4. **Air or Gootee Layering**: This method involves selecting a healthy, vigorously growing aerial branch and girdling it below a node. The girdled portion is then covered with moist sphagnum moss and wrapped with polyethylene film to promote root formation. The layer is removed from the parent plant once roots are observed, usually taking 2-3 months. Examples of plants suitable for air layering include Ficus elastica and citrus fruits.

Procedure

Select healthy, vigorously growing aerial branch having pencil-size thickness. The selected branch must be of the past growing season. Girdle the selected branch up to 2−3.5 cm wide just below the node 15–30 cm back from the tip of the shoot. A strip of the bark from the girdled portion is removed. Scrap the girdled portion, which helps in the removal of phloem tissues and prevents formation of bark at the girdled portion. Excessive moisture from sphagnum moss is squeezed out before placing it over the cut portion. A piece of polyethylene film is carefully wrapped around the branch so that the sphagnum moss is completely covered. Both the ends of the polyethylene film are made airtight by tying them with strings. The layer is removed from the parent plant when roots are observed through the transparent polyethylene film. It takes 2−3 months for rooting. Rainy season is the best for air layering.

Mound or Stooling Layering

Air Layering

Plant propagation by grafting

Plant propagation by grafting is an ancient and widely practiced technique that involves joining the tissues of two different plants to create a single composite plant. Grafting is commonly used for propagating fruit trees, ornamental plants, and woody shrubs, as it allows for the combination of desirable traits from both the scion (upper part) and the rootstock (lower part) (Hartmann *et al.,* 2011). This process enables the production of plants with improved characteristics such as disease resistance, faster growth, and increased fruit yield.

The grafting process:

Selection of scion and rootstock: The first step in grafting is to select the scion and rootstock. The scion is the upper portion of the plant that will bear the desired fruit, flowers, or leaves. It is usually a young shoot with several healthy buds. The rootstock, on the other hand, provides the root system and, in some cases, other advantageous attributes such as disease resistance, drought tolerance, or vigorous growth.

Preparing the scion: The selected scion is cut from the parent plant with a clean, sharp knife. The cut should be at a slant and should ideally be made just below a bud. It is essential to keep the scion hydrated and prevent it from drying out during the grafting process.

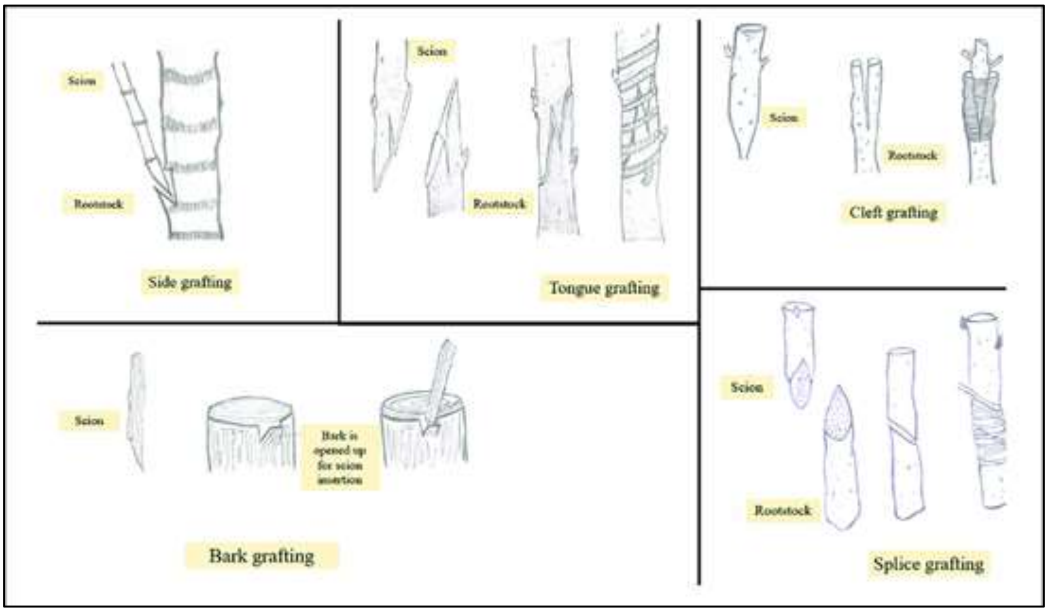
Preparing the rootstock: The rootstock is prepared by making a matching slanting cut on its stem. This cut should also be just below a bud and should align with the cut on the scion to ensure proper cambium contact.

Grafting the Scion to the rootstock: The scion is carefully inserted into the matching cut on the rootstock so that their cambium layers align. The cambium layer is a thin, greenish layer just beneath the bark that is responsible for producing new vascular tissues. Proper alignment of the cambium layers is crucial for successful grafting, as it allows for the flow of nutrients and water between the scion and rootstock (Liu *et al.*, 2019).

Securing the graft: Once the scion is in place on the rootstock, the two parts are securely bound together using grafting tape or specialized clips. This helps to keep them in close contact and promotes successful graft union.

Protecting the graft: After grafting, the joined scion and rootstock are protected to enhance their chances of successful union. This is often done by covering the graft with a grafting wax or sealant to prevent water loss and keep out pathogens.

Post-Grafting care: Once the grafting is complete, the plant is kept in a controlled environment, such as a greenhouse, to promote healing and growth. As the graft union strengthens, the plant can be gradually acclimated to outdoor conditions.



Different types of Grafting

Types of grafting

Whip or splice grafting It is the oldest method of grafting. This method is used in fruit trees like apple, pear, walnut, etc.

Selection of material

Select one-year old rootstock. The rootstock and scion must be of uniform thickness. The scion must be 10 to 15 cm long having 4–5 swollen buds. The rootstock must be in active growth phase and sap-flowing condition. It is mostly performed in early spring season.

Procedure

Head back the rootstock terminally. Give a slanting cut of 2.5−5 cm downwards from the top. Operate similarly but reversely on the scion. On the scion, a slanting cut of the same size is given from the base upward. The cuts on both the stock and scion need to be smooth. Put the operated portions on each other so that they form a single stem. Wrap the union with a polythene tape or a special nursery tape. The tape must be removed after the graft has healed, else the growth is restricted around the union, and such plants break due to the force of wind.

Veneer grafting

Veneer grafting is a cost-effective and straightforward method commonly used for establishing orchards in their natural locations and rejuvenating unproductive older orchards. This technique is particularly well-suited for propagating commercial crops such as mango, cashew, and peach. In North India, the ideal time for veneer grafting is during March to April and July to August. Veneer grafting differs from side grafting in that it involves removing the vertical flap of the stock completely. Subsequently, a slanting cut is made on one side of the scion, which will be grafted onto the stock. The slanting cut ensures better contact between the scion and the stock, enhancing the chances of successful graft union. This method has gained popularity due to its simplicity and efficiency in establishing new orchards or rejuvenating existing ones. By utilizing veneer grafting, horticulturists can effectively propagate desirable fruit tree varieties, leading to increased productivity and improved quality of the yield.

Procedure

- A shallow 3 to 5-cm long downward cut is made on the selected rootstock.
- At the base of the first cut, a short inward and downward cut is made that intersects the first cut.
- In between both the cuts, remove the piece of wood along with the bark by making a small notch in the rootstock.
- The scion is operated with a matching long cut on one side and a short cut on the opposite side is given at the base.
- Insert the scion and fix it in the rootstock. Care must be taken to ensure that the cambium layer matches at least one side of the cut surface.
- Wrap and tie the scion and rootstock firmly.
- Cut back the rootstock above the union after successful union.
- This method is used for grafting conifers, deciduous trees and shrubs.

