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Preface

The field of agriculture has undergone remarkable advancements and transformative changes in recent years, driven by scientific and technological innovations. These trends have played a pivotal role in shaping the future of agriculture, addressing global food security challenges, promoting sustainable practices, and maximizing crop productivity. This compendium, titled "*Current Trends in Agricultural Sciences & Technology*", endeavors to offer a comprehensive exploration of the latest trends, research findings, and emerging paradigms in agricultural sciences. It seeks to bridge the gap between theoretical knowledge and practical applications, providing valuable insights into the transformative potential of scientific innovations in the agricultural domain. The chapters encompassed within this volume encompass a diverse array of subjects, encompassing Nano technology, smart farming systems, Natural Farming, water saving techniques, millets, Agroforestry for climate and more. These contributions delve into cutting-edge trends, unveiling their implications for sustainable and efficient agricultural practices.

The authors of this compendium comprise a distinguished cohort of researchers, scientists, and experts, each hailing from specialized fields within agriculture science and technology. Their invaluable expertise and profound insights provide nuanced perspectives on the present state and future directions of the agricultural landscape.

Dated: 24-08-2023

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Minakshi Bezboruah
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(Editors)

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Chapter - 1

Agronomic Intervention for Increasing Productivity of Minor Millets

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In 1950 Millets are group of small grained cereal food crops belongs to the family poaceae which are highly nutritious. It has anessential role in the traditional diets of many regions throughout the country. Millets are an important food crop at a global level with a significant economic impact on developing countries. India is the largest producer of rice, wheat, and other cereals. India's cereals production stood at a record 297.5 million tons in 2019-2020. Production and productivity of rice, wheat, maize other dominant crops have been increasing due to advanced technology, which replaced the production and productivity of other important crops such as minor millets. Area under millets are cultivated have shown a steep decline between 1956 and 2006. Small millets are idyllic crops to cultivate in diverse soils, climates and harsh environments and require low inputs. Despite their nutritional qualities and climate resilience, the area under small millet cultivation is declining due to shift in area to other remunerative crops, lack of awareness and low production levels. The need of the hour is to focus on enhancing cultivation and increasing production through improved agronomic practices. Various agronomic interventions like sowing time, use of HYV, nutrient management, irrigation management and weed management should be adopted to increase the productivity of minor millets.

Keywords: *Agronomic interventions, climate resilient, HYV, nutrient management, irrigation management, weed management*

INTRODUCTION

The diverse group of small-seeded grasses known as millets is widely cultivated around the world because of its high nutritional value. This diverse group of coarse grains or grasses is cultivated worldwide for grazing and human consumption. Mostly, they are grown in semiarid tropics in Africa and Asia, dominantly in south India and Nigeria. Even 97% of the world's production takes place in developing countries. Millet thrives in shallow clay soils less than 15 cm deep and is ecologically adaptable to many conditions. Millet farming shows that a changing climate will reduce rainfall, increase heat, use less water, and cause hunger. Relatively small millet seeds thrive in dry climates.

Millet cultivation suggests that climate change means less rain, more heat, less water, and less malnutrition. Millet seeds are relatively small and grow well in dry areas. It is a drought-resistant crop that can be stored for a long time without pests. It is mainly suitable for dry cultivation, but its cultivation value is reduced due to the labour-intensive cultivation method. India is the largest producer in the world. Although total sorghum production in India has increased in recent years, small-scale sorghum production has significantly declined over the decades, from 5.29 million hectares to 0.97 million hectares. Karnataka is the largest producer of foxtail millet in India. Millet accounts for more than 58% of the world's production, but few people are aware of and benefit from its health and nutritional benefits.

Small millet is known as a nutritive grain and is used as an excellent source of fodder. It tolerates water stress, is resistant to pests and diseases, and can be grown in areas with uneven rainfall. Pearl millet (*Pennisetum glaucum*) is cultivated the most, while secondary millets include foxtail millet (*Setaria italica*), proso millet (*Panicum miliaceum*), kodo millet (*Paspalum scrobiculatum*), little millet (*Panicum sumatrense*), and Barnyard millet (*Echinochloa colona*). This secondary group can be considered small millets. Due to many factors, it is to be believed that the decline of secondary millets in Indian agriculture, economy, and society is the main reason why millets are known as a nutritious forgotten tonne crop.

The Green Revolution of the 1970s meant that government subsidies for rice and wheat pushed small-mill varieties deeper into the periphery. Continued neglect accelerates the loss of genetic diversity and traditional knowledge of millet production, processing, and utilization. Production is inefficient due to a lack of suitable high-yielding varieties, poor seed quality, and unimproved cultivation methods. Traditional processing forces women who make a million dollars to do a lot of hard work every day. In addition, there is a lack of attractive recipes to create value, a lack of awareness of the nutritional value of millet, weak integration of the organization into the market, and a generally unfavorable environmental policy. But small innovations also offer an interesting opportunity to close the food gap that plagues the world. Recent estimates state that raising yields to 50% of potential yield in all underperforming areas might raise annual production by 8.46 % 1014 kcal, or around 850 million, to fulfill demanded human caloric needs." In the case of foxtail millet, the difference in yield is largely due to existing cultivation techniques, which leave much room for improvement. The seeds are usually obtained from farms, but they are of poor quality because farmers are not able to select and save the seeds correctly.

Nutritious grains such as millet are not only a rich source of nutrients and medicinal properties compared to staple grains eaten every day but also contain sulphur and amino acids such as methionine and cysteine. I am here. Millet is not only rich in nutrients but also has many health benefits. Regulates blood pressure, reduces the risk of colon cancer, ensures a balanced diet rich in antioxidants, supports weight and weight loss, and prevents the risk of cardiac arrest, *etc*.

Types of millets

There are 9 types of millet, 5 of which are small millet; they are prosomilium (*Panicum miliaceum*), fox millet (*Setariaitalica*), small millet (*Panicum sumatrense*), millet (*Echinochloa colona*) and code millet (*Paspalum scrobiculatum*).

Minor millets

Proso millet: The common and significant minor millet known as proso millet (*Panicum miliaceum* L.) is a member of the Gramineae family. In India, a lot of this short-lived millet type is farmed. It is adapted to hot, humid climates in the tropics and high altitudes; its short season crops are grown on marginal, infertile soil that requires little water. Plains and high altitude regions are good for its growth. It possesses a mechanism for escaping drought and matures quickly. The primary carbohydrate in grains is starch. They make great livestock fodder. After seeding, harvesting happens 70 to 80 days later. It has a protein content of 12.5% and significant levels of both carbohydrates and fatty acids. It is the least expensive source of manganese when compared to other plants. It also contains a lot of calcium content, which is essential for bone repair and growth. It lowers cholesterol and heart disease risk.

Fig.1: Proso millet seed Proso millet crop

Foxtail millet: Foxtail millet (*Setaria italica* L.), commonly known as Kanni or Kakum in Hindi, is one of the oldest cultivated millets grown in over 23 countries. It was originally introduced from China in 8700 BC. This is a self-pollinated C4 cereal with a short shelf life. Millet is the second largest millet producer in the world. In India, it is mainly cultivated in Andhra Pradesh, Karnataka, Telangana, Rajasthan, Maharashtra, Tamil Nadu, Madhya Pradesh, Uttar Pradesh, and some in north-eastern India. It is also grown in the province cultivated, rich in carbohydrates. Millet contains 12.3% protein and 32 mg of vitamin A per 100 g. Grains are important sources of beta-carotene and contains minerals such as copper and iron. Highly nutritious, with a sweet, nutty flavour, it's one of the most digestible and

Fig. 2: Foxtail millet seed Foxtail millet crop

allergy-friendly cereals on the market. This millet oil is an excellent source of natural oil rich in linoleic acid and tocopherols.


Fig. 3: Little millet seed Little millet crop

Little millet- Little Millet (*Panicum sumatrense*) belongs to the Poaceae family and is smaller than other types of millet and is commonly called Kutuki and Shabang in Hindi. It is a fast-growing, short-lived crop that withstands both drought and floods. It is an important food and fodder plant. The majority of the tribal food was domesticated in India's Eastern Ghats, and it later moved to Sri Lanka, Nepal, and Myanmar. Primarily in the tribal regions of Madhya Pradesh, Chhattisgarh, and Andhra Pradesh is where cultivation occurs. Per 100 g of grain, millet has 1.7 g of minerals, 9.3 mg of iron, 5.3 g of fat, 8.7 g of protein, and 75.7 g of carbohydrates. Per 100 g of grain, millet has 1.7 g of minerals, 9.3 mg of iron, 5.3 g of fat, 8.7 g of protein, and 75.7 g of carbohydrates. Due to its high fiber content, it reduces fat deposits in the body. It prevents constipation and solves all stomach problems. Millet is high in cholesterol, good for growing children and makes the body strong. Carbohydrates are digested slowly, which is beneficial for diabetics.


Fig. 4: Barnyard millet seed Barnyard millet crop

Barnyard millet: Barnyard Millet is important small millet grown in India. This millet plant belongs to the *Poaceae* family. It is grown as a fodder and food crop in the foothills of many Indian states. Millet is very nutritious and is cooked like rice after husking. It is one of the fastest growing short-lived plants. Some varieties are harvested after 6-8 weeks. Rapid maturation allows the plant to avoid periods of drought. This annual crop is grown in India as a substitute for rice when rice fields are dry. It is grown as forage and bird seed in the United States and can be harvested up to eight times a year. Nutritionally, millet is an excellent source of protein and an excellent source of fiber, which is easily digestible and rich in soluble and insoluble fractions. Since diabetes is becoming more and more common these days, millet can be an interesting food for diabetics.


Fig. 5: Kodo millet seed   Kodo millet crop

Kodo millet: Domestic millet crop kood millet - the world's oldest grain *Paspalum scrobiculatum* originates from Africa and was domesticated in India thousands of years ago. It is a drought tolerant plant. This millet is grown in arid and semi-arid regions. In India, millet is grown in the Deccan region and the foothills of the Himalayas. Kodo-awa is rich in fiber and iron. Kodokibi has lower phosphorus content than other millets and its antioxidant capacity is much higher than other millets. Processing processes such as steaming and blanching affect mineral content and fiber but reduce nutritional factors such as phytates. It is high in protein (11%), low in fat (4.2%) and very high in fiber (14.3%). Contains many B vitamins, especially niacin, pyridoxine, folic acid and minerals such as calcium, iron, potassium, magnesium and zinc. It is rich in lecithin, which helps strengthen the nervous system.

Global scenario of millets

Millets are gaining increased recognition and popularity worldwide due to their nutritional benefits, climate resilience, and suitability for sustainable agriculture. The majority of the world's millet cultivation occurs in Africa and Asia, where they are a family of small-seeded grasses that have been farmed for thousands of years. Globally, out of the 93 countries only seven nations have more than one million ha of millets under cultivation of millets. According to FAO statistics (2020), the world production of millets was 30.5 million metric tonnes from an area of 33.6 million hectares with productivity 1229 kg/ha. India led by 41% of world’s total followed by Nigeria and China by 11% and 9% respectively are the largest producers of millets in the world, accounting for more than 55% of the total global production. In general, developing countries produce and consume more than 97% of the millets worldwide. Africa produced 42.3 million tonnes of millet in 2021, followed by Asia (21.5 million tonnes), America (19.3 million tonnes), and Europe (2.1 million tonnes) and recognized as the top millet-producing regions (FAO statistics, 2021).

India is the top millet producer in the world and the fifth-largest millet exporter globally, according to the global millet production situation. In 2021-22, United States produced 11.4 million metric tonnes of sorghum; making it the world's greatest producer of the grain followed by Nigeria produced about 6.7 million metric tonnes. Additionally, sorghum accounts for 65% of all millet production. Sorghum output ranges from 58.70 million metric tonnes to 60.18 million metric tonnes between the years 2010 and 2020, with the sorghum area being relatively consistent between 42.16 million and 40.98 million hectares.

Over 90% of the world's millets are produced from the two main millet crops, sorghum and pearl millet with productivity of sorghum (1426 kg/ha), pearl millet (850 kg/ha), which are followed by finger millet, foxtail millet, proso millet, barnyard millet, little millet, and kodo millet. Among the minor millets, foxtail millet predominates millets in terms of productivity of about 2166 kg/ha followed by finger millet (1623 kg/ha), proso millet (1535 kg/ha), barnyard millet (1034 kg/ha), little millet (469 kg/ha) and kodo millet (419 kg/ha).

Indian status of millets

In India, millets have a long-standing cultural and agricultural significance. Millets have been traditionally grown and consumed in various regions of the country, particularly in rural areas. Globally, India is the largest grower of millets with 26.6% of the world and 83% of Asia’s millet cropping area. Since ages, millets have been an integral part of tribal food in the states

Like Odisha, Madhya Pradesh, Jharkhand, Rajasthan, Karnataka, and Uttarakhand. The area under cultivation of millets has been changed from 12.29 to 15.48 million ha from 2013-14 to 2021-22. According to FAO statistics, India produced about 17.3 million tonnes of millets under the area of 13.8 million ha with productivity of 1239 kg/ha. Pearl millet production accounts for around 40.51% which holds half of total millets production followed by sorghum. After rice, wheat, and maize, pearl millet is the fourth most extensively grown food crop in India. It has a 6.93 million ha area, produces

8.61 million tonnes on average per year, and has a productivity of 1,243 kg/ha. On an area of 8.87 million hectares, India produces the most barnyard millet (99.9%), kodo millet (100%), and small millet (100%) out of all the minor millets, amounting to roughly 12.46 million metric tonnes.

Generally, sorghum and pearl millet are two primary crops that mainly grown in India. In the desert sections of Rajasthan and in some parts of Gujarat, mainly pearl millets are grown. However, in states like Telangana, Andhra Pradesh, Maharashtra, and other parts of Central India, sorghum is seeded as a significant crop. Additionally, it is regarded as a fodder crop in some southern regions. Similarly, finger millet is a primary crop in Tamil Nadu and Gujarat. Among all the states, Gujarat and Andhra Pradesh have demonstrated higher levels of productivity as compare to other states. Over the past few years, the states of Gujarat and Madhya Pradesh have increased the area planted with millets. The largest yields were recorded in Andhra Pradesh of around 2626.58 kg/ha followed by Tamil Nadu, Haryana, Gujarat and Madhya Pradesh of 2153.22 kg/ha, 1906.78 kg/ha, 1762.05 kg/ha and 1729.70 kg/ha respectively. However, in term of highest area under millets cultivation is Rajasthan of around 29.05% followed by Maharashtra, Karnataka, Uttar Pradesh, Madhya Pradesh, Gujarat and Tamil Nadu of 20.67%, 13.46%, 8.06%, 6.11%, 3.94% and 3.74% respectively.

The growing environment and the amount of rainfall in the area have a significant impact on the geographical distribution of millets, whether as a primary crop or as allied crops. In regions with annual rainfall of more than 400 mm, sorghum dominates; in regions with annual rainfall of less than 350 mm, pearl millet rivals it (20). However, in most of the southern and central states of India, particularly where the annual rainfall is less than 350 mm, minor millets including little millet, foxtail millet, proso millet and barnyard millet are found.

The Government of India has recognized the importance of millets and has implemented various initiatives to promote their cultivation, consumption, and commercialization. Some notable initiatives include:

- Millets are one of the focal crops for the National Food Security Mission (NFSM), which aims to boost their productivity and output through technical interventions, capacity building, and financial support for farmers.

- With the start of the Smart Food Initiative, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) hopes to increase global consumption of millets as well as other nutrient-dense and climate-smart crops.
- In order to guarantee farmers a fair return on their investment and promote millet cultivation, the government has established minimum support prices (MSP) for millets.
- Millets have been recommended as a way to combat hunger and increase food security because of their nutritional advantages.
- Since the United Nations has declared 2023 to be the "International Year of Millets," India can expect to see an increase in activities and campaigns to promote the consumption of millets and look into export potential.

Nutritional importance of millets

Millions of people throughout the world depend on different millet varieties as key staple foods along with other cereals. They are more important for sustaining agriculture and providing food security since they are often rain-fed crops grown in dry areas with little rainfall. Millets are high in nutrition and dietary fibre, protein, vitamins, and phyto-chemicals are all found in them in good amounts. They are gluten-free which making them suitable for people with dietary restrictions and those managing diabetes. The millets provide a good source of 7-12% protein; 2-5% fat, 6-75% carbohydrates, and 15-20% dietary fibre. Millets are incredibly gluten-free, and high in calcium, iron, phosphorus, and other micronutrients. They have a low glycemic index, which means that it allows not to significantly increasing the level of blood sugar. As millets contain dietary fibre that can bulk up and absorb water. It extends the time that food spends in the digestive system, reducing the risk of inflammatory bowel illness and acting as a body cleansing agent. Similar to cereal proteins, millet proteins are weak sources of lysine; nevertheless, they combine well with lysine-rich animal, vegetable, and leguminous proteins to create composites with high biological value that are nutritionally balanced. Also, millets play a significant role in ageing and metabolic illnesses due to the presence of phytates, polyphenols, tannins, anthocyanins, phytosterols, and pinacosanols. These substances also contribute to antioxidant activity. All millets have strong antioxidant capacities.

Reasons behind declining area of minor millets

India is the largest producer of rice, wheat, and other cereals. India's cereals production stood at a record 297.5 million tons in 2019-2020. Production and productivity of rice, wheat, maize other dominant crops have been increasing due to advanced technology, which replaced the production and productivity of other important crops such as minor millets. Area under millets are cultivated have shown a steep decline between 1956 and 2006. During the same period, wheat and rice which were cultivated in less area than millets in 1955-56, have steadily climbed to overtake millets. Millets plays an important role in rainfed region of the country which contributes 60 percent of the total area. Especially minor millets have very rich nutrients and minerals and resistant to drought and stress in rainfed farming.

During the 19th and 20th centuries, Indian agriculture underwent significant changes due to various internal and external factors. After Independence, India and other developing nations adopted the western development model, abandoning many valuable and meaningful practices, including food habits. Indigenous foods are being forgotten in favour of standardization, and millets have been dismissed as too primitive to be helpful. Eventually, area under millet growing declined from 36 million hectares in 2010 to 33.02 million hectares in 2020, along with their output fell from 32.79 million metric tonnes in 2010 to 30.46 million metric tonnes in 2020. As the demand for millets increasing among the people, more business opportunities are being created for entrepreneurs. Therefore, to increase the area under millets cultivation by addressed through governmental support such as encouraging millet cultivation, building processing facilities in millet clusters, etc., which has the advantage of both generating demand and assuring a steady supply. The millet market is estimated to be worth over USD 9 billion in 2018 and over USD 12 billion in 2025, growing at a rate of over 4.5% over that time. Also, United Nations declared 2023 as the "International Year of Millets" to raise awareness about their importance and potential contributions to sustainable agriculture and food security.

Millets are becoming more and more widely commercialized and marketed globally. They are being added to a variety of foods, including pasta, bread, millet-based cereals, and snacks. As a result, there are chances for farmers, company owners, and agribusinesses to capitalize on the rising demand for millet-based goods worldwide.