Side grafting

In this method, the operated scion is inserted into the side of the established rootstock, which has more girth than the scion, e.g., hibiscus.

Selection of material

- A rootstock of 2.5 cm diameter is selected.
- The scion needs to have 3–5 buds and must be about 7.5 cm long.
- The scion must be comparatively thinner than the rootstock.

Procedure

- Use a sharp knife for cutting the scion.
- On the stem of the rootstock, a slanting downward and inward cut of about 2.5–5 cm deep is made.
- A wedge of the same size (2.5−5 cm) of the scion is prepared by two slanting cuts oppositely towards the base.
- The scion is then inserted into the operated rootstock.
- Pour wax and make the operated portion waterproof.
- Wrap and tie the grafted portion to keep it intact.
- After the graft is complete, cut the stock above the union.

Cleft grafting

It is comparatively a simple and an easy method of grafting, which is widely used in fruit trees, e.g., mango, jackfruit, bael, amla, etc.

Selection of material

- The scion must be a terminal shoot with 3–5 buds.
- It must be of the current season and in active growth.
- The scion shoot is defoliated about two weeks ahead of being separated from the mother plant.
- This will help accumulate food in the shoots. As a result, the buds on the shoots become swollen.
- As compared to the rootstock, the thickness (diameter) of the scion may be the same or less.

Procedure

- The rootstocks of required plant species are raised in poly bags.
- The seedling of the suitable rootstock, which is 4 to 5–month old is selected.
- Head back the rootstock.
- A sharp vertical downward cut of 3−5 cm is made in the centre of the stem.
- Two slanting cuts of the same length (3–5 cm) as in the rootstock are given on the sides towards the base on the scion shoot.
- This will give a wedge-shaped appearance to the scion stick.
- The wedge-shaped scion is inserted in the split of the rootstock.

- Insert the scion in a way that it matches the cambium layer at least on one side with the stock.

Grafting offers several benefits, such as reducing the time to fruit production, creating hardier plants, and enabling the cultivation of a wide variety of fruit types on a single tree (fruit salad trees). However, successful grafting requires skill, practice, and attention to detail, as not all plant combinations are compatible. Proper timing, appropriate environmental conditions, and aseptic techniques also contribute to successful grafting outcomes.

Conclusions:

In summary, vegetative methods of plant propagation in horticulture crops offer valuable tools for efficiently multiplying desirable plant varieties. Cutting, layering, grafting, and division techniques each have their advantages and applications. Successful propagation relies on proper selection of materials, timing, and environmental conditions. Commercially, nurseries play a vital role in mass production and distribution of propagated plants. Advancements in tissue culture and biotechnology expand possibilities for conserving biodiversity and rare species. Despite challenges, integration of traditional and modern techniques, along with ongoing research, will enhance propagation efficiency and meet the demands for high-quality horticulture products while contributing to conservation efforts.

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SMART WEED MANAGEMENT PRACTICES FOR DOUBLING FARMERS INCOME

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Abstract:

Modern agriculture with recent advances in production and protection techniques provides large hopes. Conventional weed management has become labour intensive, hence more and more dependence on chemical weed management has compelled farmers to look for alternative methods which are most effective, economical and sustainable. Smart weed management practices such as use of nano-herbicides, bioherbicides, allelopathy, artificial intelligence, site-specific weed management, RNAi technology and integrated weed management act as alternative methods to the conventional practices. Nanocarrier systems have a great potential for agricultural applications in terms of maintenance of herbicidal activity at low concentrations and a substantial increase in the herbicidal efficacy, allelopathy has potential to tackle concerns associated with indiscriminate use of synthetic herbicides. The future of farming depends largely on adoption of cognitive solutions. Thus, in order to explore the enormous scope of AI in agriculture, applications need to be more robust. Only then will it be able to handle frequent changes in external conditions, facilitate real-time decision making and make use of appropriate framework/platform for collecting contextual data in an efficient manner. An open-source platform would make the solutions more affordable, resulting in rapid adoption and higher penetration among the farmers.

Keywords: Nanoherbicides, Bioherbicides, Allelopathy, RNAi technology, Artificial Intelligence (AI)

Introduction:

Weeds are considered as an important biotic constraint to food production. Their competition with crops reduces agricultural output in terms of quantity as well as quality, and increase cost of cultivation involved in the control of weeds (Zimdhal, 2013). It is also a major constraint to increase agricultural productivity and farmers' income, particularly in developing countries like India (Yaduraju and Mishra, 2018). Weeds are the most underestimated crop pests in tropical agriculture although they cause higher reduction/loss in the yields of crops than other pests and diseases. Of the total annual loss of agricultural produce from various pests in india, weeds roughly account for 45%, insects for 30%, diseases for 20% and other pests for 5% (Rao, 2000). In reference to the percentage of yield loss due to weeds, the maximum loss is seen in groundnut (35.8%) followed by soyabean (31.4%), green gram (30.8%2), maize (25.3%), sorghum (25.1%) and direct-seeded rice, mustard (21.4%) (Gharde *et al.*, 2018) as shown in (Fig

1). Herbicide, an agent, usually a chemical, for killing or inhibiting the growth of unwanted plants, such as residential or agricultural weeds and invasive species (Rao, 2000). Vast number of methods are available for the control and management of weeds viz., manual weeding, mechanical weeding, bioherbicidal approach and chemical herbicide application, great advantage was observed for chemical herbicides over mechanical weed control mainly in terms of ease of application, which often saves on the cost of labour (Das and Yaduraju, 2012). But, application of herbicides aerially can significantly kill off non-target plants and the insects that depend on them (Mahanta *et al.*, 2021) and continuous application over decades led to the development of herbicide resistant weed populations. There are few new herbicides with distinctive modes of action to reverse this trend, and in many cases, there are no viable economic alternatives to herbicides in large-acreage crops. The world population is growing at the same time, requiring more food to be produced in order to feed the estimated 9 billion people that will exist on the planet by the year 2050 (Cole *et al.*, 2018). Here, we take into account these difficulties as well as recent developments in technology and innovation that raise the possibility of sustainable weed control in the future. New modes of action may be discovered, as evidenced by the emergence of natural product leads in the development of new herbicides and biopesticides, and by the additional options provided by genetic engineering for modifying herbicide selectivity and developing wholly new methods of weed management. Insights into plant-plant interactions imply that crops can be improved by controlling their response to competition, and advancements in our understanding of plant pathogen interactions will lead to the development of new biological control agents. The ability to discriminate between weeds and crops can be provided with the help of GPS (global positioning system) along with automation helps in achieving precision weed control. Based on the deeper understanding of weed biology and ecology, it is possible to integrate old and new weed management technologies into more varied weed management systems can result in integrated weed management and resistance management strategies which will be more enduring than the dwindling current technologies.

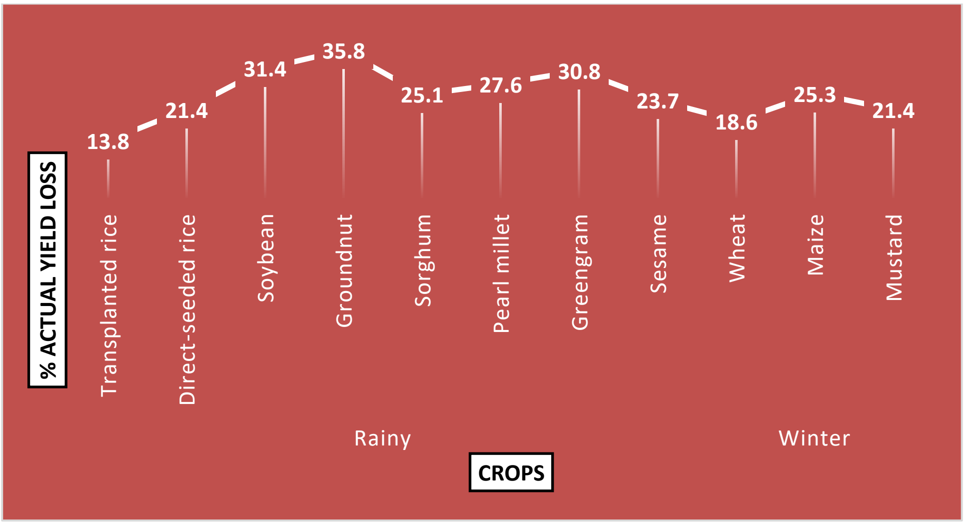

Figure 1: Percentage of yield loss due to weeds (Gharde *et al.*, 2018)

Smart weed management practices

The process of minimizing the weed population and their growth below the level of economic injury to the crop with minimum environmental pollution – Weed management. Smart weed management practices are those which are highly efficient, labour saving and sustainable (Table 1).

Table 1: Conventional *vs* smart weed management

Conventional weed management	**Smart weed management**
High labour requirement	Less labour requirement
High dose of herbicide	Low dose of herbicide
Repeated applications	Fewer applications
Less effective	More effective
Herbicide resistance in weeds-high	Herbicide resistance in weeds-low
Environmental pollution-high	Environmental pollution-low

The smart weed management practices include:

1. Nanoherbicides
2. Bioherbicides
3. Allelopathy
4. RNAi technology
5. Artificial intelligence
6. Integrated Weed Management

1. Nanoherbicides

Nanoherbicides are formulated by exploiting the nanotechnological potential for effectual delivery of pesticides with the help of nanosized or nanomaterials-based herbicide formulations. Nanomaterials or nanostructures materials-based formulations could improve the efficacy of the herbicide, enhance the solubility and reduce the toxicity in comparison with the conventional herbicides. The management of perennial weeds and the depletion of the weed seed bank are issues that are being addressed through the development of nanoherbicides. Nanostructured formulations have the potential to more precisely time the release of their active ingredients in response to biological needs and environmental cues through processes like targeted delivery, slow/controlled release, and conditional release. According to studies, using nano fertilizers improves the efficiency with which nutrients are used, lessens soil toxicity, reduces the frequency of treatment, and minimises any potential side effects from overdosing. Because of this, nanotechnology, especially in underdeveloped nations, has a tremendous potential for attaining sustainable agriculture. The main advantages of using Nano herbicides includes

a) Reduction of the amount of chemical substance required for crop management
b) Could be good carrier
c) Protection of premature degradation
d) Enhancement of absorption into plant tissue
e) Enhanced bioavailability
f) High retention time

g) Increased safety for those applying pesticides
h) Reduction of residue amounts in food stuff

Early weed control with the use of nanoparticle-based herbicide release systems could reduce the herbicide resistance potential, maintain the activity of the active ingredient and prolong their release over a longer period (Manjunatha *et al.,* 2016). A glyphosate-resistant crop was reported to be made susceptible to glyphosate upon addition of a nanotechnology-based surfactant on to a soybean micelle. Nanoparticles can act as good carrier and also can form nano formulation when added with herbicides. These nano formulations assist in overcoming the main drawback of herbicide industry such as evolution of herbicide resistant plants. In a study by Abigail *et al.* (2016) an attempt was made to use nanosized rice husk waste as nanocarrier for 2,4-dichlorophenoxyacetic acid herbicide (2,4-D). The rice husk waste was brought down to nano size and was surface adsorbed with 2,4-D to act as herbicide nano- carrier. The rice husk nanocarrier showed enhanced and reversible sorption of 2,4-D, illustrating its uniqueness to act as good carrier for encapsulating herbicides. The adsorption of 2,4-D on to the rice husk was not found to minimize the herbicidal activity when tested against target weed, *Brassica sp.* in comparison with free 2,4-D. Atrazine's herbicidal action was amplified when it was encapsulated in PCL micro capsules. Even at a 10-fold dilution, it maintained post-emergent weed control and had no lingering harmful effects on the non-target crop of maize (Oliveria *et al.,* 2015). Kannamreddy *et al.* (2021) conducted field trials and revealed that sulfentrazone @ 0.30 kg a.i. ha^{-1} with encapsulation applied at 1 DBS is better alternative for the season long weed management in blackgram without affecting the soil and ground water by reducing the vertical and horizontal leaching, as well as increasing the productivity in comparision to the application of sulfentrazone without encapsulation and pendimethalin herbicide followed by hand weeding.

2. Bioherbicides

Bioherbicides are living entities/inoculums of plant pathogens such as fungi, bacteria, nematodes and other microbes that act as a natural means of weed control and are generally applied by inundative approach. Bioherbicides are derived either from plants containing phytotoxic allelochemicals or certain disease-carrying microbes that can suppress weed populations (Hasan *et al.,* 2021). The potential advantages of bioherbicides such as (i) high degree of specificity of bio-herbicides to the target weeds (ii) ecological and eco-friendly approach (iii) minimizes health hazards to humans and animals (iv) no development of herbicide resistance in weeds (iv) Controls perennial, parasitic and invasive weeds in non-cropped areas. Some of the are given in the (Table 3).

Herbicide resistance and pollution have resulted from an overreliance on chemical herbicides for the control of economically significant gramineous weeds. The creation of a biocontrol method may be an optional strategy for controlling weeds. A number of field trials were conducted by Tan *et al.* (2022) to evaluate the potential of *Bipolaris panici-miliacei* strain SX5-2 which was isolated from diseased *Microstegium vimineum* plants for a bioherbicide against pathogenicity, host range test, crop sensitivity, culture, mass production and formulation development. Pathogenicity experiments on *M. vimineum* under greenhouse circumstances revealed a percent incidence of up to 90% and greater than 80% in the field at a conidial suspension concentration of 105 conidia/ml. The experiments on host range tests were carried out on 57 different species of 17 families revealed that *B. panici-miliacei* strain SX5-2 was found harmless for cereal crops (rice, wheat, sorghum), soybean, cotton, vegetables, *Zoysia japonica* turf and most dicotyledonous plants but maize and sugarcane were severely infected. The strain was able to suppress the seven gramineous weeds tested—*Digitaria sanguinalis, Panicum virgatum, Echinochloa crusgalli, Microstegium japonicum, Microstegium nodosum, Sorghum sudanense, and Leptochloa chinensis* in the main dryland and paddy areas, according to pathogenicity bioassays. Studies on culture and mass production have shown that sawdust mixed with bran followed by solid fermentation can be used to produce conidia in large quantities. *B. panici-miliacei* may therefore have a promising future as a bioherbicide for the biocontrol of grass weeds in most crops, but not in sensitive crops such as maize or sugarcane, based on virulent pathogenicity and practicable mass production.