Following are the main reason behind the declining area of minor millets:

- Green revolution
- Negligence in development and implementing of production techniques.
- No support in terms of crop loans and crop insurance
- Lack of modern technologies for effective processing and utilization.
- Easy availability of fine cereals like rice and wheat.
- Rapid urbanization.

Constraints in minor millet production

Both abiotic and biotic stress encountered by minor millets which declines the production of minor millets. Drought, low soil fertility, Striga, hermonthica, head miner, birds and downy mildew are the main factors. Socio-economic factors can also constrain pearl millet production Pest and disease pressure is one of the main constraints to millet production.

Agronomic constraints:

- Delayed sowings
- Lack of availability of HYV
- Poor plant population
- Grown on poor soils without any fertilizers
- No profitable cropping systems
- Weed infestation during initial crop stages
- Unavailability of protective irrigation during terminal drought

Socio-economic factors:

- Lack of input availability and higher dependency on natural resources
- Lack of proper marketing and credit system,
- Low levels of socioeconomic development
- Limited infrastructure
- Lack of institutional capacity

Agronomic intervention to increase productivity of minor millets

Small millets are idyllic crops to cultivate in diverse soils, climates and harsh environments and require low inputs. Their grains contain higher protein, fibre, calcium and minerals than the widely consumed fine cereals, and can ensure nutritional security to the poor people who cannot afford dietary diversity. These crops are last standing crop in times of severe drought and are considered as wonder grain that has a capability to enhance nutritional security in the country. Despite their nutritional qualities and climate resilience, the area under small millet cultivation is declining due to shift in area to other remunerative crops, lack of awareness and low production levels. The need of the hour is to focus on enhancing cultivation and increasing production through improved agronomic practices.

- Selection of improved varieties/cultivars: Development of high yielding varieties with wide adaptability resulted in increased production despite the decline in area under cultivation.

- Climate and soil requirement: Millets are hardy crops and can withstand harsh environmental conditions better than other cereals. They can be grown in both tropical and sub-tropical regions. Millet has wide adaptability to different soil from very poor to very fertile and can tolerate a certain degree of alkalinity. The best soils for their cultivation are alluvial, loamy and sandy soil with good drainage

- Land preparation: Millets require fine tilth for crop establishment, initial root and shoot development. One ploughing followed by 2–3 harrowing and cross plantings is necessary to obtain fine tilth. Levelling of fields is necessary for adequate drainage

- Optimum time of sowing: Millets are grown in almost all the seasons of the year. The best time for sowing *kharif* crop is last week of June to first week of July depending on the onset of monsoon. Whereas *rabi* crop is sown in the month of October-November and summer crop in the month of January–February. In Bihar and Uttar Pradesh, these crops as grown as irrigated catch crop in the month of mid-March to mid-May.

- Seed rate and spacing: Optimum seed rate and spacing ensures higher yield in millets. Seed rate depends on the method of sowing and seed size. The line to line distance at the time of sowing should be 20-30 cm and plant to plant distance should be 10-15 cm.

- **Fertilizers/nutrient management**: Millets respond well to fertilizer application especially to nitrogen (N) and phosphorus (P). The recommended doses of fertilizers vary from state to state and with seasons. Judicious use of organic and inorganic manures enhances the fertilizer efficiency. Entire P_2O_5 and K_2O should be applied at sowing, whereas nitrogen should be applied in 2 or 3 split doses depending upon moisture availability. In areas of good rainfall and moisture availability, 50% of recommended nitrogen should be applied at sowing and the remaining 50% in 2 equal splits at 25–30 and 40-45 days after sowing (DAS). In areas of uncertain rainfall, 50% nitrogen at sowing and the remaining 50% around 35 DAS are recommended.

- **Irrigation/water management**: Millets are grown as rainfed crop and do not require any irrigation. However, based on the availability of water, 1 life-saving irrigation and 3–4 irrigations at critical stages of growth *i.e.* tillering, flowering and grain developmental stage needs to be given. Summer crop requires 2–5 irrigations depending upon soil type and climatic conditions.

- **Weed management**: Millets do not compete well with weeds during early growth until 4–5 weeks after planting, thus requires special attention during this phase. Adoption of preventive measures like proper seedbed preparation (to ensure uniform stands), appropriate spacing (to ensure adequate plant populations), covering the soil surface with intercrops or cover crops and practicing proper crop rotation with densely growing legumes suppresses weeds. Application of one pre-emergence spray followed by hand weeding at 20–25 DAS, effectively controls the initial flush of weeds. Inter-cultivation/hand hoeing 2 or 3 times at 3, 5 and 7 weeks after sowing is recommended to check the weed growth, which also helps to conserve soil moisture by providing top soil mulch.

- **Harvesting and threshing**: Harvesting at appropriate time is necessary to avoid shattering and post-harvest losses. The crop is ready for harvest in 70–150 days after sowing depending on the crop and variety.

❖ Cropping system: Small millets fit well in cropping systems. Some of the promising cropping systems are:

- Millet + Black gram/green gram/cowpea
- Millet + Sesamum/soybean/pigeon pea
- Millet + pigeon pea
- Millet + Niger
- Millets + Soybean

CONCLUSION

Minor millet has become an integral part of subsistence farming due to its high nutritional content and better resistance to adverse weather conditions. Agronomically, these crops are superior to major cereals in terms of their lower water requirements, lower incidence of insect pests and diseases, and minimal vulnerability to environmental stresses, in addition to nutritional superiority. In order to increase and maintain millet productivity at the required levels for better food and nutritional security, more emphasis needs to be placed on breeding and adoption of improved agronomic practices. The agricultural systems we need today must be more resilient and diversified to meet the nation's food and nutrition requirements while ensuring sustainable use of natural resources, and therefore the role of smaller millets is inevitable. These can serve not only as a cash crop for farmers, but also improve the health of the community as a whole. The creation of demand for smaller millets and value-added products will boost the millet production and consumption scenario in India, which will have a long-term impact on the industry. Agricultural mechanization should be given equal priority to eliminate the drudgery associated with traditional processing of millets, especially small millets. Government should take measures for incentives to promote millet cultivation. Formulation of policy measures exclusively for minor millets.

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Chapter - 2

Nano-Fertilizers an Emerging Approach for Enhancing Nutrient Use Efficiency and Crop Productivity

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Nano fertilizers are essential resources in agriculture nowadays in order to increase the crop production, quality of food, productivity and boost nutrient uptake by the plants. Nano-fertilizer is an efficient for specific use of nutrients at an appropriate time of plant growth and can also provide nutrients as a whole with the crop plants. Growing crops with intensive fertilizer concentrations further aggravate may be limiting to growth due to toxicity of nutrients. Nano fertilizers provide more surface area for photosynthesis which leads to more sunlight absorption and greater yields of the crop. It will help the plants to survive in challenging environmental factors. Limitations of agricultural land and water supplies can be improving production of crop, land and water use productivity through the use of new technologies. Nanotechnology has the potential of transforming both personal use and development. Nano-structured formulations may also be developed to deliver active ingredients in response to environmental cues and biological demands more properly. The principle of fertilizer use is known to use lesser resource and free from chemical side effects. Nanotechnology has enormous potential to contribute significantly to sustainable agricultural production particularly in developing countries.

Keywords: *A Novel way, Productivity, Growth and Nano-fertilizers*

INTRODUCTION

Innovations in agriculture are an important aspect to meet global food demand because of rapid rise in natural and synthetic resources to the farm. Nanotechnology may also be used to solve a variety of agribusiness related problems. There is a great scientific interest in bridging the gap between bulk materials and molecular structures which can be achieved with the aid of nano particles. In the past decades, lots of researchers on nanotechnology have been performed in agriculture sectors too. Application of fertilizers plays a crucial role in increasing agricultural production however; excessive/ heavier fertilization limits the available land area for crop production. Sustainable agriculture pertains to a minimal use of agrochemicals that can protect ecosystem and spare the different biodiversity from extinction. Nano materials are useful in raising crop production by increasing the quality of agri inputs. Food sustainability is the main challenge in agricultural production as several researches is undertaken to adapt plants to changing climates without affecting the existing ecosystems (Vermeulen *et al.,* 2012). Nanotechnology is also a revolutionary agriculture approaches that can enables the efficient production of agricultural fields (Abbas *et al.,* 2012; He *et al.,* 2014). Nutrient use efficiency is one among the most relevant principles of crop production systems since they are strongly affected by management of fertilizers and soil and plant water relationships. Improving nutrient use efficiency is very relevant and challenging nowadays. Essential nutrients are applied to crops and cropping systems to ensure the optimal production and contribute to crop as well as soil health. Nano fertilizers perform efficiency as in contrast to traditional fertilizers due to high surface area to volume ratio.

Generally, nutrient usage efficiencies of conventional fertilizers are 30-35% (nitrogen), 18-20% (phosphorus) and 35-40% (potassium). In means that nano technology has considerable surface area which is high enough to store various types of nutrients in plentiful quantities for long durations without much relevant side effects of customized inputs (Preetha *et al.,* 2017). Nanotechnology can be used to release nutrients from the membranes. Nano fertilizers can be utilized to protect the negative impacts of fertilizers while boosting the nutrient use efficiency and minimize the nutrient lost through soil degradation. Nanotechnology can also be exploited to increase the food production (Devi *et al.,* 2023).

Nanotechnology is an emerging innovative scientific field introducing the new age of nano agriculture to revolutionize cultivation of crop and nutrition approaches through the use of various novel devices and products for enhancing crop productivity (Subramanian and Tarafdar, 2011). Nano-particles are tiny molecules (ranging from 1–100 nm) having different physico-chemical properties than other bulk materials (Reda *et al*., 2021). Nano-scale exhibits variable properties in comparison to bulk counterparts due to its reduced molecular sizes and altered molecular interactions. This allows the nano-particles to have large surface area-to-volume ratios. Furthermore, the presence of more surface atoms enhances the reactivity. These properties have great potential in agriculture such as increased bioactivity and bioavailability due to greater surface area, more reactivity, and surface and adherence effects.

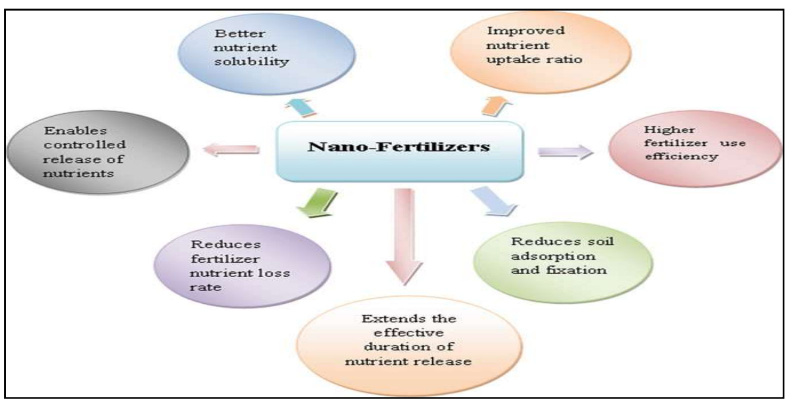

Fig.1: Nano-fertilizers: Improved traits of nutrients over conventional fertilizers

Effect of nano fertilizers on growth of plants

Nano fertilizers have a great role in physiological and biochemical processes by increasing the nutrient availability which facilitates the metabolic processes thus promoting the meristematic activities thereby higher growth and thus photosynthetic leaf area. It is well documented by the researchers, that the foliar spray of nano formulations of NPK and other micronutrients mixture increased plant height and branches in black gram (Marimuthu and Surendran, 2015). It was also observed that the nano NPK increased leaf growth in wheat which was due to enhanced nutrient availability and easy penetration of nano formulation through stomata via gas uptake.

Nano-smart fertilizers for Controlled/Slow Release of Nutrients

Nano-fertilizers are fabricated as controlled/slow release of nutrient fertilizers to ensure the sustained and targeted delivery at cellular levels. This may be attributed due to their unique potential of easy passage through the membrane barriers of plant cell walls thereby causing an altered absorption of the applied nano-fertilizers. Thus, the nano-scale formulations are anticipated to save non-renewable fertilizer sources such as rock phosphates by improving their nutrient uptake potentials by crop(s) and enhanced use efficiency (UE) of applied nutrients in the soil. As the decreasing the fertilizer granule sizes to nano-scale, it is expected to enhance the solubility and dispersion potentials through, an example is of nano-phosphorus fertilizers that derived from sparingly soluble rock phosphates in the soil solution, improved phosphorous availability can be ensured. Nano membranes can be used as a fertilizer coating to facilitate the slow releasing of nutrient supplements. To combat the major issues of overusing inorganic fertilizers, nano-fertilizers can be used. Because of slow rate of discharging, slowly released nano nutrients which may be an alternative to dissolve inorganic fertilizers. Thus, plants will able to absorb majority of nutrients requirements (Huiyuan *et al.,* 2018). In addition, nano materials make the fertilizer particles stronger since their higher surface tension than traditional fertilizers, increasing the efficacy in controlling nutrient release (Figure 2).

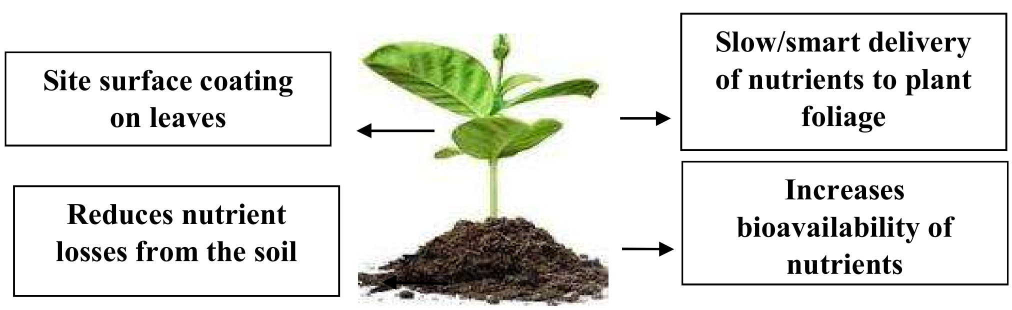

Fig. 2: An overview of nano fertilizers impact on plants

Nitrogen is one of the most important essential nutrient elements for plants. Chlorophyll is key ingredient used in extracting of sugars from carbon dioxide and water by the process called photosynthesis. Proteins are the significant components of amino acids and building blocks of protein. Out of these, some proteins act as a structural unit in plant cells while some as enzymes which carry out important chemical reactions. Nitrogen is also a major component of energy transferring compounds viz; ATP that enable cells to conserve and reuse the energy. It is also a significant part of protein such as DNA which allows cells to develop and reproduce for survival. There are three types of available nitrogen viz; organic nitrogen, ammonium ($NH^{4+)}$ ions and nitrate (NO^{3-}) ions that can be absorbed by the plants. Most of this nitrogen is not available to the plants completely. This is due to the negatively charged nitrate is very unlikely to stick on surfaces of soil particles. To overcome this problem connected with nitrate leaching during the application of fertilizers, several researchers tested various forms of coating material including neem coated urea, sulphur coated urea, polyurethane resin-coated urea. Slow-release fertilizers are too costly and it takes more time to release N. NH_3 can also be regulated by cation exchanger as additives in fertilizer because of ion exchange behaviour.

The quality of crop growth can be assured by applying the nutrients in form of nano fertilizers as nano structured carriers contains "nanoparticle" elements. Enzymes may be inserted into absorbent substrate such as chitosan, polyacrylic acid, clay or zeolite to enhance their use. Utilizing the necessary nutrients in nano structured based therapies (either in suspension or encapsulated). The problem could not always be the quantity of essential elements in soil. But there is problem in distribution of planting materials. When stabilizing nano fertilizers, a variety of methods are used as below:

a) The nano fertilizers are in combination with other partciles such as Hydrogels, biopolymers such as Chitosan to decrease the uncontrolled release. These materials aggregate fertilizers with mineral nanoparticles obtained from clay in soil or other types of ceramic material, which are used for producing controlled-release blocks, pots, or film. They are programmed to satisfy the unique needs of various kinds of plants.
b) Amongst the options to avoid the release of nano fertilizers to the atmosphere is by applying them as foliar sprays. For this reason, the encapsulated organic nanoparticles can be quite useful. Another choice to use is to ensure that the quantity of nutrients applied to the soil is sufficient for the stage of crop production.

Nano fertilizers facilitates seed germination, seedling vigor, growth parameters viz; height, leaf area index, leaf area, number of leaves, dry matter accumulation, chlorophyll, rate of the photosynthesis which resulted more production and translocation of photosynthets to different parts of plant. This improves translocation of photosynthates from source to sink (leaves to economic parts of the plant, may it be grain/tuber/bulb/stem/fibre and leaves.) which results more yield and quality parameters from the applied nano-fertilizers treated plants as compared to non nano fertilizers treated plants or traditional fertilizers treated plants. Lin D. and Xing (2007) also reported higher values of yield parameters under nano fertilizers treated plants as compared to bulk nutrient sources. The plants absorb nano-particles through their shoot and root entries which further penetrate in the roots (Fig. 3). These nanoparticles can have both positive and slight negative effects on plants, primarily dictated by physicochemical characteristics, sizes and concentrations are the most common, with more higher concentration having a negative influence and moderate concentration, a favorable one (Ruttkay-Nedecky *et al.,* 2017).

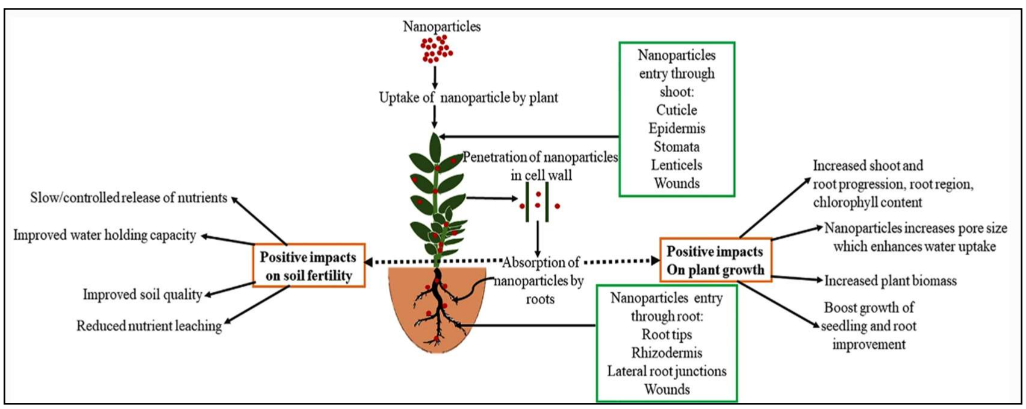

Fig. 3: Nano-particles uptake and impacts on plant growth and soil fertility

A number of organic, inorganic and composite nanoparticle based fertilizers have applied to various plants to assess application potential in plant growth and productivity (Liu and Lal, 2015). These improve the quality of nutrients, soil and environment as well as the water holding capacity and plants antimicrobial activity (Michalik and Wandzik, 2020). Silicon based fertilizers such as Si-dioxide nano particles can increase the resistance to plant diseases, nitrate reductase activity, fertilizer and water absorption capacity, thus improves seedling and root development (Wang *et al.,* 2010). Similarly, Ti-based fertilizers (Ti dioxide NPs), increases water retention, photo energy transmission, light absorption, and plant growth (Lu *et al.*, 2002). Zn oxide NPs fertilization significantly enhances plant growth and biomass production while Ag NPs significantly increase seed germination potential (Hojjat and Kamyab, 2017).