Table 2: Examples of bioherbicides and their targeted weeds

Product	**Description**	**Target weeds**
Devine	*Phytophthora citrophthora p.v. palmivora*	Strangler vine (Lethal root-rot)
Collego	*C. gleosporoides f.sp. aeschynomene*	Joint vetch (Blight)
Biomal	*C. gleosporoides f.sp. malvae*	Round leaved mallow (Anthracnose)
VELGO	*C. coccoides*	*Abutilon theophrasti*
ABG5003	*Cercospora rodmanii*	*Eichornia crassipes (leaf spot)*
Dr. BIOSEDGE	*Puccinia canaliculate*	*Cyperus esculentus*
Bipolaris	*Bipolaris sorghicola*	*Sorghum halepense*

3. Allelopathy

Allelopathy refers to the inhibitive/detrimental effects of one plant species on the germination, growth and metabolism of another plant species due to release of chemicals. It includes all stimulatory, inhibitory reciprocal biochemical interactions among plants including microorganisms (Molisch, 1937). Allelopathy is a natural, environmentally friendly strategy and an exceptional method for controlling weeds, enhancing crop yield, reducing our dependence on synthetic pesticides, and recovering the biological environment (Aslam *et al.,* 2016). It is also a viable substitute for synthetic herbicides in terms of weed control (Jabran, 2017). Various plant extracts have allelopathic nature and are effective at suppressing a variety of weeds growth and germination, including weeds that are herbicide-resistant, and can be used as soil or foliar bioherbicides. The potential of mugwort (*Artemisia vulgaris* L.) aqueous extract as a bioherbicide to manage *Amaranthus retroflexus* L. in maize was examined in a study by Pannacci *et al.* (2020). In order to assess mugwort's (*Artemisia vulgaris* L.) potential as a bioherbicide, this study assessed its allelopathic effect on the germination and growth of redroot pigweed (*Amaranthus retroflexus* L.) and maize (*Zea mays* L.) seedlings. The existence of bioactive chemicals in the mugwort aqueous extract was qualitatively investigated, and it was used in Petri dish and pot bioassays to quantify its effects on maize and amaranthus by non-linear regression analysis in accordance with the log-logistic model. Numerous bioactive substances with allelopathic activity were present in the aqueous extract of mugwort, including organic acids, polysaccharides, flavonoids, and terpenoids (Table 3).

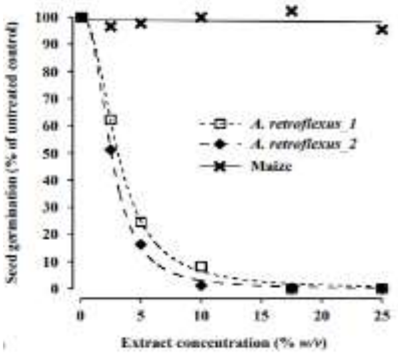

Figure 1: Aqueous extract as a bioherbicide to manage *Amaranthus retroflexus* L. in maize

Table 3: Allelopathic Extracts and plant extracts have allelopathic nature to supress weed growth

Crop	Allelopathic extracts + herbicides	(%) decrease over control	Weeds suppressed	Reference
Wheat	Isoproturon @ 400–500g a.i. ha^{-1}+ Sorghum extract (12 L ha^{-1})	85.5	*Phalaris minor, Melilotus parviflora, Coronopus didymus*	Cheema *et al.* (2003)
Cotton	S-metolachlor @ 715–1,075 g a.i. ha^{-1}+ Sorghum extract @ 12–15 L ha^{-1}	81.25	*Cyperus rotundus*	Iqbal and Cheema (2008)
Sunflower	Pendimethalin @ 413ml a.i. ha^{-1} + Sorghum extract @ 15 L ha^{-1}	72	*Chenopodium album, Melitotus indica*	Awan *et al.* (2009)
Maize	Atrazine @ 125–250 g a.i. ha^{-1}+ Sorghum + Brassica + Sunflower +Mulberry extracts @ 20 L ha^{-1} each	74.67	*Trianthema portulacastrum*	Khan *et al.* (2012)

The aqueous extract of mugwort was found to be most effective at concentrations between 7.5% and 10% w/v because it can prevent redroot pigweed seed germination, seedling emergence, and plant growth without affecting maize seed germination and seedling emergence, or rather, by promoting the growth of the plant's radicle, mesocotyl, and plant. EC90 values showed that the germination of redroot pigweed was reduced to 6.1% and 6.2%, radicle length to 8.1%, 3.8% and hypocotyl length to 3.2%, 5.7% in two repeated bioassays respectively. In addition to this application of plant extracts containing allelochemicals along with the herbicides, controlled weeds efficiently than herbicides alone as shown in (Fig. 1).

4. RNAi Technology

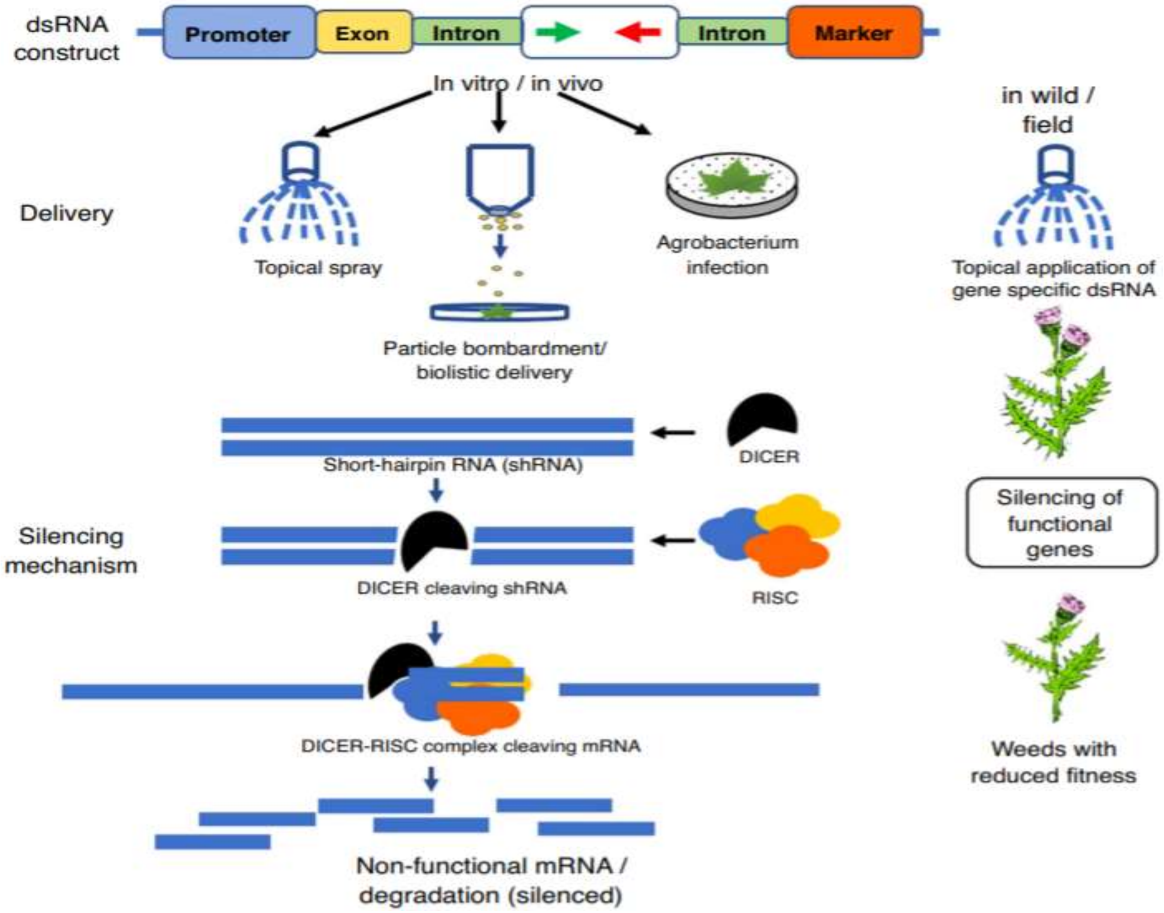

Figure 2. Mechanism of RNAi technology

Table 4: Some important particulars of RNAi technology

Particulars	**RNAi technology**
Heritability	Non-heritable mostly, heritable if the effect is epigenetic
Sustainability	Augmentative/ repeated application is necessary
Weed targets	Possibly in weeds of crops, and isolated populations of weeds
Difficulty with achieving population suppression	Comparatively easier with stable dsRNA, efficient delivery and repeated applications
Delivery mechanisms	Exogenous application of dsRNA specific to genes of interest

RNA interference (RNAi) is a powerful gene-silencing tool and has potential to control herbicide-resistant weeds and also acts as an alternative tool to add to the integrated weed management programs (Zabala-Pardo *et al.,* 2022). Spray-induced gene silencing (SIGS), also known as sprayable RNAi, has been proposed as a next-generation weed control strategy (Table 4). Small RNAs (sRNA) that target the mRNA of genes encoding for i) herbicide targets, ii) deadly phenotypes when transcription is decreased or deleted by RNAi, and iii) normal growth and development are intended to be sprayed on weeds (Yoder *et al.,* 2009; Duke and Heap, 2017). sRNAs would be designed to selectively target a weed or a group of related species (Westwood *et al.,* 2018) as depicted in (Fig. 2).

RNAi has made significant strides in entomology and plant pathology, but its advancement in weed research has been slower. Sammons *et al.* published a patent in 2011 describing how to use SIGS to silence the enhanced expression of EPSPS in *Amaranthus palmeri* to reverse glyphosate resistance and reintroduce glyphosate as a weed-control agent. Different targets, sRNA sizes, and delivery techniques were investigated. The endogenous and systemic silencing of reporter transgenes like Green Fluorescent Protein (GFP) and Neomycin Phosphotransferase II have been assessed in more recent SIGS publications.

Why RNAi technology for controlling weeds has not developed as quickly as other crop protection fields???

The possible reasons that led to the slow pace of development of this technology in weed management are:

a) The stability and delivery of sRNAs inside plants
b) The close relatedness of many weeds with crops, at the genus or even species level, creates challenges to identify weed-species specific regions of genes to target;
c) Availability of sequenced and annotated genomes for weeds; and
d) sRNAs production costs.

5. Use of Artificial Intelligence in weed management

Artificial intelligence is a branch of computer science that deals with the simulation of intelligent behaviour in computers. As quoted by Sudipto Ghosh, “Artificial Intelligence is not a Man versus Machine saga; it's in fact, Man with Machine synergy”. AI has the ability to transform the way we think about agriculture by bringing about numerous advantages to farmers by allowing them to produce more with less work. However, AI is not a self-contained technology, it is the next phase in the transition from conventional to creative farming and can support already implemented technologies. The integration of robotics, artificial intelligence (AI), and various sensors ensure the possibility of a better outcome by implementing various agricultural tasks, including weed detection and removal (Jha *et al.,* 2019). The application of technological gadgets embedded with Artificial Intelligence (AI) in agriculture is currently yielding significant results in weed detection and improving crop yield, thus necessitating the need to consider the technological roles of Artificial Intelligence in Weed detection (Onashoga *et al.,* 2018). Despite the fact that weed distribution is often uneven, the majority of traditional sprayers apply agrochemicals uniformly, wasting valuable compounds and increasing costs, the risk of crop damage, pest resistance to chemicals, environmental pollution, and product contamination. A study conducted by Gerhards and Oebel (2006) found that an average of 60% herbicide savings when spraying annual broadleaved weeds and up to 90% savings in annual grass weeds through patch sprayer in comparision to the conventional method of spraying**.** Partel *et al.* (2019) conducted a trial on development and evaluation of a low-cost and smart technology for precision weed management by creating a smart sprayer utilizing artificial intelligence with two different scenarios of identify target weeds from non-target crop plants under artificial and real conditions. The powerful GPU (NVIDIA GTX 1070 Ti) achieved an overall precision of 71% and recall of 78% (for plant detection and target spraying accuracy) on the most challenging scenario with real plants, and 91% accuracy and recall for the first scenario with artificial plants.

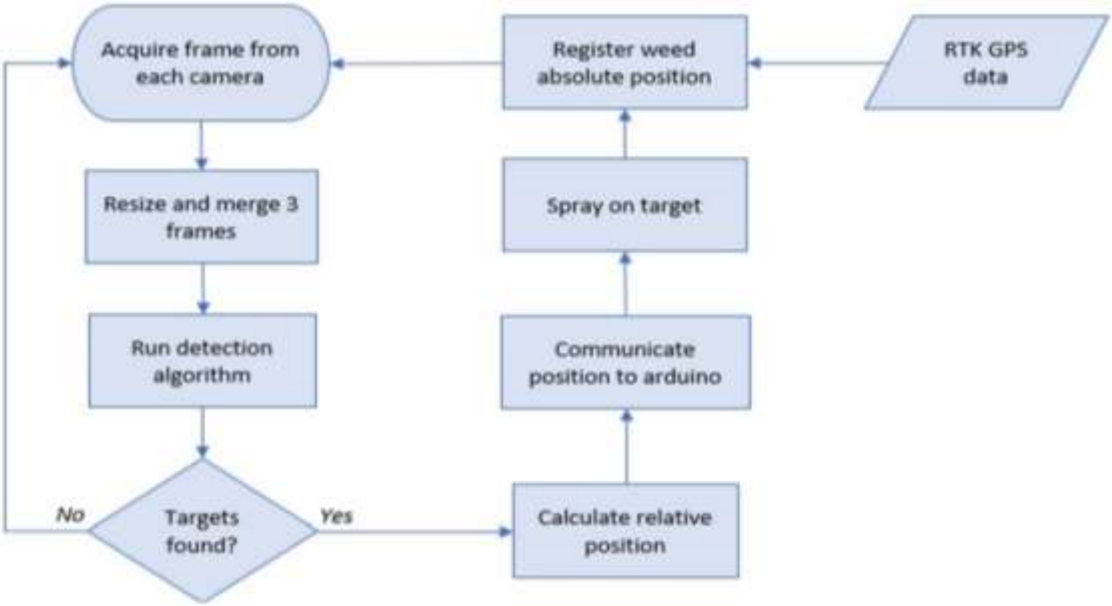

Figure 3: Flowchart of smart sprayer operation

Integrated weed management practices

Weed science must advance as a crucial component of agricultural output by engaging in complicated problem-solving through cross-disciplinary research. This indicates that weed science must shift from its mono-disciplinary perspective on targeting weeds, often a single species, through an overreliance on a small number of single herbicide modes of action to the inclusion of diverse techniques to attain sustainability. (Lamichhane *et al.*, 2016; Smith *et al.*, 2006). Weed science has been left wanting for a strong theoretical foundation rooted in evolutionary and ecological disciplines (Neve *et al.*, 2009). Therefore, there is a great need for a new weed management paradigm in modern agriculture (Bajwa, 2014) based on ecological principles and nonconventional weed management approaches. Information for this need can be harnessed already from the literature on weed demographics and population dynamics within crops and cropping systems, weed eco-physiological aspects and weed-crop interactions where weeds are considered as intrinsic elements of the agroecosystem in which crops and weeds coexist. These approaches may offer more durable weed management solutions to lessen problems of herbicide resistance, environmental pollution, weed diversification, weed invasion, and yield losses (Chauhan, 2013; Chauhan *et al.,* 2010; Singh, 2007; Travlos, 2012). The "many little hammers" concept (Liebman and Gallandt, 1997) and the "use of technological advancement" (Young *et al.,* 2017) are two major IWM components that are gaining momentum (Harker and O'Donovan, 2013; Menalled, 2018). The former refers to a combination of interconnected control tactics with a cumulative impact on weed abundance and weed-competitive ability; the latter refers to the use of crop improvement, remote sensing, decision support systems, or other modern technologies (Harker and O'Donovan, 2013; Menalled, 2018). As the number of herbicide-resistant weed ecotypes increases, and the discovery of new herbicide modes of action (MOAs) declines (Strek, 2014), the need to utilize all available weed management options is crucial.