Enhanced nutrient use- efficiency fertilization (EEF) concept through nano-fertilizers

Plants demands the mineral nutrients during specific times during which there is need to supply the required amount of nutrient. At this point of time split application of nutrient is really a tedious task because of the scarcity of labours and high cost of labour wages making the agriculture non remunerative. Because of that those reasons the concept of EEF came. In EEF concept fertilizer formulations are capable of minimizing the various losses and enhance the use efficiency of the nutrients by providing the continuous availability of the plant nutrients throughout the plant growth (Fig. 3).

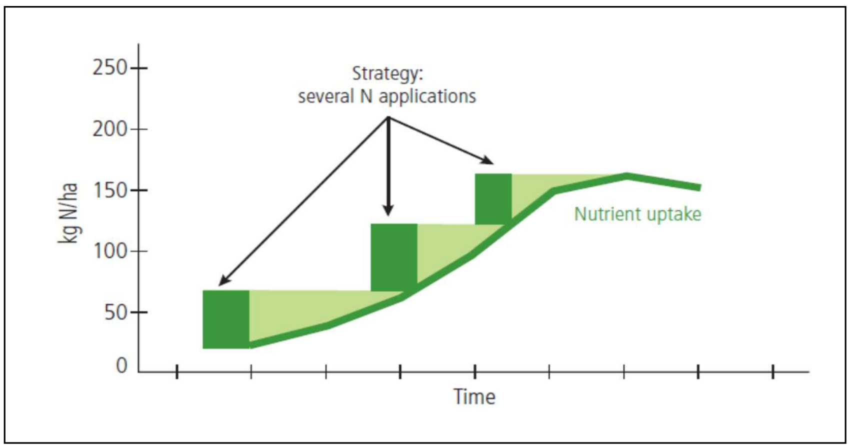

Fig. 4: Enhanced nutrient use-efficiency fertilization concept
(Source: Adapted from Kumar *et al.,* 2018)

Improving the nutrient use efficiency is a worthwhile goal and fundamental challenge is facing the fertilizer industry today. Now, the idea of nutrient use efficiency is driven by growing public believe that the crop nutrients are in excess in environment. Farmer concerns about rising the fertilizer prices and stagnant crop price, exerted pressure to improve nutrient use efficiency. Most of the agricultural soils in India have low to medium native fertility and to sustained crop production on these soils requires regular nutrient inputs and managements. The quantum of available nutrients for recycling via crop residues and animal manures is inadequate to compensate the amounts removed in crop production. Thus, the mineral fertilizers have come to play a key role in areas especially with low fertility soils, where an increased agricultural production is required to meet growing food demand.

Nano fertilizers possess several certain unique properties asserting more effective nutrient uptake by the plants. Some relevant properties are as follows:

The tiny sizes of the nano fertilizers makes them useful in providing effective sites for plant food metabolism while having its high surface area enhances their mode of action. This resulted more plant developmental process through lesser consumption of essential nutrients.

a) They are highly soluble in water.
b) The size of particles of nano fertilizers is very small (usually less than 100 nm), that means the penetration rate of particles is increased within the plant system.
c) Nano particles have more surface area and smaller sizes than surface area of roots and leaves of plants. This way improves the penetration into the plant system more rapidly from the applied surfaces through foliar resulting in increased utilization of nutrients and bioavailability.
d) Lesser the particle size, higher surface area and more particles per volume increases its performance and effectiveness.
e) The micro particles are being combined with the fertilizers provide greater absorption capacity and supply of nutrients to plants. Thus, release nutrients slowly into the crops and increase availability over its entire growth cycle. This is one of the important mitigation measures as it prevents the heavy loss of nitrogen fertilizers

f) through the processes of denitrification, leaching, volatilization and fixation in soil particularly in the form of nitrate (NO^{3-}) form.

Achievements of nano-fertilizers

Crop production: Over the years several studies have been shown that nano-fertilizers increases and advances the crop yield and quality. This is primarily due to enhanced photosynthesis from improved growth of plant thus enhanced plant metabolisms leading to more accumulation and translocation of photosynthates. Foliar application of nano fertilizers greatly improved yield of crops

Nutritional value: Nano fertilizers can improve nutrient availability to plants. This encourages to increase quality parameters such as protein, oil and sugar content in plant parts by increasing their rate of chemical reaction/synthesis process inside the plant cells. Nano formulation of iron and zinc increased the total carbohydrate, indole-3-acetic acid, chlorophyll, starch, and protein content in crops.

Plant health: Some plant elements helps in improving the plants resistance to numerous diseases. Nano nutrients can also protect the plants from pest's infestation, bio-diversity stresses and nutrient deficiency.

Nano fertilizers for sustainable and precision farming

Sustainable agriculture highly demands the minimal use of agrochemicals and the development of an efficient nutrient system of plants causing lesser or no damage to environment. Tropical and subtropical soils like India, are mostly acidic and greatly defcient in available phosphorous with high phosphate sorption capacity onto soils. Thus, nano-technological and nano-engineering techniques can be used to overcome a global agricultural crisis by providing the novel and advanced solutions (Kim *et al.*, 2018) that aim to improve crop production and the efficiency of pesticide treatments, enable the development of efficient water management systems (Ram *et al.,* 2014), and promote the use of NFs to ensure agricultural sustainability. The proper utilization of phosphate rocks as P sources can contribute to worldwide development by facilitating a sustainable agricultural supplement, particularly in developing countries that are covered with native phosphate rock resources, and help minimize pollution in countries where phosphate rocks are processed industrially.

EPILOGUE

Agriculture is the major backbone of Indian economy utilizing both renewable and non-renewable resources however, ensuring food security to the masses. Increasing the awareness to consumers regarding food traceability, environment friendly agri-inputs and sustainable farm operation needs for revisiting agriculture through introduction of novel innovative solutions like nano fertilizers. Nanotechnology has potential to revolutionize the fertilizer use in agriculture. Nanotechnology plays an important role in crop nutrition and they mainly target at cellular level action resulted physiological changes in crops, which ultimately results the good yield and fertilizer use.

Nano nutrients are more efficient and economical than conventional ones. Application of different types of nano-fertilizers has a major impact on yield of crops, the protection of natural resources and the reduction of fertilizer cost for crop production. With the use of nano-fertilizers in agriculture fields, nutrient use quality will be increased. The nano-fertilizers promote good crop growth and yield by proper dosage and concentration. Exceeding certain cap would have inhibitory effect on the crops. Optimal doses of various nitrogen fertilizers would be of crucial importance. With optimizing dosing for different nano subs and different crops, in near future, the production system will be highly productive and eco-friendly. Nanomaterials can be used as seed treatment, soil application and foliar application. Nanomaterials performed better under lower concentration, but under the situation of high fertilizer dose crop requires higher concentration of nano materials. Over all fertilizer/nutrient use efficiency can be enhanced by using nano materials.

Hence, nano fertilizers might be one important tool in the toolkit for increasing nutrient use efficiency and thereby soil fertility along with environmental protection and crop productivity.

Future prospects of nano-fertilizers

The toxicity of newly developed NPs depends on, size of NP (smaller the size more the toxic as higher specific area), seed size (small seeds are more sensitive), plant species and ability to absorb NPs on seed surface. Hence, there is need of extending new research area to find the appropriate NPs along with their concentrations and their effect on specific crops. In addition, research needs to be done how to be avoiding the use of herbicides that not only acts against weeds but also affects the crop growth. Will nano-particles able to solve this problem? Nowadays, there are many environmental issues such as urbanization, climate change, which has severely impacted in agriculture. In this condition, lies a scope where the nano technology approaches can be a boon.

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Chapter - 3

Natural Farming: The Need of the Hour in the Era of Ecological Crisis

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Natural farming, also known as ecological or sustainable farming, is an agricultural approach that focuses on harmony with nature and mimics natural processes for crop and livestock cultivation. It is a holistic and environmentally friendly system that emphasizes the use of natural inputs and minimizes reliance on synthetic chemicals, pesticides, and GMOs. Natural farming practices prioritize soil health and fertility, promoting biodiversity conservation through techniques like composting, crop rotation, and cover cropping. This leads to improved soil structure, increased water retention, and reduced erosion. Biodiversity conservation is encouraged through agroforestry, which creates a balanced ecosystem and reduces the need for chemical pest control. Water conservation is achieved through mulching and cover cropping, while chemical reduction is minimized through the avoidance of synthetic chemicals. Climate resilience is fostered through diverse crop rotations, soil conservation practices, and the integration of trees and shrubs, which help mitigate the impact of extreme weather events. In conclusion, natural farming offers a holistic and sustainable approach to agriculture that addresses the ecological crisis by promoting soil health, biodiversity conservation, water conservation, chemical reduction, climate resilience, and human well-being. By adopting

these practices on a larger scale, we can significantly contribute to mitigating environmental issues and building a more sustainable future.

Keywords: *Biodiversity conservation, environmental sustainability, natural farming, soil health*

INTRODUCTION

Natural farming, also known as organic farming or sustainable agriculture, is a method of agricultural production that focuses on harmony with nature and minimizing synthetic inputs. It offers several benefits, including environmental sustainability, health benefits, soil health and fertility, economic viability, climate change mitigation, and long-term sustainability. Natural farming practices promote ecological balance, biodiversity, conserving natural resources, and minimizing pollution and soil erosion. By avoiding synthetic pesticides and fertilizers, natural farming reduces the risk of contamination and potential health hazards. Additionally, natural farming promotes soil health and fertility, promoting beneficial microorganisms and earthworms. By adopting natural farming practices, we can create a more resilient and regenerative agricultural system that supports the well-being of our planet and its inhabitants.

What is natural farming

Natural farming is an environmentally friendly practice similar to organic farming, developed in Japan during 1935. Natural farming, also known as ecological or sustainable farming, is an agricultural approach that seeks to work in harmony with nature and mimic natural processes to cultivate crops and raise livestock. It is a holistic and environmentally friendly farming system that emphasizes the use of natural inputs and minimizes the reliance on synthetic chemicals, pesticides, and genetically modified organisms (GMOs). Unlike conventional farming, natural farming improves soil health by altering soil microbial diversity and also act as defence to plant pathogens (Devi and Laishram, 2023).

The key principles of natural farming include:

1. **Organic and sustainable practises**: Organic fertilisers, compost, and other natural inputs are promoted in natural farming to maintain soil fertility and plant health.

It seeks to reduce the usage of external inputs while relying on the natural processes of the ecosystem.

2. **Biodiversity and ecosystem preservation**: Natural farming understands the value of biodiversity in sustaining a healthy and resilient agricultural system. It emphasises biodiversity preservation and enhancement through practises such as crop rotation, intercropping, and the preservation of natural habitats.

3. **Soil conservation and regeneration**: Natural farming emphasises the development and maintenance of healthy soils. Minimal tillage, mulching, and cover cropping all help to avoid soil erosion, enhance water retention, and stimulate the growth of beneficial microbes.

4. **Pest and disease management**: Rather of relying on synthetic pesticides, natural farming employs pest and disease management strategies such as crop diversification, companion planting, and biological control. Natural farming lowers the need for chemical treatments by encouraging natural predators and producing a healthy ecosystem.

5. **Closed-loop systems**: By using closed-loop systems, natural farming strives to reduce waste and resource loss. Crop residues and organic waste, for example, are recycled as compost or animal feed, while livestock manure is used to fertilise fields.

6. **Community and social well-being**: Natural farming encourages farmer cooperation and a sense of community. It prioritises information sharing, local seed conservation, and the building of resilient local food systems.

Overall, natural farming seeks to create sustainable and regenerative agricultural systems that work in harmony with nature, preserve biodiversity, and produce healthy, nutritious food while minimizing the negative environmental impacts associated with conventional farming practices.

What is the need of natural farming

Natural Farming (NF) is recognised as one of the most promising crop growing systems for significantly cutting production costs by eliminating dependency on the market for critical ingredient purchases by its proponents. It delivers several ecological and social benefits as an agro ecologically diverse agricultural practise; nonetheless, two schools of thought dispute each other on the efficacy of its practises (Kumar *et al.,* 2019). In natural farming concept, everything in nature is useful and serves a purpose in one or other in the web of life. It also termed as 'Do Nothing Farming', as the real work is done by the Nature itself (Saikia *et al.*, 2023).

Natural farming, also known as organic farming or sustainable agriculture, is a technique of agricultural production that strives to operate in harmony with nature by reducing the use of synthetic inputs such as pesticides, herbicides, and artificial fertilisers. There are numerous key reasons for the necessity for natural farming:

1. **Environmental Sustainability:** The goal of natural farming is to conserve and preserve the environment by fostering ecological balance and reducing the detrimental impact of traditional agricultural practises on soil, water, and air quality. It aims to promote biodiversity, conserve natural resources, and reduce pollution and soil erosion.

2. **Health Advantages:** Natural agricultural practises place a premium on producing healthy, nutritious food that is devoid of synthetic chemicals and genetically modified organisms (GMOs). Natural farming decreases the danger of contamination and potential health problems connected with chemical residues in food by eliminating the use of chemical pesticides and fertilisers.

3. **Soil Health and Fertility:** To improve soil fertility and structure, natural farming techniques such as crop rotation, composting, and green manure are used. Natural farming encourages the presence of beneficial microbes and earthworms, which help to soil health and nutrient cycling by maintaining a balanced ecosystem inside the soil.
4. **Economic viability:** Farmers can benefit economically from natural farming. While switching to natural farming methods may necessitate an initial investment and a change in practises, it might result in lower output costs over time. Furthermore, the increased demand for organic and sustainably produced food allows farmers to reach premium markets and get higher prices for their products. For Indian farmers of all sizes, debt is a drain. Under such conditions, 'zero budget natural farming' promises

to stop dependency on loans and substantially reduce production costs, thereby breaking the debt cycle for desperate farmers (Mural, 2016).

5. **Climate Change Mitigation**: By lowering greenhouse gas emissions, natural agricultural practises can help to mitigate climate change. Organic farming methods, for example, emphasise the utilisation of organic materials, which helps trap carbon in the soil and lower CO_2 levels in the atmosphere.
6. **Natural farming** emphasises the importance of maintaining and nourishing the soil for future generations. Natural farming attempts to ensure that agricultural systems may continue to develop and provide food security without depleting natural resources or jeopardising future generations' well-being by implementing sustainable practises.

Overall, the goal to build a more harmonious and sustainable relationship between agriculture, the environment, and human health drives the need for natural farming. By adopting natural farming practices, we can work towards creating a more resilient and regenerative agricultural system that supports both the present and future well-being of our planet and its inhabitants.

Origin and importance of natural farming

Natural farming - an agricultural method that emphasizes the use of natural processes and materials to cultivate crops and raise livestock. It is a holistic approach to farming that aims to work in harmony with nature, preserving the health of ecosystems, minimizing environmental impact, and promoting long-term sustainability. The origin and importance of natural farming can be traced back to several key factors:

1. **Traditional Farming Practices:** Natural farming draws inspiration from traditional agricultural practices that existed before the advent of synthetic fertilizers and pesticides. Many indigenous cultures around the world had sustainable farming systems based on ecological principles and a deep understanding of nature.

2. **Response to Industrial Agriculture:** The emergence of industrial agriculture in the 20th century brought significant changes to farming practices. Increased reliance on synthetic inputs, mono-cropping, and intensive use of machinery led to various

environmental and health concerns. Natural farming arose as a response to the negative consequences of industrial agriculture.

3. **Environmental Sustainability:** One of the primary aims of natural farming is to promote environmental sustainability. By reducing the use of synthetic chemicals, natural farming helps preserve soil health, maintain biodiversity, and prevent water and air pollution. It encourages practices like crop rotation, composting, and biological pest control, which work with natural ecosystems rather than against them.
4. **Soil Conservation and Fertility:** Natural farming recognizes the vital role of healthy soil in supporting plant growth. Practices like composting, cover cropping, and minimal soil disturbance help maintain soil structure, improve water retention, and enhance nutrient cycling. By prioritizing soil health, natural farming promotes long-term fertility and reduces the need for external inputs.
5. **Health and Nutrition**: Natural farming emphasizes the production of high-quality, nutritious food. By avoiding synthetic pesticides and genetically modified organisms, natural farming reduces potential health risks associated with chemical residues in food. It promotes the use of organic methods to enhance the nutritional content of crops and prioritize the well-being of consumers.
6. **Climate Change Mitigation:** Natural farming can contribute to mitigating climate change. Practices such as agroforestry, conservation tillage, and the use of cover crops can sequester carbon in the soil, reducing greenhouse gas emissions. Additionally, natural farming often focuses on local and diversified food production, which reduces the carbon footprint associated with long-distance transportation.
7. **Cultural and Ethical Considerations:** Natural farming is closely tied to cultural and ethical values. It embraces a holistic view of agriculture, considering the interconnectedness of ecosystems, animals, and humans. It often promotes the fair treatment of farmworkers, supports local economies, and fosters a sense of community through direct relationships between farmers and consumers.

The importance of natural farming lies in its potential to create a sustainable and regenerative food system. By prioritizing ecological balance, soil health, and human well-being, natural farming offers an alternative to conventional agriculture that addresses the challenges of environmental degradation, climate change, and public health concerns. It promotes a more harmonious relationship between humans and nature, striving for a resilient and sustainable future for agriculture.

How natural farming is game changer for ecological crisis

Natural Farming (NF) is defined as an agroecology-based diversified farming system that integrates crops, trees, and livestock, allowing functional biodiversity (Rosset and Martinez-Torres, 2012) to drastically reduce production costs by replacing chemical fertilisers and pesticides with home-grown products such as Jeevamritham, Beejamritham, Neemastra, etc., and implementing intercropping and mulching (Palekar, 2005). Soil can be supplemented with microbial inoculums like Panchagavya, Beejamruth, Jeevamruth and Kunapajala to hasten the soil micro flora propagation and as soil enrichment. These indigenous concoctions are very significant to nurture the growth of soil microorganisms without adding external inputs (Devi and Laishram, 2023).

Natural farming, also known as organic or sustainable farming, is indeed considered a game changer when it comes to addressing the ecological crisis. Here are several ways in which natural farming can have a positive impact on the environment:

1. Soil health: Natural farming practices prioritize soil health and fertility. Instead of relying on synthetic fertilizers and pesticides, natural farmers focus on building and maintaining healthy soil through techniques such as composting, crop rotation, and cover cropping. This leads to improved soil structure, increased water retention, and reduced erosion. Healthy soil also acts as a carbon sink, helping to mitigate climate change by sequestering carbon dioxide.

2. Biodiversity conservation: Natural farming encourages biodiversity by promoting the use of diverse crops and the preservation of natural habitats. Farmers often employ techniques like agroforestry, which involves planting trees and shrubs alongside crops. This helps create a more balanced ecosystem, attracting beneficial insects and birds while reducing the need for chemical pest control. By

preserving biodiversity, natural farming contributes to the overall resilience of the ecosystem.

3. **Water conservation**: Traditional agriculture often relies heavily on irrigation, leading to water scarcity and environmental degradation. Natural farming methods, such as mulching and the use of cover crops, help conserve water by reducing evaporation and improving soil moisture retention. By minimizing water usage and preventing runoff, natural farming practices contribute to the preservation of water resources and the protection of aquatic ecosystems.
4. **Chemical reduction**: One of the key aspects of natural farming is the avoidance or minimal use of synthetic chemicals. This reduces the pollution of soil, water, and air, which often results from the excessive application of synthetic fertilizers and pesticides. The food we eat to fuel our lives has turned into a slow poison. According to the most recent WHO reports, more than half of all foods contain carcinogenic substances (Prasad, 2016). By minimizing chemical inputs, natural farming helps prevent contamination and its detrimental effects on both human and environmental health.
5. **Climate resilience**: Natural farming techniques foster resilience in agricultural systems, making them more adaptable to climate change. Diverse crop rotations, soil conservation practices, and the integration of trees and shrubs help mitigate the impact of extreme weather events, such as floods and droughts. Furthermore, the emphasis on soil health and organic matter promotes carbon sequestration, contributing to climate change mitigation.
6. **Improved human health**: By avoiding the use of synthetic chemicals, natural farming reduces the exposure of farmers, farm workers, and consumers to potentially harmful substances. Additionally, the higher nutrient content and lack of chemical residues in organic produce can have positive effects on human health.

Overall, natural farming offers a holistic and sustainable approach to agriculture that addresses the ecological crisis by promoting soil health, biodiversity conservation, water conservation, chemical reduction, climate resilience, and human well-being. By adopting these practices on a larger scale, we can significantly contribute to mitigating environmental issues and building a more sustainable future.

Zero budget natural farming

Zero budget natural farming (ZBNF) is an agricultural practice that aims to eliminate the use of synthetic inputs such as chemical fertilizers and pesticides, as well as reduce the overall cost of farming. It was popularized by Subhash Palekar, an Indian agriculturist and philosopher.

The key principles of zero budget natural farming include:

1. **Zero external inputs**: ZBNF advocates for the use of natural resources available on the farm itself, such as cow dung, cow urine, crop residues, and locally available materials, as inputs for farming. This eliminates the need for costly external inputs like chemical fertilizers and pesticides.

2. **Seed treatment**: ZBNF emphasizes the use of indigenous seed varieties and promotes seed treatment with natural substances like cow dung and cow urine. This helps in improving seed germination and plant health.

3. **Mulching**: Mulching is an important practice in ZBNF, which involves covering the soil with a layer of crop residues or other organic materials. Mulching helps in retaining soil moisture, preventing weed growth, and improving soil fertility.

4. **Intercropping and crop rotation**: ZBNF encourages the practice of intercropping, where different crops are grown together in the same field, and crop rotation, where different crops are rotated on the same land in a planned sequence. These practices help in pest and disease management, improve soil health, and increase overall crop productivity.

5. **Biological pest control**: ZBNF promotes the use of natural methods for pest and disease control. This includes the use of biopesticides, botanical extracts, trap crops, and maintaining a diverse ecosystem on the farm to encourage beneficial insects and birds that help control pests. Several studies have shown that artificial fertilisers and pesticides harm soil health by killing millions of microorganisms that are essential for plant (Jayashree and Vasudevan, 2007).

6. **Nutrient management**: ZBNF emphasizes the use of locally available resources to improve soil fertility. This includes the preparation and application of natural fertilizers like jeevamrutha (a fermented mixture of cow dung, cow urine, jaggery, gram flour, and water) and ghana jeevamrutha (a concentrated form of jeevamrutha). These biofertilizers help in enriching the soil with beneficial microorganisms and nutrients. Kunapajalais a promising and eco-friendly plant stimulant for sustainable crop production and safe agro ecosystem (Devi *et al.,* 2022).

The aim of zero budget natural farming is to promote sustainable agriculture, reduce input costs for farmers, and minimize the negative impact of chemical-intensive farming on the environment. While ZBNF has gained popularity in certain regions, its adoption and effectiveness may vary depending on local conditions, farmer knowledge, and availability of resources.

Social, ecological and economic attributes of natural farming

Natural farming, also known as sustainable or organic farming, is an agricultural approach that emphasizes working in harmony with nature while minimizing the use of synthetic inputs and promoting ecological balance. It encompasses a range of practices and principles that have social, ecological, and economic attributes. Here are some key attributes of natural farming in each of these domains:

1. **Social Attributes:**

a) **Community Building**: Natural farming often fosters strong community ties by encouraging farmers to share knowledge, resources, and experiences. It can promote cooperation, networking, and the exchange of traditional farming practices among farmers.

b) **Health and Well-being**: By avoiding the use of synthetic pesticides and fertilizers, natural farming aims to produce food that is healthier for both farmers and consumers. It can contribute to improved nutrition and reduce the risk of exposure to harmful chemicals.

c) **Cultural Preservation**: Natural farming methods often emphasize the preservation of traditional and indigenous agricultural practices. It respects local knowledge, cultural diversity, and the wisdom passed down through generations.

2. Ecological Attributes:

a) Biodiversity Conservation: Natural farming encourages the preservation and enhancement of biodiversity on farmland. It promotes practices such as crop rotation, intercropping, and agroforestry, which create habitats for diverse plant and animal species.
b) Soil Health and Conservation: Natural farming prioritizes building and maintaining healthy soil ecosystems. It focuses on practices like composting, mulching, and minimal tillage to improve soil structure, fertility, and water-holding capacity.
c) Water Conservation: Natural farming techniques, such as drip irrigation and water-efficient practices, aim to reduce water usage and minimize water pollution caused by synthetic chemicals. It promotes sustainable water management practices.

3. Economic Attributes:

a) Cost Reduction: Natural farming can help reduce production costs by minimizing the need for expensive synthetic inputs such as chemical fertilizers and pesticides. It promotes the use of locally available resources, such as organic matter for composting, which can be cost-effective.
b) Market Demand: With the growing consumer interest in organic and sustainably produced food, natural farming can tap into niche markets and demand for premium products. It may offer economic opportunities for farmers to sell their produce at higher prices.
c) Long-Term Sustainability: By focusing on soil health, biodiversity, and natural resource conservation, natural farming aims to build resilient agricultural systems. This can lead to increased productivity and long-term economic stability for farmers, reducing the reliance on external inputs.

Overall, natural farming seeks to integrate social, ecological, and economic aspects to create a sustainable and harmonious farming system that benefits farmers, consumers, and the environment.

Four main principles of system for crop intensification

The System of Crop Intensification (SCI) is an agricultural approach aimed at improving crop productivity while reducing inputs and environmental impact. While there is no fixed set of principles universally agreed upon, the following four principles are commonly associated with SCI:

a) **Soil Health and Fertility**: The first principle of SCI emphasizes the importance of maintaining and enhancing soil health and fertility. This involves practices such as organic matter addition, crop residue management, and reduced tillage. By improving soil structure, nutrient availability, and water-holding capacity, the productivity and sustainability of the cropping system can be increased.

b) **Plant Spacing and Population Management**: SCI promotes the optimization of plant spacing and population density. It suggests that plants should be spaced wider apart than traditional methods to allow each plant to develop a larger root system and canopy. This wider spacing reduces competition for nutrients, water, and light among plants, leading to healthier and more productive crops.

c) **Nutrient Management**: The third principle of SCI emphasizes efficient nutrient management. It encourages the use of organic fertilizers, composts, and biofertilizers to enhance soil fertility and nutrient availability. Additionally, targeted and balanced nutrient application based on crop needs helps prevent nutrient imbalances and reduces the risk of nutrient leaching into the environment.

d) **Water Management**: Efficient water management is a crucial aspect of SCI. The principle suggests techniques such as alternate wetting and drying (AWD) in paddy fields, drip irrigation, and mulching to conserve water and reduce water stress on crops. By optimizing water use and reducing water loss through evaporation, SCI aims to improve water efficiency and productivity.

It's important to note that the specific practices and techniques associated with the System of Crop Intensification may vary depending on the crop, region, and local conditions. The principles mentioned above provide a general framework for sustainable and intensified crop production.

Important guidelines for zero budget natural farming

Zero budget natural farming (ZBNF) is a farming practice that aims to minimize external inputs and maximize natural processes in agriculture. It was popularized by Subhash

Palekar, an Indian agriculturist. Here are some important guidelines for practicing Zero Budget Natural Farming:

a) **Eliminate external inputs**: The key principle of ZBNF is to eliminate or minimize the use of external inputs such as chemical fertilizers, pesticides, and herbicides. Instead, focus on utilizing local and natural resources available on the farm.

b) **Mulching**: Mulching is an important technique in ZBNF. Cover the soil surface with organic materials like crop residues, leaves, or straw. This helps retain moisture, suppress weeds, and improve soil health.

c) **Seed treatment**: Treat seeds with cow dung and cow urine before sowing. This helps to control seed-borne diseases and enhances germination rates.

d) **Jeevamrutha**: Jeevamrutha is a fermented microbial culture made from cow dung, cow urine, jaggery, and other plant materials. It is used as a natural fertilizer and soil conditioner. Regular application of jeevamrutha improves soil fertility and promotes beneficial microbial activity.

e) **Crop rotation and intercropping**: Practice crop rotation and intercropping to diversify the plant species grown on your farm. This helps break pest and disease cycles, improve soil fertility, and increase overall productivity.

f) **Natural pest management**: Encourage natural predators and beneficial insects to control pests. Avoid using chemical pesticides and instead use natural pest management techniques like neem-based sprays, insect traps, and companion planting.

g) **Cow-based activities**: Incorporate cow-based activities in ZBNF. Cow dung and urine are valuable resources for making natural inputs like jeevamrutha, ghanajeevamrutha, and herbal extracts. Cows also provide organic manure and biogas, which can be utilized on the farm.

h) **Soil health improvement**: Focus on improving soil health through practices like vermicomposting, green manuring, and crop residues incorporation. Healthy soil with good organic matter content supports better plant growth and nutrient availability.

i) **Water conservation**: Adopt water conservation techniques like drip irrigation, mulching, and contour ploughing. Efficient water management ensures optimal water use and reduces the risk of soil erosion.

j) **Continuous learning and experimentation**: ZBNF is an evolving practice, and it's important to stay updated with new techniques and learn from other farmers practicing ZBNF. Experiment with different methods and adapt them to suit your specific farming conditions.

Remember that transitioning to Zero Budget Natural Farming may require time and effort. Start with small steps, learn from your experiences, and gradually scale up. It's essential to understand your local conditions, seek guidance from experienced practitioners, and adapt the guidelines to suit your specific farm.

Impact of zero budget natural farming on crop yields

Crop production growth has been declining as a result of injudicious/overuse of inputs such as synthetic fertilisers and pesticides (Pingali, 20 12). Zero Budget Natural Farming (ZBNF) is an agricultural practice that promotes chemical-free and sustainable farming methods. It aims to eliminate the use of synthetic inputs like chemical fertilizers and pesticides, relying instead on natural resources and traditional farming techniques.

The impact of ZBNF on crop yields can vary depending on several factors. Here are some key points to consider:

a) **Transition Period**: When transitioning from conventional farming to ZBNF, there is typically an initial decline in crop yields. This is because the soil and crops need time to adjust to the absence of synthetic inputs. The transition period can range from a few months to a few years, depending on the condition of the soil and the practices used.

b) **Soil Health Improvement**: One of the fundamental principles of ZBNF is to improve soil health through organic matter, composting, and other natural techniques. Over time, these practices can enhance the fertility, structure, and water-holding capacity of the soil. Improved soil health often leads to better nutrient availability, root development, and overall plant growth, which can positively impact crop yields in the long run.

c) Pests and Diseases: ZBNF advocates for the promotion of biodiversity, natural pest control mechanisms, and the use of biopesticides. While it may take time to establish a balanced ecosystem, the reduction in chemical pesticide usage can help preserve natural predators and beneficial organisms. However, during the transition phase, pest and disease management can be a challenge, potentially affecting crop yields until natural equilibrium is achieved.

d) Water Management: ZBNF encourages practices like mulching, intercropping, and water conservation techniques to optimize water usage. These methods can help retain soil moisture, reduce evaporation, and improve water infiltration. Efficient water management is crucial for crop growth, especially in regions facing water scarcity, and can contribute to maintaining or improving crop yields.

e) Local Adaptation: The success of ZBNF can also depend on the specific local conditions and the knowledge and expertise of the farmers. Understanding local soil types, climate patterns, and crop varieties is essential for implementing appropriate ZBNF practices. Farmers who have a deep understanding of their local environment can effectively adapt and optimize ZBNF techniques, potentially leading to improved crop yields.

CONCLUSION

It's important to note that the impact of ZBNF on crop yields may vary from crop to crop, region to region, and even farmer to farmer. While ZBNF has shown promising results in some cases, it may not guarantee consistently higher crop yields compared to conventional farming practices, particularly in the short term. However, it can contribute to long-term sustainability, soil health, reduced input costs, and environmental benefits.

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Chapter - 4

Millets: The Miracle Grain for Addressing Food and Nutritional Security

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Human kind is dealing with both agricultural and food security issues. Concentration must be given on drought prone areas in order to increase food grain production because cultivable lands with irrigation facilities have been utilized fully. Because they are less fertile it is difficult to use drought prone areas to produce nutrient rich grains. Millets being a resilient to climate change regulations has proved to be superior to other grains in terms of growing conditions and nutrient constitution. Millets are considered "Miracle Grains" as they have the capability to acclimatize to a various range of ecological conditions and uses lower amount of water for irrigation and produces more effectively in less fertile soils. Millets are rich source of proteins, fiber, niacin, thiamine and riboflavin, methionine, lecithin and vitamin E also they are good source of minerals like iron, magnesium, calcium and potassium. Because they are high in nutrients, they may help to prevent cancer, reduces the risk of cardio vascular disease, stops the growth of tumors, lower blood pressure levels, lowers the rate at which fat is absorbed, delays gastric emptying, and increases gastro intestinal bulk. Thus, millets justify the incorporation of true climate resilient technologies for the satisfaction of the world’s future needs.

Keywords: *Miracle grain, food security, nutritious, health, climate resilient*

INTRODUCTION

Millets belong to cereals from the Poaceae grass family and considered one of the oldest crops to be cultivated by man. Millets have been staple food in Northern Africa for thousands of years, and was staple in China and India before the popularity of fine cereals like rice. They are hardy and drought-resistant, and can acclimatize to a variety of agro-climatic conditions. Being adaptable to various agro-climatic conditions they play an important role in agriculture that is followed in the semi-arid tropical regions and hilly terrains. Millets being C4 plants have a very effective photosynthetic behaviour than the less effective C3 plants. Millets are regarded as "Nutri-cereals" as they have higher protein, fibre, calcium and minerals than the widely consumed rice and wheat.

Two major challenges that the world faces are feeding the hunger as there is deficiency in the supply of food and micro-and macro-nutrients, shortage in food production leading to demand-supply imbalances, leading to conflicts that de stabilize various parts of the world. Millets are multipurpose as they require less water, takes half the time of wheat to grow; and less energy is required in processing. They are one-stop solution for water scarcity, drought and climate change conditions along with high nutritive value to provide food security which is sustainable (Fig.1).

Diets having lower negative impact on environment protect the bio diversity and ecosystems which help to ensure availability of food and nutrition. Diversifying cropping systems through the increase in use of coarse cereals like millets, increases production of food, lower the greenhouse gases (GHG) emissions, and improve resilience to climate without decreasing the nutritive value. Millets have been identified as a good option for ensuring environmental balance and food security in a quantitative analysis of changing monsoon cereal production in India. The Fig.2 indicates the contribution of cereals grown in monsoon to calories with maximized supply of protein and iron, maximum savings in water, energy, greenhouse gases, and climate resilience.

Millets are called smart foods due to their benefits to our health and the environment, as they require less water for growth, have a low carbon footprint, and are more tolerant of climate change. They are a source of food for more than 90 million people in Asia and Africa, whereas wheat, rice, and maize are staple foods for 4 billion people. 51% of the world's calorie intake is provided by millets. Millets can also be considered a poor farmer's insurance against the variations of the Indian monsoon. Millets can be our future insurance in times of climate change. Millets can grow in very harsh and arid regions. At present, in arid regions, around 55% of millets are grown in Africa, 40% in Asia, and 3% in Europe. In India, the demand for millets has increased by 140%, but the production is less than 50%.

A farmer gets a yield of 600 kilograms of millet per hectare from 400 millimetres of grain. Investments in input technology, such as good quality seeds and irrigation, can reach yields of up to 4.5 tonnes per hectare, and pearl millet and sorghum can reach up to 9 tonnes. Due to their diverse genetic make-up, millets require few cultivation inputs. Millets are richer in nutrients than traditional grains. Millets are grown for both fodder and food and also provide nutrition and livelihood security to people assisting them in inefficient farming, especially for small and marginal farmers in rain-fed areas. Minor millets, which have been missing from the food basket in recent years, are essential food groups that are well-known for their health advantages.

Chart 1: Millets: an approach for sustainable agriculture and healthy world

Food Security	**Nutritional Security**	**Safety from diseases**	**Economic security**
Sustainable food source for combating hunger in changing world climate	Rich in micronutrients like calcium, iron, zinc, iodine, etc	Gluten free: a substitute for wheat in celiac diseases. Low GI: a good food for diabetic persons	Climate resilient crop
Resistant to climate stress, pests and diseases	Rich in bioactive compounds	Can help to combat cardiovascular diseases, anaemia, calcium deficiency, etc.	Sustainable income source for farmers
	Better amino acid profile		Low investment needed for productions
			Value addition can lead to economic gains

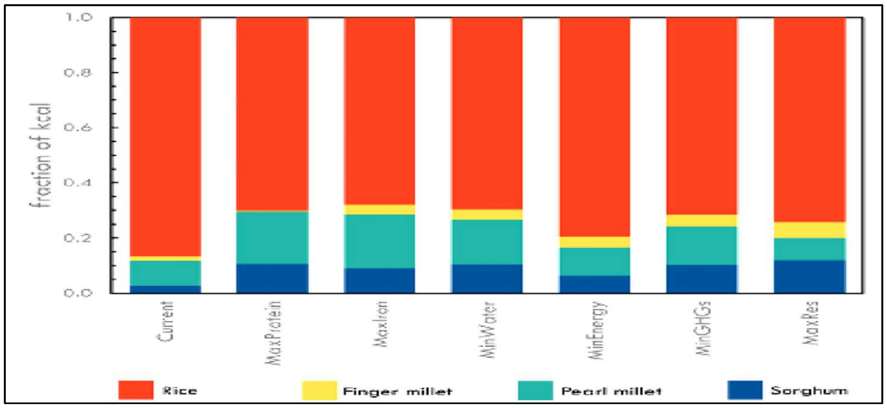

Fig. 1: Current and optimised shares of monsoon cereal production (Davis *et al.,* 2019)

Because millets are a good source of nutrients, they need to be promoted as a source of reliable nutrition. Millets have been significant staple foods, especially in Asia and Africa, in human history. Consumption of soy, human, and other cereals as major foods has significantly reduced over the last few years. Production of millets in India has significantly decreased as demand for them has declined. Sorghum production in India has decreased from 7 million metric tonnes during 2010–11 to 4.2 million metric tonnes during 2015–16; bajra production decreased from 10.4 million metric tonnes to 8.1 million metric tonnes; ragi production reduced from 2.2 million metric tonnes to 1.8 million tonnes; and production of small millets decreased from 0.39 million metric tonnes to 0.44 million tonnes during the same period.