Future thrust:

When it comes to handling realistic challenges faced by farmers - using autonomous decision making and predictive solutions to solve them, farming is still at a nascent stage. Much effort is needed to fully understand weed population dynamics and their competition with crops so as to implement the approach in real agricultural contexts. Navigating all these aspects to balance the risks, costs and benefits of these approaches will be crucial for the safe and sustainable use of weed management. Universities and government laboratories should create new positions devoted to novel approaches to weed management. Regulatory modifications and incentives that smooth the way for innovation in weed control would also be valuable in accelerating implementation of research advances over the next decade. The future of farming depends largely on adoption of cognitive solutions. While large scale research is still in progress and some applications are already available in the market, the industry is still highly underserved. In order to explore the enormous scope of AI in agriculture, applications need to be more robust. Only then will it be able to handle frequent changes in external conditions, facilitate real-time decision making and make use of appropriate framework/platform for collecting contextual data in an efficient manner. Another important aspect is the exorbitant cost of different cognitive solutions available in the market for farming. The solutions need to become more affordable to ensure the technology reaches the masses. An open-source platform would make the solutions more affordable, resulting in rapid adoption and higher penetration among the farmers. Thus, in the current scenario, the overuse of herbicides to boost the crop production has left the soil, ground water and food products polluted. Therefore, development of systems that would improve the release profile of herbicides without altering their characteristics and novel carriers with enriched activity without significant environmental damage is the focus areas that require further investigations.

Conclusions:

Scientific and technical understanding of the specific goals and available technology is necessary to rapidly advance in this field. Smart weed management practices not only contribute to increased crop yields and economic viability for farmers but also promote long-term environmental sustainability. By striving for a balanced approach that considers both economic and ecological factors, we can effectively address the challenges posed by weeds while safeguarding our natural resources for future generations. Adopting integrated weed management practices, including diverse strategies, preventive measures, precision technology, natural controls, responsible herbicide use, adaptability, education, and collaboration, is crucial for maintaining healthy agricultural and natural ecosystems. These smart weed management approaches enhance productivity while minimizing environmental impacts, promoting sustainability and a harmonious coexistence with weeds for a prosperous future.

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INSECT: A TOOL FOR WEED MANAGEMENT

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Introduction:

The Chinese learned long ago that increasing ant numbers in their citrus trees reduced damaging populations of big boring beetles and caterpillars. The first instance of biological control was when a pest was controlled by a natural opponent. Today, biological control research and application are even more important and advanced. The potential for using weed eating exotic and indigenous organisms as biological control agents are being gradually investigated. In addition to traditional approaches, biological control is a strategy for managing weeds which is favourable to the environment. Due to nondirectional use of chemicals, some weeds have developed a resistance to some herbicides. The over reliant on chemical control of weeds has notorious issues which are worse to solve, so for that demand for novel weed management techniques has got vital necessity. Biocontrol agents focus on specific weeds. Furthermore, both users and applicators of this technology can handle it safely.

Weeds as invasive pest:

Plants that are growing unpredictably are referred to as weeds. For instance, water hyacinth, while lovely in floating gardens, can quickly choke streams and impair transportation. Similar to corn stalks, morning glory is lovely in the garden but may ruin a farmer's harvest if it entangles them.

What does biological weed control entail?

Utilising organisms that exist, such as insects, nematodes, bacteria, or fungus, to suppress weed populations is known as biological weed control. In nature, naturally existing creatures regulate the biology of plants. When plants proliferate due to the lack of or diminished effectiveness of their natural enemies, they are referred to as "weeds" and turn into pests. When a plant is put into a new area or when people disturb the ecological system, the natural cycle may be disrupted. By deliberately introducing biological control agents, we can improve or restore the natural systems before being to ruin.

Role of biocontrol agent?

Plants receive water and nutrients through their roots. Some biological pesticides cling to roots and prevent plants from growing normally. On the surfaces of the roots, specific microbes produce poisons that inhibit root development. Numerous fungi affect roots and interfere with the water transport system, which slows the growth of leaves. Beneficial insects and nematodes eat directly on the roots of weeds, injuring them and opening them gate way for entry of bacteria and fungus. Sunlight is absorbed by plant leaves, which then store it as sugar. Feeding insects limit the amount of leaf surface that may be used to absorb energy. The innate ability of fungi and bacteria to infect leaves reduces the leaf's capacity to produce sugars. There is less energy available for weed growth in either scenario. Severe biological control agent can actually kill weeds by damaging their roots or leaves, decreasing their negative impact on desirable plants. By generating seeds, many weed species are able to persist from year to year. The quantity of weed seeds stored in the soil can be decreased by fungi or insects that prey on seeds, which in turn can lower the size of weed populations in the nature. This reduces the amount of energy required to eradicate the remaining developing weeds. When used as biological control agents, some bacteria and fungi do not endure from year to year. Each year, these organisms must be administered regularly which termed as "bioherbicide" approach to manage unwanted and noxious weed. This strategy uses biological agents in a way that is comparable to the usage of chemical herbicides. Foreign introduced weeds frequently call for a different approach. Pathogens and insects are gathered at the place of origin and assessed before being released in a newer area. Often, it takes a while for insect agents to reach their peak efficiency. Unfavourable weather conditions frequently impede their growth. To ascertain their efficacy, long-term surveillance is required. The "classical" approach to biological control refers to the release of organisms that act as biological controls in this way.

Criteria / qualities of a successful bio-agent

Host-specific:

Bioagents must be host-specific and must not harm other species of economically important plant life. They must pass the starving test, meaning they would rather starve to die than consume anything other than the host weeds. The insect bio-agent, *Teleonemia scrupulosa* managed to control lantana. However, it is likely to harm sesame; *Sesamum indicum* and teak; *Tectona grandis* in India. An efficient leaf-eating bio-agent against Parthenium (carrot grass) is *Zygogramma bicolarata*. But in India, it has been discovered to harm sunflower.

Bioagent hardiness:

The biological agent must be free to attack of its own parasites and predators. When the target weed, population is reduced to a low level, the bio-agent should be able to endure famine for either brief or extended periods of time. Carp, however, cannot endure even a brief period of famine.

Feeding habit:

In comparison to root and leaf feeders, bio-agents are more effective in controlling weeds when they target the flowers or seeds or pierce weed stems. Perennial weeds can be more successfully managed by insects that feed on their roots.

Ease of multiplication:

The natural reproduction rate and ease of a bio-agent should be high. For diseases, snails, insects and aggressive plants, it is crucial. With carp, however, it is undesirable because of the rising population's impact on wild fish.

Types of classical bio-agents

Both specific and non-specific bioagents are possible. While non-specific bio agents graze on a range of plants, particular bio agents target just one or two types of weeds. Insects, plant infections and competitor plants are examples of specific bio agents. Carp fish, snails and mites are examples of general bioagents.