A substantial increase in iron supply can be achieved through millets, more protein supply, less consumption of water and energy and GHG emissions, and enhancements of climate resilience (Fig. 2), all while maintaining calorie production from cereals. A big gap has been realized between the amount of food produced today and the amount needed to feed future generations. There will be nearly 10 billion people on Earth by 2050, *i.e.*, about 3 billion hungry people to feed as compared to 2010.

Therefore, to feed approximately 10 billion people by 2050, three gaps are required to be closed:

- **Food gap of 56 percent** between calories of crop produced in 2010 compared to that needed in 2050 under usual growth;
- **An extra land requirement of 593 million hectare** has to be met by the world by 2050; and

- **Mitigating greenhouse gas emission by 11 gigaton** that is expected from agricultural lands in 2050.

Millets provide us with fibre, minerals, and B-complex vitamins. They are also rich in health-promoting phytochemicals like polyphenols, lignans, phytosterols, phytoestrogens, and phytocyanins. They provide us with antioxidants, immune modulators, detoxifying agents and protect against age-related degenerative diseases. As millets are non-glutinous, they can be consumed by people with allergies to gluten and celiac disease. Millets do not form acid, can be digested easily, and do not cause allergies. Millets can also protect us from degenerative diseases that appear once a person starts ageing. Consumption of millets reduces heart-related diseases, increases the chances of diabetes, helps improve the digestive system, lowers the risk of cancer, acts as a detox, boosts immunity and energy, improves the muscular and neural systems, and protects us from several degenerative diseases like metabolic syndrome and Parkinson's disease. Nutrients like oligosaccharides, lipids, and antioxidants such as phenolic acids, avenanthramides, flavonoids, lignans, starch, and phytosterols that are believed to be responsible for any health benefits.

Millets are climate-resilient, can be cultivated in a wide range of environmental conditions, require less irrigation, have better growth and productivity in low nutrient input conditions, have less dependence on synthetic fertilisers, and are less affected by environmental stresses. In India, micronutrient insufficiency is a growing concern. Cultivation of millets addresses some of the Sustainable Development Goals (SDG), such as SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and wellbeing), and SDG 15 (life on land) (FAO, 2015). To tackle these challenges, a shift from existing methods needs to be adopted; this will give importance to human and environmental health and nutrition as a whole. The current natural disasters make it even more imperative to shift towards a climate-resilient agriculture system.

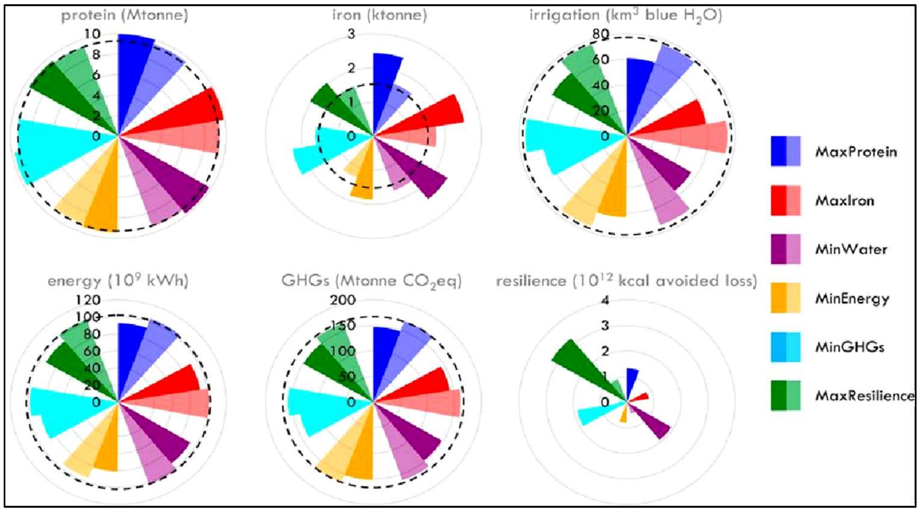

Fig.2. Outcomes of optimizations for nutrient supply, environment, and climate resilience (Source: Davis *et al*., 2019)

Global Distribution and Production of Millets

The world was producing 26.7 million metric tonnes of millets from 33.6-million-hectare area. Africa was the largest producer of millet in 2009 (20.6 million metric tonnes), followed by Asia (12.4 million metric tonnes) and India (10.5 million metric tonnes). Relative to wheat, rice, maize and barley, sorghum ranks fifth in importance, in terms of both production and area planted, accounting for 5% of the world cereal production.

Nutritional Composition

Carbohydrates: Starch, soluble sugar and fiber constitute the carbohydrate portion of millets. Carbohydrates in millets are divided into non-structural (starch and fructosans and sugars) and structural (cellulose, hemicelluloses and pectin substances) carbohydrates. Starch is the chief constituent of non-structural sugar. Amount of the pigments in the pericarp and in the leaves of the sorghum plant defines the colour of starches in sorghum. Most abundant component is starch while soluble sugars are low.

Starch: Weight is starch varies from one half to three fourth. Energy is utilised from stored starch for germination. It is composed of linear chains of glucose joined by α-1, 4-glycosidic bonds called amylopectin. The pigments of millet grain pericarp sometimes discolour the starch, giving a light pink colour, green and yellow colours.

Fatty Acid (Lipids): In millets lipids are relatively minor constituents. Lipid content is significantly reduced when the germ is removed during decortication or degermination. The typical fatty acid composition of sorghum lipid is similar to that of maize oil. The lipids can be subdivided into polar, nonpolar and non saponifiable lipids.

Protein: Protein content in millets varies due to agronomic conditions (water availability, soil fertility, temperatures and environmental conditions during grain development) and genotype. Millet proteins are located in the endosperm (80%), germ (16%) and pericarp (3%). These fractions are located primarily within the protein bodies and protein matrix of the endosperm, respectively. Protein quality of millet in terms of amino acid profile is poor when compared to other cereals.

Phytochemicals: Millets are a rich source of various phytochemicals including tannins, phenolic acids, anthocyanins, phytosterols and pinacosanols. These phytochemicals have potential positive impact on human health. All millet grain and especially sorghum fractions possess high antioxidant activity in vitro relative to other cereals and fruits. The major phytochemicals include phenolic compounds and others. Millets are a good source of phenolic compounds with a variety of genetically dependent types and levels of phenolic acids, flavonoids and condensed tannins. Most sorghum does not contain condensed tannins, but all contain phenolic acids.

Millets for Nutritional Importance

The world is in the midst of several health disorders and chronic diseases. A nutrient-imbalanced diet is responsible for most of the diseases. According to the estimates of the United Nations Food and Agriculture Organisation, about 795 million people were reported as under nourished. On the other hand, more than 1.9 billion adults 18 years of age were overweight, and a further 13% were reported to be obese. India is home to the world's largest under nourished population. About 194.6 million people, *i.e*. 15.2% of the total population of India, are under nourished. According to the 2017 Global Hunger Index report, India ranked 100th among 119 countries. Protein energy malnutrition (PEM) was reported to result in 4,69,000 deaths, with 84,000 deaths from the deficiency of other vital nutrients such as iron, iodine, and vitamin A. Obesity is also a major health concern in India with the prevalence rate of 11% in men and 15% in women.

The millets contain 13–38 % of total dietary fibre, which could be considered in the management of disorders like diabetes mellitus, obesity, hyperlipidemia, *etc*. The glycemic load-lowering effects are highest in barnyard millet. Antihyperglycemic and antilipidemic activities are exhibited by millets. Millets are also a good source of carotenoids and have a higher antioxidant capacity. The antioxidant activity of millets is also attributed to their tocopherol content. 49–65% carbohydrates are present in barnyard millets. Here, dietary fibre is the main constituent of carbohydrate. This prevention of constipation reduces the glycemic load and lowers blood cholesterol levels. It has the highest content of crude fibre and minerals among all the millets. Their protein content is higher among all the millets.

Brick-red-naked caryopsis of finger millet with a coloured seed coat is used in the form of a whole meal in traditional food preparations such as muddle, roti, and ambali. As millets are used as a whole; they provide essential nutrients such as minerals, dietary fibre, phenolics, and vitamins that are concentrated in the outer layer of the grain or the seed coat to form an essential part of the food and offer their nutritional and health benefits.

Consumption of small amounts of millet on a regular basis reduces the chances of developing type 2 diabetes. This is because millets contain high amounts of magnesium, which serves as a co-factor in various biochemical activities in the body and thereby aids in the secretion of glucose and insulin.

Millets for climate smart agriculture

Future agriculture will face some common environmental changes like a rise in temperature, uncertainty in rainfall, elevated CO_2 gas and GHG levels, and a rise in natural calamities. Climate-smart crops should be adopted, which will play a pivotal role in climate-smart agriculture. There is no doubt in the fact that millets are climate-smart crops that can simultaneously mitigate the ill effects of climate change and adapt to the changes and agro-climatic conditions. Millets have efficient morphological, physiological, molecular, and biochemical traits that can withstand biotic stresses. Short-duration crop millets complete a cycle within a short span of time and can escape environmental stress conditions under early or late sowing conditions. Also, millets possess a lesser leaf area, a thick cell wall, and a dense, fibrous root system, which facilitates their ability to tolerate biotic stress. Being a C4 plant, millets can utilise more atmospheric CO_2 and, through the process of photosynthesis, can produce more CO_2 to assimilate, even at higher CO_2 levels in the atmosphere. Also, the water use efficiency (WUE) of millet is higher than that of major cereals, and, in the future, under the crucial situation of water deficit in a major portion of the world, millet will be chosen to combat water shortage. As millets are less nutrient-demanding crops, promotion of millet cultivation will indirectly save the environment.

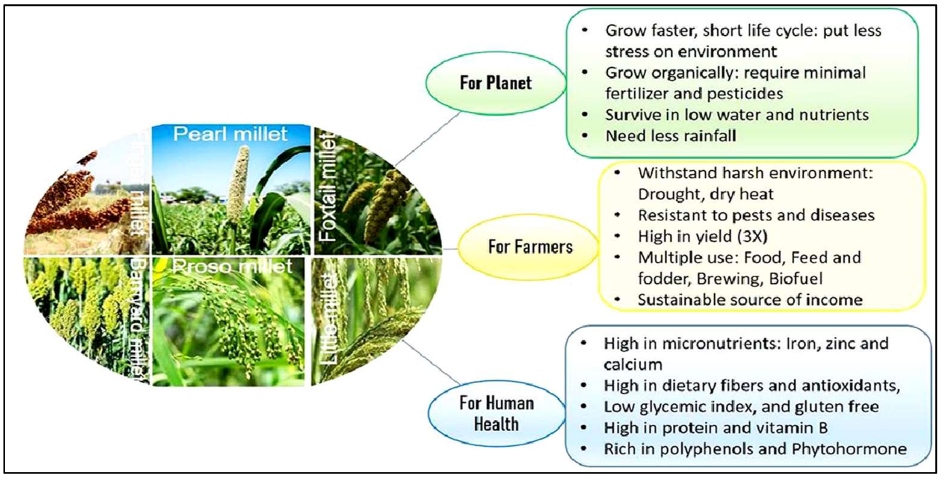

Fig.3: Unique properties of millets for climate smart agriculture, ensuring human health, food and nutritional security (Rathinapriya *et al.*, 2020)

With the growth of population, the demand for food increases. Majority of the staple cereals consumed are rice, maize and other cereals, millets on the other-hand are lagging behind. As the world is facing the challenge of dryland expansion, scarcity of ground water and degradation in soil quality or fertility the scope of crop improvement is decreasing, soil degradation. To solve these growing concerns cultivation of millets can be taken up as they can be grown on shallow, less fertile land with a wide (ranging from 4.5 to 8.0) pH. There are many types of millet such as proso, finger, foxtail, barnyard, Kodo, teff, little, guinea, brown top, and fonio. Wheat and rice can be easily replaced with millets. As millets can feed a population limited in resources and offers several opportunities for their cultivation in developing countries it can be very easily considered as poor man's food.

Drought and millets: Impact and Adaptation

Many biotic and abiotic stresses regulate crop production. As the world witness's rapid changes in climate, major losses of arable land used for cultivation, and increasing abiotic stresses during critical stages of plant growth and development, there is a rapid decline in crop yields. Abiotic stress such as extreme temperature (cold, frost), drought, flooding, salinity, etc. are the major yield limiting factors in semi-arid and arid regions. Millets possess numerous morpho-physiological, molecular, and biochemical properties that give them better adaptability to environmental stress than major cereals. Many molecular mechanisms govern the plant's responses to abiotic stresses, like sensing, signalling, transcription, transcription processing, translation, and post-translational protein modifications, which are governed by both genetic and environmental factors. Among all major abiotic stresses, increased drought and heat due to climate change adversely affect current crop production and cause more annual losses. The climate change models predict that drought stress will continue as a major biotic limitation for food production.

Millets have numerous morpho-physiological, biochemicals, and molecular traits that confer superior adaptability to drought compared to major cereals. The rainfall requirement of pearl and proso millet is 20 cm, which is many fold lower than rice, which requires more than 120–140 cm. The short life cycle of millets compared to other major crops also supports their stress tolerance. Higher photosynthetic rates are observed in millets in warm conditions that confer immediate water and nitrogenous efficiency. Being C4 plants, millets have many benefits, including better growth and development under warm temperatures, good storage of photosynthates, and reduced hydraulic conductivity per unit leaf area.

Pearl millet can regulate its membrane functions better for permeability to water to attain better water retention during osmotic stress. Tensile strength of leaf and length of root increased in teff and little millet under drought. Several biochemical events, *e.g.*, reactive oxygen species (ROS) regulation, enhance ROS scavenging enzymes and other stress-related proteins. The accumulation of antioxidants and osmolytes has been reported in response to abiotic stresses. Owing to these qualities, studies and research on millets can be taken up to study their stress-responsive behaviour and how they regulate their mechanisms to mitigate stress at the physiological, biochemical, and molecular levels.

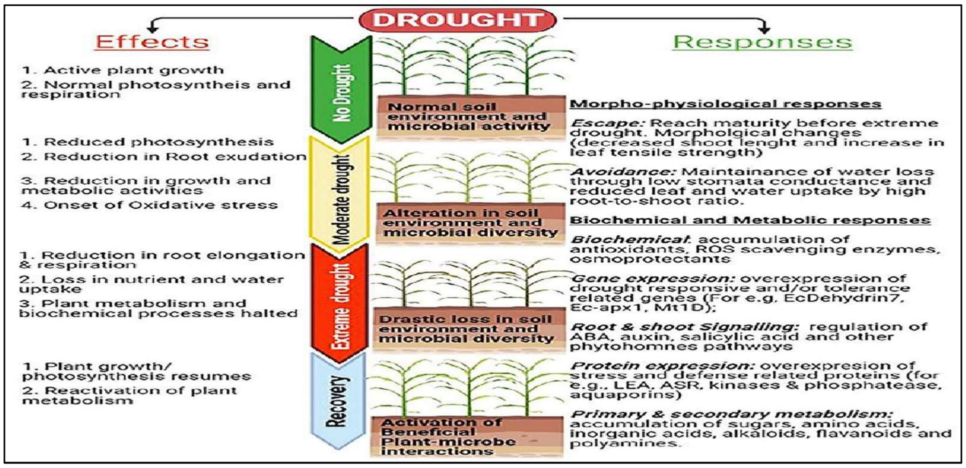

Fig. 4: Drought responses and adaptive strategies linked to numerous morpho-physiological, molecular, and biochemical processes that confer better tolerance to environmental stresses in millets compared to major cereals (Kumar *et al*., 2018)

Incorporation of millets in Indian food supply chain

To feed the population, we first need to produce and process millets and enjoy their nutritional benefits. But the scope for enhancement of productivity under irrigated conditions is limited because of over exploitation of available resources, but there are many opportunities for boosting yield in drylands by uptaking suitable crops and cropping systems. The combination of cereal and legume intercropping can be a major help to farmers in subsistence farming, targeting livelihood security. They also have numerous advantages, such as increased crop productivity, increased resource efficiency, reduced water run-off, soil conservation in erosion-prone areas, and prevention of soil nutrient loss, improved soil health, and insurance against crop failure. Due to unusual weather, and a higher monetary return and benefit-cost ratio.

Snacking has become a common practice among children and adults; therefore, an attempt should be made to develop some healthy snacks like muffin cakes and biscuits from processed malted finger millet flour to get the maximum advantage of their nutrient content in terms of bioavailability.

Fermenting and cooking the ready-made mix to create idli and dosa, germinated powders of minor millets were blended and incorporated with other fundamental traditional components like rice powder and de-husked black gram powder in defined proportions. In comparison to rice-based idli, high proportions of protein (15–18%), fat (8.5–9.8), and carbohydrates (69–72%) were determined.

A key factor in achieving the estimated benefits of real diversification is the extent to which agronomic characteristics will permit switches between crops. On the one hand, historical policy regimes have promoted the widespread cultivation of crops in places that may not have otherwise been agro-ecologically suitable or sustainable (*e.g.*, rice in northern India), and on the other hand, certain areas where rice is grown may not be able to support the cultivation of coarse cereals. Assessments quantifying the range of biophysical conditions that can support the cultivation of each cereal will therefore be essential for understanding the potential magnitude of co-benefits from increased cereal production.

An increase in the production of coarse cereal has largely occurred in the places where the cultivation of these cereals is currently centred. This is encouraging from a farmer's perspective, as the local knowledge of effective crop management practises may be more readily available.

CONCLUSION

Climate change has had many effects on the agricultural sector globally. These extreme climate events, like rises in temperature, variations in rainfall patterns, droughts, etc., have added pressure on agricultural and food systems. Climate change has disrupted many agriculture and supply chain activities, causing food and nutrition security challenges, and sustaining livelihoods. Climate change has the most negative impact on developing countries by hampering resource availability, such as water, and causing pollution and soil degradation. Millets not only serve as an income crop for farmers but also improve the health of the community. Therefore, climate-smart or resilient agriculture should be adopted, and millets promise to be one such important tool to help feed the population and provide nutrition in these days of growing concern.

Diversifying crop production by including more cereals can make food supply more nutritious, decrease resource demand and greenhouse gas emissions, and enhance climate resilience without reducing calorie production or requiring more land. Millets can contribute to sustainable food systems under climate change. Because they are resilient and have outstanding potential to survive low water availability and stressful environments, they are the best alternative to staple cereal crops.

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Chapter - 5

Sustainable Insect Pest Management of Rice

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The main obstacles to the production of rice (*Oryza sativa*) are insect pests and disease outbreaks. Chemical pesticides are essential for controlling crop diseases and pests. However, the overuse and inappropriate application of pesticides has grown to be a significant issue and a barrier to sustainable agriculture. As a result, quality and security of agricultural goods are compromised, endangering the ecological and environmental integrity. Integrative pest management, an ecologically based strategy to eliminate hazardous insects and pests, has been widely adopted in response to concerns about the sustainability of conventional agriculture. By using natural parasites and predators to regulate insect populations, integrated pest management aims to lessen the harm chemical pesticides cause to the environment and human health. It is highly recommended that, in addition to adopting diverse IPM practices to combat insects and pests and reducing the use of pesticides, farmers and their educational initiatives should be given a little more attention. The current chapter will discuss various pest management strategies, with a focus on biological pest control in rice crops.

Keywords: *Rice; chemical pesticides; conventional agriculture; ecological and environmental integrity*

INTRODUCTION

Over half of all people in the planet eat rice as their primary food. In the developing world, it contributes 27% of the dietary energy and 20% of the dietary protein. At least 114, largely developing, nations farm the crop, which provides the main source of income and employment for more than 100 million households in Asia and Africa (FAO, 2004). Together, China, India, and Indonesia occupy more than half of the world's rice land and consume more than three-fourths of the world's rice output

(Hossain, 1997; MacLean *et al.*, 2002). Many nations' economies depend heavily on the production of rice, so any crises that reduce this commodity's output could have a negative impact on those nations.

Practicallyin all nations that produce rice, insect pests and crop diseases are reg arded as the main causeof a decline in rice production. Integral India comes second in output (104.31 million tonnes in 2011–12) and has the greatest area under rice cultivation in the world (44.6 million hectares). Rice is farmed in India amid a variety of agro-ecological circumstances, including waterlogged, deep water, hills, high humidity, high temperatures, salt, and places that are prone to flooding. Due to the availability of continuous irrigation, rice can only be grown in the fertile deltaic regions for a maximum of three seasons each year depending on the environment. Due to an onslaught of various pests like insects, nematodes, diseases, weeds, and rats, the rice crop is vulnerable to stress throughout the crop growth period. Concern over food security has grown in recent years, particularly in emerging nations where the supply of rice has not kept pace with population growth.

Unfortunately, as irrigated rice cultivation became more intensive and more insecticides were used, pest issues got worse. Only pesticides continue to predominate and be the main element among the various management strategies offered. Insecticides make up the greatest component of the global market for rice pesticides. Insecticides for rice accounted for an estimated US $1,114 million in 1993, or 37% of the total (Woodburn, 1993). Each year, biotic and abiotic causes result in the loss of more than 200 million tonnes of rice (Khan *et al.*, 1991). Insect-borne viruses are the primary means of transmission for several fatal diseases of rice, including yellow dwarf disease and tungro (Heinrichs *et al.*, 1985). The lepidopteran stem borers (*Tryporyza incertulas* and *T. innotata*) and rice leaf folder (*Cnaphalocrocis medinalis*), which annually cause losses in the range of 10 million tonnes, are the most devastating insects for rice. It is uncommon for a crop to completely fail, although on occasion, outbreaks can wipe out anywhere between 60 and 95% of it (Yambao *et al.*, 1993; Pathak and Kehan, 1994). In particular, the use of insecticides was found to be associated with outbreaks of secondary pests, such as the hitherto insignificant brown planthopper, *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae) (Kenmore, 1991). The use of insecticides to combat secondary pest outbreaks of increasing size resulted in other issues, most notably the development of pest resistance, which led to the abandonment of several large-scale rice production plans, such as those in the Solomon Islands (Rombach & Gallagher, 1994). In addition, insecticide poisoning of agricultural workers developed into a significant problem (Teng & Heong, 1988), and chemicals used to control rice pests caused insecticide resistance in human disease vectors that reproduce in flooded fields (Way, 1987). In order to significantly reduce the use of expensive insecticides that, in addition to exacerbating some pest problems, can also be environmentally harmful and may involve virtually unresolvable dilemmas for farmers needing to use insecticides on a need-basis, it is necessary to make natural, non-chemical controls collectively more effective (Goodell, 1984). We must spread awareness of Integrated Pest Management (IPM) worldwide in response to growing concerns about the sustainability of conventional agriculture. IPM lacks a defined definition but includes methods that range from the biological management of pests through the use of natural parasites and predators to the targeted application of chemical pesticides (Sorby *et al.,* 2003).

Predators do not harm plants, although they consume a lot of their prey. They can achieve balance in pest management. Predators are important in the management of pests in agriculture. Because there is so little knowledge about the ecological significance of predators in pest management, they have typically not been considered an essential biological control agent. Spiders in rice fields can play a significant role as a predator in reducing the populations of insect pests of the rice crop, according to research conducted by numerous researchers (Gavarra and Raros 1973; Hamamura 1969; Choi and Namkung 1976; Kobayashi 1977; Chiu 1979; Holt *et al*., 1987). The equilibrium between insect pests and their natural antagonists can be readily upset by the indiscriminate use of insecticides. It is crucial to understand that a few insect pests that cause no financial harm are advantageous because they offer food to keep populations of beneficial species at levels that can stop detrimental pest outbreaks. Rearing predators in large numbers for release onto rice fields is very expensive. It is crucial to preserve bio-control agents, which can be done by reducing the use of broad-spectrum insecticides or by using insecticides that are only poisonous to pests and not to predators (Thomson, 1994; Shepard *et al*., 1995). Under extensive crop cultivation, it has frequently been found to be challenging to control insect pests with conventional approaches. In the recent past, emphasis has been placed on the significance of pest control, which involves having a thorough understanding of the ecology of the main pests.

The best way to handle pest issues is to adopt integrated pest management (IPM) tactics. A framework for integrating knowledge, abilities, and information on rice pest management is provided by rice IPM. Regular pest monitoring, studies on the most effective use of pesticides, supplemental weed control methods, and alternative cultural and biological controls are all examples of IPM practises used in rice production initiatives. Several attempts have been made in this regard to design, confirm, demonstrate, and document site-specific IPM technology appropriate for various ecosystems. IPM requires ongoing technology upgrades because it is a dynamic process that must adapt to changing pest situations. The goal of raising production levels to satisfy future demand requires farmers to adopt contemporary and intense agricultural practises. However, biotic restrictions like insect pests, illnesses, and weeds exacerbate in tandem with the practise of intensive agriculture. More than 100 insect species, of which around a dozen are significant in India, have been identified as rice pests. According to coordinated network trials carried out in various places in India, controlling insect pests alone can enhance output by about 1 ton/ha.

The purpose of this chapter is to emphasise the significance of integrated pest management practises in the agricultural sector, particularly recent advancements in biological control techniques within an ecological framework in rice crop, and to also draw attention to a potential avenue for offering ecologically based integrated pest management programmes. The review's practical goal is to highlight the chances for the farmer to maximise the use of the various natural controls as a substitute for reliance on pesticides.

Evolution of pest management in rice

For Asian rice producers, controlling insect pests continues to be a major issue. The "ravages due to pests" were blamed for yield losses of 15 to 25% or higher (Oerke *et al*., 1994). Crop losses from pests continue to be 30%, unchanged from 30 to 40 years ago. A sensitive insect breeding ground was thought to consist of two or three harvests per year, frequently overlapping extensively fertilised monocultures of the "Green Revolution" (GR), and high yielding cultivars (Kiritani, 1979). The GR was a technology that was packaged for mass consumption, both literally and metaphorically. High yielding variety seeds, inorganic fertilisers, insecticides, and fungicides were typically included in the package. When natural enemies and their food sources are destroyed by insecticides, the field is left open for secondary and resurgent pests like the brown plant hopper (BPH), Nilaparvata lugens Stal (Kenmore *et al*., 1984), and the green leaf hopper (GLH), Nephotettix spp. (Kiritani, 1988), to establish a pest population. In addition to encouraging the survival and reproduction of virulent individuals, pesticide use is thought to have sped up the adaptation of BPH to resistant cultivars (Gallagher *et al*., 1994). Insecticide use has also adversely affected the faunal makeup of rice and damaged the environment, leading to pesticide residues in food and breast milk (Kiritani, 2000). Although various entomologists worked diligently to develop rice IPM on a global scale, its acceptance has not reached the required level for a variety of reasons. One of the main causes of IPM's sluggish deployment is the powerful influence agrochemical producers and distributors have in preventing its widespread acceptance. A comprehensive view of the rice ecosystem was either never thought to be significant or was disregarded.

Pests as constrains in rice cultivation

A. Insect Pests of National Significance:

a) Yellow stem borer (*Scirpophaga incertulas* Walker)
b) Leaf Folder (Cnaphalocrocis medinalis Guenée)
c) White-backed plant hopper (*Sogatella furcifera Horváth*) and Brown plant hopper (*Nilaparvata lugens* Stal)
d) Gall midge (*Orseolia oryzae*).
e) Gundhi bug (*Leptocorisa acuta*)

B. Insect Pests of Regional Significance:

a) Termite (*Odontotermes obesus* Rambur) - In rainfed upland areas, irrigated rice-wheat system.
b) Rice Hispa (*Dicladispa armigera* Oliver) - Bihar, West Bengal, Assam, Odisha, Meghalaya, Mizoram, Tripura, Punjab, Himachal Pradesh, Uttar Pradesh and Uttarakhand Punjab.
c) Swarming caterpillar (*Spodoptera mauritia* Boisduval) - Odisha, West Bengal, Jharkhand, Chhattisgarh a
d) Climbing cutworm/Rice Ear Cutting Caterpillar/ Armyworm (*Mythimna separata* Walker) - In coastal rice growing areas, Haryana, Punjab and Uttar Pradesh.

e) Thrips (*Stenchaetothrips biformis* Bagnall) - In upland rice in Odisha, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana, Assam and Tamil Nadu.

f) Caseworm (*Nymphula depunctalis* Guenée) - In low lying and water logged areas in eastern India.

g) Panicle mite (*Steneotarsonemus spinki* Smiley)-Andhra Pradesh, Odisha, West Bengal, Gujarat and Western Uttar Pradesh and Leaf mite (*Oligonychus oryzae* Hirst) –Eastern India and Andhra Pradesh.

h) Mealy bug (*Brevennia rehi Lindinger*) - In upland rice in Uttar Pradesh, Bihar, West Bengal, Odisha, Madhya Pradesh, Tamil Nadu, Kerala, Pondicherry and Karnataka.

i) Root weevil (*Echinochemus oryzae* Marshall) - Haryana, Punjab and Tamil Nadu.

j) Black bug (*Scotinophara coaractata* Fabricius) - Andhra Pradesh, Tamil Nadu and Kerala.

k) White grub (*Holotrichia* spp.) - Hill rice.

l) Blue beetle (*Leptisma pygmaea* Baly) - Kerala, Maharashtra and Tamil Nadu

Table 1: Economic thresholds of various common insect pests of rice are listed in

Pest	Economic thresholds	Reference
Stem borer	10% dead hearts or 1 egg mass or 1moth/m2	Pasalu *et al.* 2004
BPH and WBPH	10 insects/hill at veg. whereas 20 insects/hill at later stage	Pasalu *et al.* 2004
Green leaf hopper	2 insects/ hill in tungro endemic areas. 20-30 insects/hill in other areas	Pasalu *et al.* 2004
Gall midge	1 gall/m^2 or 10% silver shoot	Pasalu *et al.* 2004
Leaf folder	2-3 damaged leaves/ hill post active tillering stage	Pasalu *et al.* 2004
Case worm	1-2 cases/hill	Misra and Jena, 2007
Cutworm	1 damaged tiller/hill or 2 larvae/m^2	Prakash *et al.* 2014
Earhead bug	1 nymph or adult/hill	Prakash *et al.* 2014
Rice hispa	2 adults or 2 dead leaf/hill	Prakash *et al.* 2014
Rice black bug	5 bugs/hill	Prakash *et al.* 2014
Whorl maggot	25% damage leaves	Misra and Jena, 200

Insect pest management strategies for rice insect pests

Cultural methods are methods of crop husbandry that serve the dual purposes of crop production and crop protection. Farmers developed these techniques through observation and trial-and-error.

a) Synchronous planting: One of the IPM strategies that is popular in many places is the promotion of synchronous planting as a measure of pest management. The idea is that because non-synchronous planting patterns provide the rice bugs with a steady supply of food, they encourage pest issues.
b) Water management: Farmers have long used techniques like draining to get rid of whorl maggots, yellow stem borers, and caseworms, flooding to get rid of armyworms, white grubs, grasshoppers, root aphids, and termites, and alternate flooding and draining to get rid of plant hoppers, black bugs, gall midges, and numerous stem borers. However, the most recent advances in water management technologies have negatively impacted these tried-and-true strategies.
c) Weed Management: The majority of rice pests, both inside and outside the rice fields, are hosts for grassy weeds. It's frequently advised to weed frequently to control rice pests. There are connections between water, soil preparation, seeding, and weed management. An efficient and effective technique to prevent weed invasion in annual crops is through proper soil preparation. It is frequently advised that effective insect control necessitates regional weed control. Weeds can directly supply food supplies for herbivorous arthropods or other ecosystem resources, and they can also indirectly support carnivorous (beneficial) arthropods by giving their prey food and shelter. When their normal crop host is absent, pest and beneficial arthropods might use weeds as an alternate host.

Use of resistant cultivars

In rice, the potential utility of insect-resistant cultivars hasn't been fully realised, whether used on their own or in conjunction with other IPM strategies. It is important to remember that farmers will only use an insect-resistant variety if it produces high yields of good-quality wheat. A significant barrier to producing and using resistant cultivars is the presence of insect biotypes. There are now five biotypes known for *N. lugen*s. To delay the formation of new biotypes, varieties with more stable resistance should be produced.

Marker assisted breeding in Rice

When developing insect-resistant cultivars of rice, marker-assisted breeding should take advantage of the plant's innate insect resistance. Additionally, quantitative trait loci (QTL) mapping was used to conclusively prove the existence of quantitative resistance to BPH in rice (Alam and Cohen, 1998). Combining traditional genetic analysis with current molecular marker technologies will make it simple to identify DNA markers that are intimately connected to the gene(s) of interest. Another strategy for breeding for long-lasting resistance to insect pests is selective phenotypic screening for the components of resistance, such as antibiosis, antixenosis, or tolerance, and identifying certain QTLs. With the exception of two instances—creating introgression lines with brown plant hopper resistance using marker assisted breeding (Jairin *et al*., 2009) and characterising a gene for BPH resistance based on QTL analysis (Du *et al*., 2009—multiple major genes and QTLs are mapped for BPH resistance in rice—the success of exploiting them in rice breeding is insufficient.

Insect resistance in transgenic rice

Using a Bt-gene to convert rice, yellow stem borer (YSB) (*Scirpophaga incertulas*), striped stem borer (*Chilo suppressalis*), and leaf folders (*Cnaphalocrocis medinalis*) were the first pests to be addressed (Fujimoto *et al*., 1993). Bt rice is extremely effective against rice borers and leaf folders, which are the two main classes of rice lepidopteran pests that severely reduce yield in all countries that grow rice, according to the results of numerous studies and evaluations of Bt rice (Wu nn *et al*., 1996; Chen *et al*., 2005). *Galanthus nivalis* agglutinin (GNA), an insecticide gene, was expressed in transgenic rice plants, and these plants shown varying degrees of resistance to all of the major sap-sucking insects examined, including BPH, GLH, and WBPH. The effects of transgenic rice on cropping systems are not yet recognized, and genetically modified rice with insect resistance genes is not as well-known as transgenic cotton with the Bt gene. Before releasing such kinds or hybrids for production, the safety of transgenic rice grains for human consumption and the straw to cattle must be rigorously investigated over an extended period of time.

Biological control methods in rice crop

The effectiveness of biological control agents in controlling nematode, snail, and herbivorous insect infestations in rice has been studied. Although research continues to uncover effective biological control agents against introduced aquatic weeds that also exist in rice, traditional biological management is rarely considered even after the introduction of noxious weeds and destructive insects to new places (Culliney, 2005). Despite being targeted at rice farmers, traditional biological management is not exclusive to rice fields and operates at the regional level. An essential component of integrated pest management is the use of biological control agents to combat crop insect pests. Several parasitoids and predators have been successfully used for biological control, offering a viable alternative to chemical control. However, they only demonstrated their efficacy against one or a small number of insect pests, primarily yellow stem borer and leaf folder, and they were ineffective against occasional pests including cutworm, gundhi bug, and rice hispa. In contrast to other crops, rice ecosystems have shown inconsistent success with the deployment of biocontrol agents through inundative or inoculative releases (Pathak *et al.,* 1996). Because egg parasitoids are easily grown in laboratories, inundative releases of natural enemies have been limited to egg parasitoids, primarily Trichogramma japonicum and T. chilonis, in the rice environment of India. The four species T. japonicum, T. chilonis, T. ostriniae, and T. dendrolimi are the most often seen Trichogramma spp. in rice fields. According to reports, stem borer infestation in India was successfully reduced by the inundative introduction of the exotic parasitoid T. japonicum @ 20,000 per acre (Pasalu *et al*., 2004).Similar to the previous example, 4 to 9 times releases of T. japonicum @ 1,00,000 adults/ha beginning from 20 to 38 days after transplanting with an interval of 7–10 days led to a 4–59% reduction in leaf damage caused by leaf folder (Pasalu *et al*., 2004).

Ducks and fish-based biocontrol of insects and snails has received more attention recently as a component of integrated farming systems. It has been demonstrated that ducks in particular can lower snail concentrations. Insect and snail management by fish has proven to be more challenging and can present challenges. For instance, the common carp, Cyprinus carpio L, significantly lowers snail numbers, yet in other areas; carp pose an invasive concern (Ip *et al*., 2014). It has been challenging to assess the success of biological control in general. Another effective strategy for controlling rice insect pests is to utilise microbiological pesticides like Bt (*Bacillus thuringiensis*), viruses, and fungi since they are safe for use around people, animals, and the environment. In a 1978 study, Nayak *et al.* examined the effectiveness of Bacillus thuringiensis var. Kurstaki (Thuricide) against different stages of the rice yellow stem borer, S. incertulas, and discovered that while Bt had no toxic effects on the egg, pupae, and adult stages of the stem borer, it did reduce the incidence of dead hearts and white heads when sprayed at the time of the larvae's hatching under greenhouse conditions. According to Liu *et al.* (2013), the Cnaphalocrocis medinalis granulovirus (CnmeGV) shown synergistic effect with Bt against rice leaf folder. Beauveria bassiana, a fungal infection, was reported to be effective against rice hispa in India (Hazarika and Puzari, 1997), whereas Pandora delphacis was effective against BPH (Narayanasamy, 1995).