Six types of bio-agents were used to control weeds

Insects

These are typically host-specific, meaning that just one insect species is used to eradicate the one species of weed and the first successful instance was *Lantana camara* controlled by the moth *Crocidosema lantana* and it was reported from Hawaii in 1902. Lepidoptera, Hemiptera, Coleoptera and Diptera are insect orders that have been discovered to be productive.

Carp fish

Aquatic weeds are heavily consumed by some freshwater carp species. The Chinese grass carp, or Whiteamur, is a promising species of "*Ctenopharyngo donidella*" for controlling aquatic weeds. This has a growth rate of 5 kg per year and may reach a maximum weight of 50 kg when fully grown. Fish that consume just plants are omnivorous. In contrast, the common carp; *Cyprinus carpio*, a non-herbivorous fish, is utilised to manage aquatic weeds that are submerged.

Plant pathogen

Numerous fungi target certain weed species. For instance, *Cephalosporium zonatum* spore suspension-controlled *Acacia glauca*. The rust-causing fungus *Puccinia chondrillana* controls the plant known as skeleton weed (*Chondrilla juncia*).

Competitive plants

Some plant species compete aggressively to control particular weeds. *Eleocharisa cicularis*, a water plant, may cover the canal bottom and prevent tall, harmful plants from growing there. *Panicum purpurascens* and *Brachiari amutica* (Para grass) are capable of suppressing the growth of *Typha* grass. *Parthenium* spp. may be replaced with marigold or senna.

Slender spikerush

Brachiari amutica, Marigold displacing *Parthenium*

Snail

Aquatic weeds are the main food source for the giant tropical freshwater snail *Marisa cornuarietis*. Marisa eats salvinia leaves, water lettuce and water hyacinth roots.

Merits

- Less harm to the environment
- No residual effect
- Relatively cheaper and comparatively long-lasting effect
- Safe to non-targeted plants and safer to use
- Very effective at converting weed vegetation into seafood for some fish, snails and other animals
- Restrict the future spread of adventitious weeds
- Reduce the cost of cultivation of crop, ultimately increase the farmer income

Demerits

- Very few hosts-specific bio-agents available

- Multiplication is more expensive
- Control is extremely sluggish
- Success of control is quite restricted
- Lack of awareness

Mode of action

a. Differential growth patterns, the capacity of crops to compete and crop types also inhibit the development of weeds. For instance, cowpeas and groundnuts grow quickly and are excellent weed suppressants.

b. By depleting the plant's food supply, defoliating the leaves, damaging into the plant's structure and weakening will cause plants to die.

c. The host plants are harmed by pathogenic organisms by the enzymatic breakdown of cell components, toxin generation, disruption of hormone systems, impediment to the movement of nutrients and minerals and dysfunction of physiological processes.

Ratification of insects for the control of weeds

It is the most well known and effective biocontrol agents for eliminating the severe weed issues. The insect that is chosen for weed biocontrol must be able to measure the amount of its plant host and in turn, assess its own abundance through interaction. The bioagents of weeds must be predator and parasite free, target specific damaging organisms with a high degree of environmental adaptability. It must be able to multiply effectively to keep up with the expansion of its host species (Table 1).

Table 1: Common weeds and their biocontrol agents

Weed		**Biological control agent**	
Common name	**Scientific name**	**Common name**	**Scientific name**
Water hyacinth	*Eichhornia crassipes* (Mart.)	Water hyacinth weevil	*Neochetina eichhorniae* Warner
Prickly pear	*Opuntia* spp.	Cactus moth, cochineals	*Cactoblastis cactorum, Dactylopius* spp.
Gajar Ghas, Carrot Grass	*Parthenium hysterophorus*	Mexican beetle	*Zygogramma bicolorata* Pallister
Lantana	*Lantana camara*	Lantana leaf beetle	*Crocidosema lantana, Octotoma scabripennis*
Purple loosestrife	*Lythrum salicaria*	Loosestrife root weevil,	*Hylobius transversovittatus, Galerucella* spp
Alligator weed	*Alternanthera philoxeroides*	Alligator weed *Flea beetle*	*Agasicles hygrophila, Disonycha argentinensis* Jacob
Coco-grass, Java grass, Nut grass	*Cyperus rotundus*	Javelin moth	*Bactra verutana*
Water lettuce, Nile cabbage,	*Pistia stratiotes* L	Water lettuce weevil	*Neohydronomus affinis* Hustache

Diffuse knapweed	*Centaurea diffusa*	Broad-nosed seed head weevil	*Bangasternus fausti* (Reitter)
Spotted knapweed	*Centaurea maculosa* Lam.	Sulfur knapweed root moth	*Agapeta zoegana Linnaeus*
The tansy ragwort	*Jacobaea vulgaris*	Ragwort seed fly	*Botanophila seneciella* (Meade)
The common broom or *Scotch broom*	*Cytisus scoparius*	Broom seed beetle	*Bruchidius villosus* (Fabricius)
Ragweed	*Ambrosia artemisiifolia* L	Ragweed borer	*Epiblema strenuana* (Walker)

Effectiveness of insect bioagents as weed antagonists

Since they may fully destroy the weed plants and can help to reduce their general growth, vitality and reproductive capacity, insects that can harm various portions of weed plants are more likely to manage the weed population. The management of water hyacinth by *Neochetina eichhorniae* (mottled water hyacinth weevil) and *Orthogalumna terebrantis* Wallwork (water hyacinth mite) is an example of how different species can be used together if one cannot sufficiently kill the weed on its own. This may increase the level of control by causing more damage to the weed plants. Pests species that damage a plant root or shoot system are more destructive than defoliators and flower-feeding species. These killers have more dramatic effects on their control and can quickly destroy the plant. The seed-feeding biocontrol agents are more effective against weeds that grow from seeds or fruits. The main obstacle for phytophagous insects is that they are few in number. Due to the fact that these insects are vulnerable to parasitism, predation and harmful illnesses, different species are only present in small numbers, mostly during the vulnerable periods of the weed plants' life cycles. For instance, the larvae of the noctuid *Eulocastra argentisparsa* may entirely kill the seeds of a single *Striga angustifolia* (Witch weed) plant, yet their natural populations are always quite small. They are known to contract a microsporidian illness. The overall number of seeds produced by *Striga* plants in an infected area cannot be greatly reduced by *Eulocastra* because it cannot establish its population early enough.

Major weeds and their control by insects

West Indian Lantana:

Fast-growing perennial, woody shrub *Lantana camara* Linnaeus, sometimes known as lantana, is a native of Central and South America. It has become a significant poisonous invasive plant in many nations, damaging both agricultural and natural environments. One of the worst weeds of many crops, including cotton, coffee, oil palm and coconuts. Lantana contains triterpenoids in its leaves and seeds, it is also poisonous to sheep and cattle. In early 20th century, this was the first weed ever targeted for traditional biological management. Since then, 36 insect species have been distributed in 33 countries to reduce the weed population. In order to bring Lantana insects to Hawaii, Koebele went to Mexico and Central America to gather them. Only eight of the total number of imported insects survived and spread; The lantana seed fly, *Agromyza lantanae* Froggatt. Other insects include the stem galling fly, *Butreta xanthochaeta*

Aldrich. Two butterflies, *Thecla echion* Linnaeus (Red-spotted hairstreak) and *Thecla bazochi* Godart (Lycaenid butterfly). *Trachyderes succintus duponti* Aurivillius, 1912; and *Dorcacerus barbatus* (Olivier, 1790) are the two other longhorn beetle species linked to *L. camara*. Over 95% of the individuals discovered were *Dorcacerus barbatus*

Lantana seed fly

Lantana camara

Longhorn beetles

Water hyacinth:

Eichhornia crassipes (Mart.) Solms- Laub., known as water hyacinth, is a harmful aquatic weed that grows freely and either as an annual or perennial. It is indigenous to South America. One of the most pervasive aquatic invasive weed in the world, it has been linked to significant ecological and social impacts. It frequently creates dense, interconnecting mats, changes the quality of the water and reduces the levels of heavy metals, nitrogen, phosphorus and phytoplankton as well as other impurities. Water hyacinth was initially introduced in 1884 for its lovely blossoms and since then, it has spread to many tropical and subtropical areas worldwide. Due to its lovely bluish-violet blossoms, it was viewed as an aesthetic plant when it first arrived in India in the State of West Bengal in the early 19th century. Today, it is referred as the Bengal terror, blue devil or noxious weed. It has negative consequences on aquatic life in addition to the commercial uses of surface waterways, such as navigation, irrigation and fishing.