Integrated farming system (IFS)

Because of their harmonious co-development, IFS and animal husbandry, such as rice-duck and rice-fish, are an excellent mutually beneficial combination (Hong-xing *et al.*, 2017). Ducks are introduced into rice fields as part of a rice-duck system to alter the microclimate, eliminate unproductive tillers, encourage more sunshine and gas exchange, increase soil health, and lessen insect pests (Long *et al.*, 2013; Hong-xing *et al.*, 2017). The rice-duck system also contributed to a rise in biocontrol agents, which in turn led to a decrease in rice insect pests. Similarly, rice fish farming also help sustainable rice production by decreasing input costs in terms of fertilizer and insecticide application as fish decreasing insect population by feeding them whereas enhance soil organic matter by their excreta (Ahmed and Garnett, 2011; Rahman, 2016). Although rice duck and rice fish integrated rice farming system is followed in different low lying areas of West Bengal and Assam but that should be popularize in other places in India for sustainable rice production.

Semio-chemicals

It is well-known that plants emit volatile compounds that draw natural enemies when they are attacked by arthropod herbivores (Bruce and Pickett, 2007). It has been possible to identify some of these herbivore-induced plant volatiles (HIPV), synthesise them, and employ them as sprays or slow-release dispensers. After 2 to 24 hours of infestation, N. lugens attacks cause plants to release ethylene, HIPV, and activate salicylate signalling pathways, all of which lead to increased parasitization by luring Anagrus nilaparvatae, a primary parasitoid of N. lugens (Gurr, 2009). Therefore, using such exogenous compounds on rice plants may increase the natural enemies' appeal, aiding in the management of insect pests.

Ecological engineering techniques

Ecological engineering techniques can be used to diversify habitats in order to control the population size and frequency of insect pest outbreaks (Lu *et al*., 2015; Gurr *et al*., 2016; Hong-xing *et al*., 2017). It was found that rice fields with nectar-rich flowering plants surrounding them produced higher yields and had higher populations of natural enemies (Lu *et al*., 2015). Like other plants, rice lacks resources for flower nectar that natural enemies could consume. In order to promote the longevity and reproduction of natural enemies as well as the effectiveness of their biological control, nectar-rich flowering plants and vegetable patches should be carefully chosen and planted in rice landscapes (Hong-xing *et al*., 2017). In order to ensure that flowering plants are available at all stages of rice growth, flowering plants should be planted on the bunds of rice fields prior to rice transplantation and new plantings should be made one month following rice transplanting (Lu *et al*., 2015). Similar to this, sesame flowers greatly boosted the fertility of Trichogramma chilonis, a common egg parasitoid of many Lepidopteran insects (Hong-xing *et al*., 2017). In India, more spiders, mirid bugs, and plant hopper parasitoids were discovered in rice fields when flowering plants like marigold, balsam, and crops like sesame, sunflower, were grown in rice bunds (Anonymous, 2021).

Botanicals

The use of botanicals is a novel strategy because they are thought to be safe for both people and the environment. Botanical pesticides, unlike industrial pesticides, do not kill insect pests in their natural habitats; instead, they discourage them from feeding, reproducing, and ovipositing (Pasalu *et al*., 2004). Neem formulations are somewhat effective against stem borer, leaf folder, plant, and leafhoppers, according to numerous greenhouse and field investigations (Pasalu *et al*., 2004; Seni and Naik, 2019). According to Misra and Jena (2007) neem seed kernel extract at 0.001-0.4% was successful in keeping plant hoppers away. Additionally, it was noted that Cedar wood oil at 1000 ml/ha was effective against gall midges while eucalyptus oil at 1000 ml/ha was shown to be promising against yellow stem borer and plant hoppers (Seni, 2019).

Nanotechnology

The use of bio-conjugated nanoparticles (encapsulation) to increase agricultural productivity, the protection of plants through the formulation of nano-particle-based pesticides, the development of insect-resistant plant varieties through the use of nano-based biomarkers, and many other opportunities are all made possible by nanotechnology. In addition, nanoparticles can be used to create different kinds of biosensors that can be incorporated into the remote sensing equipment needed for precision farming (Rai and Ingle, 2012). By lowering the pesticide dose while increasing the pesticides' effectiveness, using nanoparticles and nanocapsules of pesticides helps reduce environmental contamination.

Information technology for pest management

The efficient and cost-effective management of rice insect pests is made possible by information technology. Rice knowledge banks, which were created and made accessible through specialized websites, may provide farmers and other government extension workers with information on numerous elements of rice production systems. Farmers can access some rice knowledge "apps" via smart phones (such as the IRRI Rice Knowledge Bank), while in others (such as the IRRI Crop Manager and IRRI Rice Doctor), they can submit photos of potential pests they may have found in their fields in exchange for various diagnostic support from remote specialists. The "e-National Pest reporting and alert system" was created in India by the National Centre for Integrated Pest Management (NCIPM), New Delhi, based on data meticulously processed to enable the system to deliver the results immediately to the farming community via short messaging service (SMS) in their native tongue. Similar to this, the Indian government established Kisan Call Centres to provide extension services to the farming community by responding to their inquiries.

Management of some other pests of rice

Numerous pests, including rodents, snails, birds, and others, also significantly harmed various crops. So, more community-level planning and action are needed to control the harm caused by these insects. Rats are one of these pests that severely harm rice plants in the field. It travels locally to rice fields. After the panicle has emerged, it favours the rice plant. Farmers sometimes employ various tactics, such as different insecticides, to control the rat population in their crops. In order to ensure that the baits are effective, rat management strategies identify the main species of rat's present. Following this, community-level mapping techniques are used to plan and carry out continuous trapping along feeding routes, fumigation or the digging of rat holes, modification of the appropriate habitat, and the establishment of early season bait stations using second-generation anticoagulant baits. However, some farmers employed extremely poisonous substances such unlabeled aldicarb (Temik) and zinc phosphide. According to FAO (1998), community programmes can incorporate educational activities on rat biology and behaviour to enhance strategy development and participation.

Birds are yet another pest that can seriously harm rice. When they arrive in big groups at such time, they are dangerous. Most Asian nations utilize netting to catch large numbers of birds in their rice and other crops. While it is also possible for some species to destroy a lot of nests. In Asia, these techniques have been successful in bringing down pest bird populations to extremely low levels. When used to catch fish, locals may benefit financially or occasionally receive more dietary protein in an area like Africa. During the ripening season, certain fields in northeast Asia are protected by being covered with readily accessible bird nets. In Asia and Africa, several bird-scaring techniques are occasionally used to keep fields free of birds. While shouting or throwing dried mud at birds is prevalent in Africa, reflecting ribbons are frequently used to scare birds in Asia (Gallagher *et al*., 2009). Overall, more community-level planning and action is needed to effectively control some pests, such as rats and birds.

Role of non- rice habitats

Enemies may be found in the ecology of rice in a variety of non-rice settings. Unquestionably, non-rice ecosystems could occasionally be the source of a localized invasion by pests that feed on multiple species, such armyworms and locusts. In contrast, many predators are polyphagous and eat on a variety of foods, whereas the majority of significant pests are specialized or exclusively oligophagous pests for rice. Non-rice habitats must unquestionably be taken into account or acknowledged as potentially being quite significant, especially for some natural enemies' off-season continuity. The paddy agroecosystem is home to a wide variety of arthropod species with various life cycles.

After emerging from rice fields, sympetrum dragonflies stay in coppiced woodlots to develop sexually before returning to paddy fields to lay their eggs. The water scorpion, *Ranatra chinensis*, moves its newly born adults from paddy fields to irrigation ponds during the winter. As a result, the rice agroecosystem's biodiversity is reliant on more than just the paddy fields themselves, including nearby fallow fields, neighbouring farms, secondary forests, wetlands, rivers, and remote hibernation places (Kiritani, 2000).

CONCLUSION

Understanding the changes in the community structure is crucial since pest management techniques have an impact on all of the animals in the system. In the past several years, the integrated pest control programme for rice crops has made significant success, but more information on the potential of natural enemies, microbial insecticides, and cultural practices is still required. However, insect pests will still pose a problem for rice production globally. The biological control strategy is reducing the usage of chemical pesticides, which is increasing the abundance of some beneficial insects and enhancing the natural control of particular pests. It is advised that IPM adoption boost rice farmers' earnings since pesticide expenditures are decreased without a corresponding drop in output. IPM approaches and strategies that are compatible with conservation must be used for environmental protection. Tolerant cultivars that exhibit resistance to worms and insects should be used to replace varieties that are sensitive to an insect or pest assault. There is a lot of room for designing rice systems, cycle crops, and landscapes to feed, shelter, and make it easier for natural enemies to get to newly planted rice. For the development of ecologically sound control measures and for the improvement of current levels of natural control, a better understanding of the causes and timing of pest outbreaks is required (Matteson, 2000). Scientists must make sure that new technology supports the natural equilibrium in the rice crop, which largely shields rice from pest issues.

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Chapter - 6

Indigenous Technology Knowledge for Enhancing the Muga Silkworm Cultivation and Yield

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Indigenous Technical Knowledge (ITK) is the real knowledge held by a population that reflects both current technological experiences as well as experiences based on tradition. Muga culture is an ancient tradition that has persisted among rural people in Assam and a few other states in North East India. To ensure high crop production, diverse ITKs are significantly used in the muga culture. Since long years past, muga culture has been seen as one of the most promising initiatives for improving the socio economic status of the rural population in Assam. The culture includes a variety of indigenous customs and beliefs, differing from place to place and is also believed to greatly effective in the muga production system This chapter includes various traditional practices of ITKs in Muga culture based on the experiments and surveys conducted at North Lakhimpur district of Assam and presented vividly in this manuscript.

INTRODUCTION

Sericulture is an agricultural-based enterprise. It entails raising silkworms for the purpose of producing raw silk, which is the yarn made from cocoons spun by specific insect species. Sericulture's main tasks include growing food plants to feed the silkworms that spin silk cocoons and reeling the cocoons to unwind the silk filament for uses like processing and weaving.

In sericulture, four separate silkworm species creates the four natural silks:

- Eri silkworm
- Mulberry silkworm
- Muga silkworm

- Tasar silkworm

Sericulture and its economic importance

In a number of nations, including China, Japan, India, Korea, Brazil, Russia, Italy, and France, sericulture has emerged as one of the most significant cottage industries. China and India are the world's two largest producers now, producing 90% of all goods. In the country, between 60 and 100 lakh people work in various sericulture-related fields. In both on- and off-farm activities, sericulture is predicted to be able to produce 11 man days of employment per kg of raw silk output over the course of the year. Sericulture is utilised as a method to improve the rural economy since it has exceptional job potential and no other industry does, particularly in rural areas. About 57% of the total gross value of silk garments is returned to cocoon farmers as revenue split among several groups. 56.8% to the cocoon grower 6.8% for reelers, 9.1% for twisters, 10.7% for weavers, and 16.6% for crafts. The mulberry only needs six months to reach full size before silkworm rearing may begin. Depending on the inputs and maintenance given, mulberry will support silkworm rearing year after year for 15-20 years after it has been planted. A farmer can achieve net income levels of up to Rs. 5000 per acre per year by implementing the prescribed package of practises. With the right upkeep and inputs, diligent farmers can generate up to 2 lakh in annual income from one acre. More than 60% of people working in the nation's downstream sericulture activities are women. This is achievable because women are more successfully involved in sericulture operations, such as managing mulberry gardens, collecting leaves, and raising silkworms. They provide complete support for the weaving and silk reeling industries.

Sericulture can be carried out on very little area. A family of five can be supported on one acre of mulberry cultivation and silkworm breeding without the use of hired labour. Sericulture is an excellent programme for the disadvantaged segments of society due to characteristics like low gestation and large returns. Rural households primarily gain from sectoral value addition. Money goes from high end groups to low end groups because the majority of end-product users come from higher economic groups.

Muga silkworm

Locality: *Anthereae assamensis*, also known as the muga silkworm, is found in the Brahmaputra valley in Assam, the East, West, and South Garo hills of Meghalaya, a few districts of Nagaland, the Lohit and Dibang valleys, Chanlang and Papumpare districts of Arunachal Pradesh, Tameng-Long district of Manipur, and the Cooch Bihar district of West Bengal. It also occurs in Sikkim, Himachal Pradesh, Uttar Pradesh, Gujarat, Pondicherry, Bangladesh, Indonesia, and Sri Lanka, as well as the Kumaon and Kangra valleys in the western Himalayan ranges. Although attempts to domesticate the muga silkworm have failed, new efforts have been made to sustain it in semi-domesticated settings and enhance its economic characteristics (Thangavelu & Sahu, 1983).

Taxonomic position: *Anthereae assamensis* belongs to the: -

Phylum- Arthropoda,
Class- Insects,
Order- Lepidoptera
Family- Saturniidae.

Muga culture or rearing of muga silkworm:

The Muga silkworm is reared outside on a tree. One mature tree may generate 1000 cocoons each year when used for two rearing, one in the spring and one in the autumn. Five mature trees are needed to produce 5000 cocoons, which yields one kilogramme of muga silk. The semi-domesticated, multivoltine Muga silkworm has 5–6 generations per year.

Muga larva feeding on muga tree

Eggs of muga silkworm

Muga rearing field (sumoni)

Pairing of Muga moths

Shifting of Muga worms with the help of Chaloni

In accordance with the Assamese year calendar, the different generations in a year are as follows:

Sl.no.	Assamese name	SeasonMonth	Remarks
1.	Jarua	Winter, Dec-Feb	Pre- seed crop
2.	Chotua	Early spring, Mar-April	Seed crop
3.	Jethua	Spring, May-June	Second commercial crop
4.	Aherua.	Early Summer, June-July	Pre- seed crop
5.	Bhodia	Late summer, Aug-Sept	Seed crop
6.	Kotia	Autumn, Oct-Nov	Main commercial crop

To produce good agricultural yields, farmers and other rural workers have adhered to a number of traditional practises for raising livestock for many centuries. The term "indigenous technical knowledge" is often used to describe these traditional beliefs.

Indigenous technical knowledge

Indigenous Technical Knowledge (ITK) is the real information held by a population and reflects both more current technological experiences as well as experiences based on tradition. Indigenous practises represent a body of undocumented knowledge. There is currently no systematic documentation of what they are, what they do, how they do it, how they can be altered, how they operate, where their boundaries are, or how they are used.

As many groups, civilizations and situations as are available now hold it in various brains, languages, and talents (Atte, 1989). The ITKs are also a part of rural poor people's life and are becoming recognised as a source of concepts and solutions for numerous serious preventions in numerous fields. Farmers' long-standing relationships with the land, its flora, and fauna have taught them traditional agricultural and other crop practises that are eco-friendly and sustainable. Farmers in Assam who practise Muga culture also adhere to a number of these beliefs and have done so for a very long period, or from one generation to the next. During five months of stay in the North Lakhimpur district of Assam, for the Rural Sericultural Work Experience Program (RSWEP), we have noticed several such believes and tried to collect more information's about it. Three villages—Gohain Tekela, Bhogmon, and Silikhaguri-with a long history of involvement in the muga culture were the subjects of the survey. Using an interview schedule designed for the purpose, farmers were questioned directly to learn about the indigenous practises used, particularly in the production of silkworm seeds, the rearing of silkworms, and the management of pest and disease management for silkworms. All of the farming methods that the farmers detailed were meticulously documented. Additionally, the five-month period's worth of fieldwork was witnessed and verified to a large extent. The most popular indigenous methods for raising silkworms, producing their eggs, and controlling pests and diseases of the worms were noted and supported by additional data.

Selection of healthy silkworm brood:

- The farmers often preferred the seed cocoons from the Garo Hills in Meghalaya, but due to distance, they frequently used to collect the seed cocoons locally. The farmers used to watch the silkworms' diverse behaviours as they were being raised in order to choose a healthy brood.
- Regular upward and downward movements of silkworm larvae in the direction of the feeding plants.
- Green body with a copper mandible
- Free of diseases including Flacharie (often referred to as "Mukhlaga" by farmers) and Pebrine (usually referred to as "Phutuka" by farmers).
- The feeding habits of larvae, such as eating the entire leaf of a plant or having consistent size, are thought to be positive indicators of a healthy silkworm brood
- Additionally, regarded as a sign of a healthy worm is the presence of more than two pieces of solid form excreta in the rectum or hindgut of the larvae.

During the process of choosing healthy silkworms, one of the most frequent observations reported by farmers is that the larvae react instantly to touch while moving.

Selection and preservation of seed cocoons:

- Cocoons are often stored in perforated bamboo cages called "Chakari Pera" during the spinning season's "Bharpak" peak.
- Seed cocoons are typically transported at dusk in perforated bamboo baskets with a layer of paddy straw inside to protect the cocoons from any jerk.

- Farmers used to spray the ground and walls of the grainage house (the building where silkworm eggs are produced) with cow dung mixed with mud before entering the seed cocoons.
- Some farmers also hang the twigs of tulsi (*Ocimum sanctum*) from the ceiling of the grainage houses for making the room hygienic.

Moth emergence and egg laying:

- The male and female moths are allowed to spontaneously pair up in the night as the moths are emerging from the seed cocoons in the evening. Following the completion of natural pairings, cotton thread is used to tie the hind wings of each female moth in each pair in a "khorika" (bunch of dry thatch grass). Sometimes more than one pair of moths is tied in a single khorika in order to reduce the number of khorikas, the amount of space needed, etc.
- In a dimly lit chamber, the khorikas are hung from rope fastened to two poles or walls. Sometimes the khorikas are stored in a dark room and hung in a particular gadget created for the purpose. Extreme caution is used to prevent any type of disturbance to the connected moths during the coupling process. Farmers do not prefer mechanical couplings. However, occasionally farmers compel moths to pair up.
- Male and female moths pick jointly in their left and right hands at the time of mechanical connection. Male and female moths are kept together so that their abdomens can touch. The female moth receives a gentle airburst through her mouth to aid in the rapid pairing. Moth pairing is permitted for 10 to 12 hours.
- Moths decouple after 10 to 12 hours of pairing by releasing smoke produced by burning paddy straw for a short period of time, usually in the evening. The farmers also believed that exposing the moth in to smoke, quantity of egg laying are increased.
- At the time of shortage of male moths, the female moths are tied in khorikas and hang at branches of plants or bamboo in outside to allow coupling with wild male moths at night. No lights and sounds are allowed at the places of keeping moths for pairing with the wild moths.
- Moths are allowed to lay eggs for maximum three days. After three days of egg laying, female moths are removed from the khorika. The Khorikas with the eggs are kept aside and observed carefully till hatching of worms.