Water hyacinth

Water hyacinth weevil

Water hyacinth weevil, *Neochetina eichhorniae* Warner a natural enemies of *E. crassipes* in Argentina and South America, was taken into account for the environmentally friendly management of water hyacinth by biocontrol agent. Male and female are both cryptic, dull-brown in colour and when they become wet, they get mottled. The four phases of the life cycle *viz.*, eggs, larva, pupa and adult take place over the course of around 92 days. The larval stage has five instars and lasts for around 46 days. The 32 day pupal stage is located in the submerged root zone. Typically there are three generations every year. The epidermal layers of the laminae and petioles are removed when they feed on the leaves of *E. crassipes*, leaving behind the plant's distinctive rectangular scars. Females are also reported to pierce the epidermis and create holes in which they lay solitary eggs. Females have a lifespan of more than 50 days and can deposit up to five eggs every day. The plants rot, die and submerge as a result of the larval instars' internal tunnelling through the petioles and into the crowns of the plants.

Congress grass

Congress grass, *Parthenium hysterophorus* Linnaeus has gained international significance, is the most common of the different weeds. Due to its invasiveness, ease of spread and other adverse effects on the economy and ecology, this plant is considered as worst weeds in India. More than 5 million hectares of the country land is under its jurisdiction, which is extensively scattered in wastelands, pastures, deteriorated soil, water canals, railway tracks, desolate regions, hillsides and agricultural fields. As a result, it is mostly known as a weed of no man's land.

Congress grass

Mexican beetle or Parthenium beetle

The most noticeable bioagent is the leaf eating beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae). With the exception of the pronotum, which has off white patches at the anterior borders and the elytra, which have undulating dark brown longitudinal lines, the adults of *Z. bicolorata* measure 5 to 6 mm in length, are off white in colour and the remaining of the body and appendages are dark brown. While the rear margin of male is somewhat serrated at the tip, the female posterior margin is whole. On leaves, flower heads, stem surfaces, terminal and axillary buds, females deposit eggs individually or in groups. The freshly born instars gorge themselves on axillary and terminal buds. To reach adulthood, the grubs pass through three moults. A few hours to a day before they bury themselves in the soil to pupate, fully developed larvae remaining on the underside of leaves and stop feeding. The whole developmental period taken 27 to 29 days. Larval and pupal stages lasting for 11 to 13 and 10 to 12 days, respectively. There can be up to four generations each year, depending on rainfall and food availability and the entire life cycle lasts 6 to 8 weeks. Beetles live up to two years in adult stage and they typically hibernate for about six months beneath the earth (about three centimetres deep) during fall and winter. *P. hysterophorus* has been found to be a poisonous plant by chemical analysis and Z. *bicolorata* has enormous ability to detoxify and metabolise the poisons of this weed. The Parthenium plant suffers significant damage as a result of *Z. bicolorata* defoliation and voracious feeding. Damage to the plant meristems causes the primary stem to grow more slowly, the plant branching pattern to change, which produce fewer flowers and root and shoot biomass decreases as the defoliation period lengthens.

Prickly Pears:

Prickly pears are member of the genus *Opuntia*, some of which species are regarded as weeds or potential weeds. The species *Opuntia* is widely utilised as fodder, forage, fruit and a green vegetable in Mexico and Guatemala, where it appears to be native. The subtropical, semi-arid and warmer temperate regions are more favourable. This species is most frequently found at roadsides, railroads, pastures, meadows, open forests, rangelands, disturbed sites and waste areas. They are little shrubs or trees with succulent stems that are cylinder-shaped or flattened and are covered with spines.


Prickly Pears


Cactoblastis cactorum


Cactus moths

For the biological management of this weed, wild cochineal insect; *Dactylopius indicus* Green and cactus moth; *Cactoblastis cactorum* (Berg) were introduced. Insects introduced before *C. cactorum*, such as the Tomentose Cochineal Scale, *Dactylopius tomentosus* Lamarck, the Leaf footed Bug, *Chelinidea tabulata* (Burmeister) and the Desert Spider Mite, *Tetranychus desertorum* Banks. All other insect species that were utilised for the biocontrol of prickly pears were entirely dominated by *C. cactorum*. While *Opuntia dillenii* (Ker Gawler) was likely imported much earlier, *Opuntia vulgaris* Miller and *O. elatior* Miller were introduced in India in the year 1787 for the commercial production of the cochineal insect, valuable for its dye. The cochineal insects, *Dactylopius indicus* Green, which reportedly came with the imported *Opuntias*, had long been successfully controlling *O. vulgaris*.

Alligator weed:

The Alligator Weed, *Alternanthera philoxeroides* (Mart.), is a South American invader that has spread to tropical and mild-temperate climates all over the world. In Florida, Arizona, California, Florida and South Carolina, it is a forbidden plant and a noxious weed. A perennial herb that may grow on land or in water, alligator weed has long, fibrous roots. Pink, hollow stems can grow up to 1 m in length and have opposing, thin elliptical leaves. It often grows in dense mats along the edge of lakes and streams. However, it can also grow on land when lacks and stream dry. For biological management of this aquatic weed, the alligator weed flea beetle, *Agasicles hygrophila* Selman was the first insect ever investigated. The alligator weed is killed by the beetle by depleting its food reserves and obstructing photosynthesis by removing leaf tissues. Alligator weed stems are frequently stripped bare by the larvae and adults who consume the plant leaves.


Alligator weed


Alligator weed flea beetle

Witch weed:

Striga hermonthica Benth is an annual herbaceous hemi parasitic plant often known as purple witch weed or giant witch weed. The most vigorous type, which may grow to a height of 30 to 100 cm. Mostly found in Ethiopia and Sudan. It is harmful to important crops like rice, *Oryza sativa* and sorghum, *Sorghum bicolor*. These hemiparasites cling to and enter the roots of agricultural plants before feeding on the nutrients of their host, which stunts the host plant development. *Smicronyx* spp. weevils are known to decrease seed output through gall-forming, however no successful biological control programme has been created using these weevils. The attempts to introduce *S. albovariegatus* and the noctuid moth, *Eulocastra argentisparsa* to Ethiopia from India appear to have failed. Other organisms that might be helpful in managing it include the following: The African leaf butterfly, also known as the eared commodore or *Precis tugela* Trimen, is thought to be an effective tool for weed management. The leaves, buds and capsules of many *Striga* species are consumed by the butterfly larvae.

Witch weed

Eared commodore or African leaf butterfly

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