- On particularly hot days, the khorikas containing the eggs may occasionally be submerged in cool water for a short period of time to protect the embryo from the effects of high temperatures.
- To shield the moths from nocturnal birds, foes, etc., branches of thorny plants such as Jatulypaka, Bogori, etc. are hung at the door or windows.
- Farmers watch the morphology of the moths, their mating habits, how the female moths urinate, their egg-laying habits, the colour of their eggs, and other things during grainage Farmers claim that the peak moth emergence in the evening, dark brown colour, natural coupling before midnight, heavy wing fluttering, white urination by female moths at the time of decoupling, scattered egg laying, the production of 140–170 eggs by a moth, brown colour, no depression of eggs, and moth survival for 5–6 days after egg laying are all signs of a successful crop.

The emergence of cripple moths, a decrease in wing-flipping, a lack of desire towards coupling, gritty urination by female moths, laying of eggs in clusters, an increase in the amount of white eggs, etc. are all regarded to be unfavourable signs for the crop that follows.

Rearing of silkworms and cocoon production rearing of silkworms

- On the early morning, newly-hatched, small silkworms are immediately brushed by hanging the khorikas on the twigs of plants with fragile leaves. Farmers hold the belief that if newly hatched silkworms consume the egg crust still clinging to the khorika, the silkworm will be in good health. Because of this, the farmers leave the eggs in the khorika and allow the silkworms to hatch there instead of removing them.
- Hatching typically takes two days. In the summer, worms are brushed in shady areas, and in the winter, in sunny areas. The farmers maintain routine field surveillance in order to safeguard the little worms from numerous birds, predators, etc.
- Farmers used to scatter ashes at the base of trees in order to shield tiny worms from ants that dwelt in dirt.
- In order to block the worms from creeping towards the ground, the muga farmer typically wraps the tree stem with banana leaf or bark above 2/3 feet from the ground. When a plant's leaves are completely devoured, the worms descend to the

tree trunk to look for another plant. The farmers at the time harvested the worms from the tree trunk and collected them in a bamboo tray with a triangular form known as a "Challoni." The worm-filled Challoni are strung up in a particular leafy plant.

- The worms are typically moved from one plant to another in the third or fourth stage. If weak worms are seen during the transfer, they are gathered and stored under delicate leaves of particular plants where they can develop swiftly.

Spinning and harvesting of cocoons

- In the evening, as the ripening worms descend from the branches or tops of the trees, they should be caught in a bamboo basket and released into mountage, which farmers refer to as "jail." The leaves and twigs of several plants known locally as Azar, Singari, Nahar, Mango, and Som itself are used to construct the jails.
- When they reach maturity, some of the worms stop feeding and rest during the daytime on tree trunks or plant branches. The farmers gather the worms at that time in "Challoni" and store them in the temporary shed (Mounting hall) to make it simpler to mount them once they are fully mature.
- The farmers gather the worms at night using a torch light or kerosene lamp that was specially built with bamboo.
- Jalis are typically housed in an open, well-ventilated shelter that has been constructed temporarily in the rearing field itself. These sheds are constantly under observation for ants, birds, lizards, bats, owls, snakes, monkeys, etc. protection.
- The cocoons are typically harvested 6-7 days after spinning in the summer and 8-12 days in the winter. The fragile and melting cocoons must be separated during cocoon harvesting.
- The reeling cocoons are exposed to direct sunshine or hot smoke produced by burning firewood in order to suffocate, while the seed cocoons are stored in shady locations with the utmost care. Farmers used to expose the cocoons to sunlight for two to three days after the pupae had died in order to lower the moisture content of both the cocoons and the pupae.

Management of pest and disease of silkworms

- The farmers use a brush to remove all the dried leaves and twigs from the host plants used to raise silkworms. To ward off various silkworm pests like wasps, flies, bugs, and other insects that have taken up residence in the host plants by the smoke, all of the dried leaves, twigs, and trash are collected and burned in various parts of the rearing field.
- Farmers used to clean up any ants, spiders, termite trails, etc. before brushing.
- Before brushing silkworms, various sucking pests from the plants, such as bugs, mantis, grasshoppers, etc., are collected and mechanically exterminated. In order to draw the ants' attention away from their nests in the host plants, they also used to store dead fish or frogs near the tree trunk.
- The farmer burned the ants as they approached the fish or frog.
- Keeping bananas just beneath the surface of the soil in the rearing field to control red ants.
- The farmers used to place corm plants (Colocasia) in the tree trunk during rearing to prevent the death of silkworms.
- During rearing, farmers typically forbid people from entering the rearing field because they believe that the evil sight of outsiders may be the cause of the Flacherie diseases of silkworms.
- Some farmers hang tulsi twigs between khorikas during grainage and believe that this practice prevents the outbreak of pebrine disease of silkworm.
- People are also prohibited from entering the somani raising field after using performance, fragrance, or heavy makeup. They think that these compounds might have an impact on silkworms.
- Clean water is kept in a clear polythene bag and hung in the plants used for rearing to protect the worms from the invasion ofuzi flies, a significant pest of muga silkworm. According to some farmers, they also occasionally burned dry leaves and twigs in the rearing field to protect the worms from the uzi fly infestation.
- The farmer also used to use a tall bamboo to hang a metallic empty container at the top of the plants in the raising field to protect the worms from birds, bats, etc. To scare away birds, bats, owls, etc., the containers are connected with the aid of a rope and pulled at regular intervals during the day and night.

- While any symptoms of silkworm diseases are seen, the worms are to be screened and raised them separately in a safe distance.
- Farmers occasionally used to hang lighting lamps at the top of the plants in the rearing field with the help of a tall bamboo.
- The farmer used to burn dry plant twigs or paddy straw around the field every evening and morning to protect the worms from the fungus. Some farmers also prohibited women from working in the barn during menstruation.

CONCLUSION

It has been discovered that farmers generally choose healthy silkworm brood by keeping an eye out for several positive indicators and behaviors of silkworms during its upbringing in order to prepare quality silkworm seed. If any disease has affected the silkworm larvae, they will not contemplate raising the following generation's brood. These methods are obviously very relevant for harvesting a quality Muga crop. The farmers never used any inorganic pesticides or insecticides in the silkworm breeding field to control pests and diseases. The chemical pesticides used to manage the other pest of the silkworm or its host plants may harm the silkworm greatly. Because of this, they are employing alternative pest control techniques that are safe for both silkworms and their host plants. Farmers have found that many of the traditional Muga practices they have embraced are quite eco-friendly. Researchers who studied the customs of the Muga people found that the same customs were followed by Muga farmers in various regions of Assam. Some farmers adopted particular methods for choosing healthy Muga broods. When choosing a healthy silk worm brood for seed purposes, factors like egg laying pattern, egg colour, moth morphology, coupling behaviours, detached eggs from the khorika, hatching pattern, worm mobility, feeding behaviour, cuticular pigmentation of the worms, presence of excreta in the larval rectum, larval growth, pupal character, silk contents, etc.

Additionally, it was stated that the Muga farmers used many traditional methods, including burning in the rearing field, incomplete weeding, direct brushing, mixed plantations, day-by-day brushing, spreading banana leaves on the ground after brushing, restricting women's access to the rearing field, screening worms based on size, non-vegetarian foods during rearing, and location preference for obtaining Muga seeds, among others. The same procedures were reportedly used by Muga farmers in the Upper

Assam areas, according to Phukon *et al.* (2006). When silk worm seeds were being produced, farmers would typically transfer the cocoons from the various seed zones in Assam and other North Eastern states at night. They noted the presence of concentrated excrements on the ground of the raising field, the existence of the least egg shell in the khorika, the presence of excrements in the rectum of the larvae, the copper colour of the mouth portion, the peak harvest of cocoons, etc. while collecting the seed cocoons. In order to manage the room's temperature, humidity, and cleanliness, the farmers sprayed Tulsi (*Ocimum sanctum* Linn) and Neem (*Azadirachta indica*) mixed water on the floor. The female is tied to a khorika once the moths hatch, and the male moths are then allowed to spontaneously pair. The rearers used to tie dead scaly fish, frogs, and put molasses at the base of the host plants to attract ants and eventually burn them before brushing the newly hatching worms. The movement of worms into the ground is typically stopped by the rearers using slippery leaves or bark of banana plants, Tora (*Zingi beraceae*), buffalo dung, ash, etc. The Muga rearers adhere to these ancient beliefs in various parts of Assam. Some of the customs that have been practiced for centuries are also supported by science. They actually do contribute to preserving a healthy habitat, which helps to breed healthy silkworms and produce cocoons of high quality. It is important to gather, document, analyze, and preserve these ITKs for future records.

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Chapter - 7

Agroforestry as a Tool for Achieving Mitigation and Adaptation to Climate Change

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Agroforestry is one of the most conspicuous land use systems across landscapes and agroecological zone in the world. Agroforestry is essential for attaining biodiversity goals, sustaining livelihoods, localising the Sustainable Development Goals, and reducing greenhouse gas emissions and increasing carbon sequestration. In addition to providing ecosystem services and lowering human effects on natural forests, agroforestry generates assets and revenue from carbon, wood energy, increased soil fertility, and improved local climatic conditions. The majority of these advantages support international efforts to reduce atmospheric greenhouse gas concentrations while providing immediate advantages for local adaptation. Agroecosystems may be created to help communities and families adapt to regional and global change. Through the provision of financial and environmental stability, agroforestry systems provide prospects for improving the standard of living for the poor.

Keywords: *Agroforestry, climate change, mitigation, adaptation, climate neutrality*

INTRODUCTION

Agriculture is the main source of rural livelihood and development in low-income nations. Nevertheless, land pressure and climate change, which both jeopardise food supply, have a negative impact on agricultural systems in developing nations.

Climate change is an actuality, and it is well-established that the world is in the midst of a climate emergency that calls for swift action to limit the global warming increase to 1.5 ˚C (IPCC, 2019). Each year, the agriculture industry alone releases 6 billion metric tonnes of greenhouse gases (GHG) into the atmosphere. The main environmental problem that the world is currently dealing with is the increased emissions of greenhouse gases (GHGs) into the atmosphere caused by human activities like changing land use patterns, deforestation, industrialization, transportation, and anaerobic crop cultivation (Devi *et al*., 2023). Climate, food security, and on-farm income are negatively impacted locally as a result of the many environmental effects of agricultural intensification and food production, which have a detrimental influence on soil and biodiversity. Risks associated with climate change, such as severe droughts, flooding, and diseases, can have a significant negative influence on agricultural systems, leading to soil erosion, crop failure, biodiversity loss, decreased soil moisture, insect damage, and financial losses. Real-time climate change is already intensifying, making it more challenging to farm land and raise livestock. The future effects of climate change appear to be more detrimental (Laishram *et al*., 2023).

The primary international issues of the present are reducing global warming, ensuring food security, protecting biodiversity, restoring ecosystems, and localising the Sustainable Development Goals (SDGs). Agroforestry is a land management practice where trees and/or shrubs are deliberately combined with crops or livestock as a way of increasing ecological function and sustainability (Schoeneberger, 2009). Agroforestry has the ability to address a number of issues and provide a variety of economic, environmental, and societal advantages. Agroforestry can enhance farmers' livelihoods and the environment by reducing climate change and assisting them in coping with intense and unpredictable weather. Agroforestry has a particular potential role in the mitigation of atmospheric accumulation of greenhouse gases (IPCC, 2000). Of all land-use types considered in the IPCC Land-Use, Land-Use Change and Forestry Report, agroforestry systems have strong potential for resilience-building in the face of climate change with the highest mitigation potential lies through soil carbon sequestration and decreased destruction of primary ecosystems and greenhouse gas emissions (Figure 1).

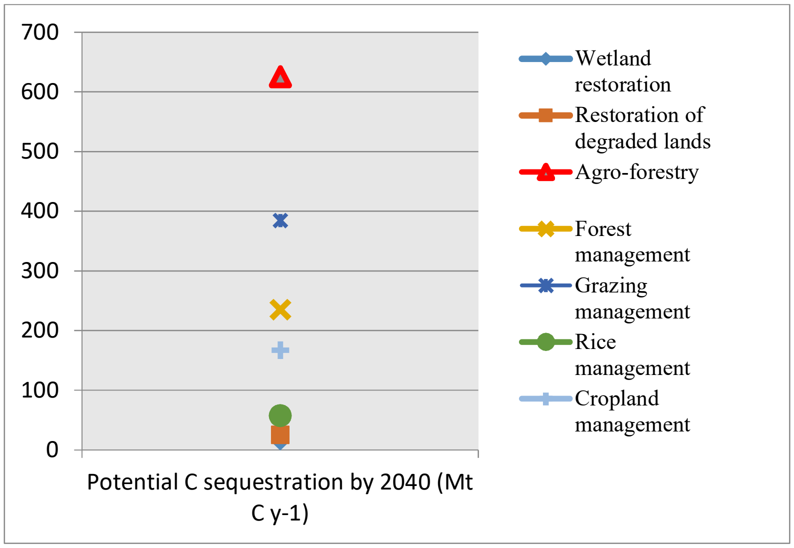

Figure 1: Carbon sequestration potential of different land-use system

(Source: Basu *et al.*, 2014)

Given that it enhances carbon storage and may also raise agricultural production, agroforestry may be a win-win solution to the ostensibly conflicting decision between reforestation and agricultural land usage (Kumar *and* Nair, 2012). The ability of agroforestry to mitigate the effects of climate change through short-term resource conservation, microclimate management, and long-term carbon sequestration is well acknowledged (Saikia *et al.*, 2023). Agroforestry promotes ecosystem services associated to trees, including the control of water and sediment flows, the cycling of carbon and nutrients in soils, and the provision of habitat for biodiversity. Increased soil fertility, decreased soil erosion, and pest and flood management result from this.

Smallholder farmers can gain from agroforestry by increasing farm production, diversifying their output, and using less outside inputs like traditional fertilisers and pesticides, which increases their revenue. The ability of farmers to continue living on their land depends on how well they adapt to climate change risks. There are several ways to use agroforestry for farm-level climate adaptation and improved landscape resilience. For instance, agroforestry may improve warming and cooling of the environment while reducing air pollution, so producing a microclimate that is tolerant of both crops and cattle (Ellison *et al.*, 2017). The need to recognise and support initiatives for climate adaptation and mitigation is becoming more pressing as a result of rising natural catastrophes and climatic unpredictability. The capability to increase overall resilience to climate vulnerability has been highlighted as being mostly dependent on adaptation measures to enhance land and water management related practises.

Under the current climate change scenario, adaptation is urgently needed, especially in poor and impoverished nations, which are predicted to be significantly impacted by climatic extremes. In light of climate change, it is essential and germane to comprehend the state of regional agroforestry, provide chances for additional promotion to satisfy climate commitments, and ensure that agroforestry practises are successfully adopted. In this context, global communities are in a quest of identifying more efficient farming practices which reduce GHGs emissions (mitigation) as well act as resilient systems that able to adapt impacts of climate change.

Agroforestry: Potential mitigation strategy

There are many gases that influence global climate change, but CO_2, CH_4, and N_2O are the three most significant because of their concentration and capacity to warm the planet (IPCC, 2013). These three gases all have intricate paths and come from various places. According to environmental factors, organisms can breathe in but can also breathe out carbon dioxide, CH_4 can be breathed in but can also be devoured by microorganisms in the soil, and N_2O may be released or ingested by a variety of microbiological activities. All three of these GHGs have a soil flux that is influenced by land use. Agroforestry increase the total fine root production, rhizo-deposition, and litter-fall, which can all promote organic C sequestration in soil. By using better farming techniques and planting more trees on farms, cultivated areas have the potential to considerably reduce the effects of climate change. The projected worldwide potential for total greenhouse gas (GHG) sequestration in agriculture is between 1500 and 4300 Mt CO_2 yr^{-1}, with around 70% of that potential coming from poorer nations. 90% of this potential is related to soil carbon restoration and prevented net soil carbon release (Smith and Wollenberg, 2012). The effectiveness of mitigation solutions in agroforestry systems will rely on the relative importance of factors such as tree species selection and management, soil characteristics, terrain, rainfall, agricultural practises, priority for food security, and economic development choices, among others. There are various choices that may be used to increase carbon sequestration or decrease carbon emissions, but they are all based on the demands of local communities for development.

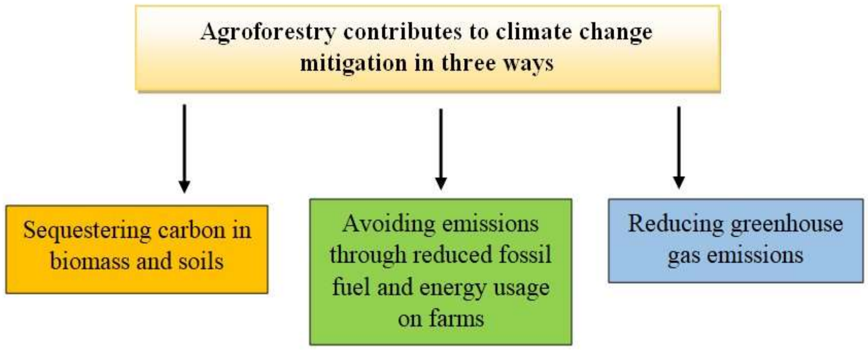

Figure 2: Agroforestry climate change mitigation

Integrating agroforestry may significantly enhance carbon sequestration by incorporating agroforestry into crop and animal management systems. Agroforestry techniques that sequester CO_2 include home gardening, boundary planting, fruit orchards, riverine, hedgerows, woodlots, and firewood lots. These agroforestry practices are based on a variety of management approaches and have potential positive implications for climate change mitigation (Albrecht and Kandji, 2003). It has been shown that agroforestry systems have 3-4 times more biomass than traditional treeless cropping systems. In addition, Zomer *et al.* (2009) show that the area suitable for agroforestry worldwide is much larger with substantially greater potential than existing systems. There are many methods to estimate carbon sequestration in agroforestry systems; some of them are based on in situ measurements, but the application of different assumptions introduces large inconsistencies into available data. Reported C stocks and C sequestration vary widely across agroforestry systems. Integrated land use practices, such as agro-silvo-pastoral systems, combine high C stocks with high C sequestration potentials.

Among agroforestry techniques, silvopasture systems, which include trees in pastures, may offer the most potential to slow global warming. The soils and the trees that are cultivated in the pasture act as carbon sinks. Additionally, silvopasture may reduce methane (CH_4) emissions, a significant source of greenhouse gas emissions. Through the use of a grazing plan that involves moving cattle in a rotational stocking system, silvopasture management can lower methane emissions. Another factor leading to lower methane is more digestible feed and greater overall gain from feed efficiency due to shade-induced microclimate changes. Agroforestry can play a crucial role in improving resilience to uncertain climates through microclimate buffering and regulation of water flow. Greater soil pore space under agroforestry system reduced net CH_4 emissions as reflected in reduced soil bulk density under agroforestry. Nitrous oxide (N_2O) emissions may be reduced in systems such as slash-and-burn systems, tree plantations on arable land and riparian buffers because N inputs in these systems may be no higher than under intensively N managed agricultural fields (Kim *et al.*, 2009).

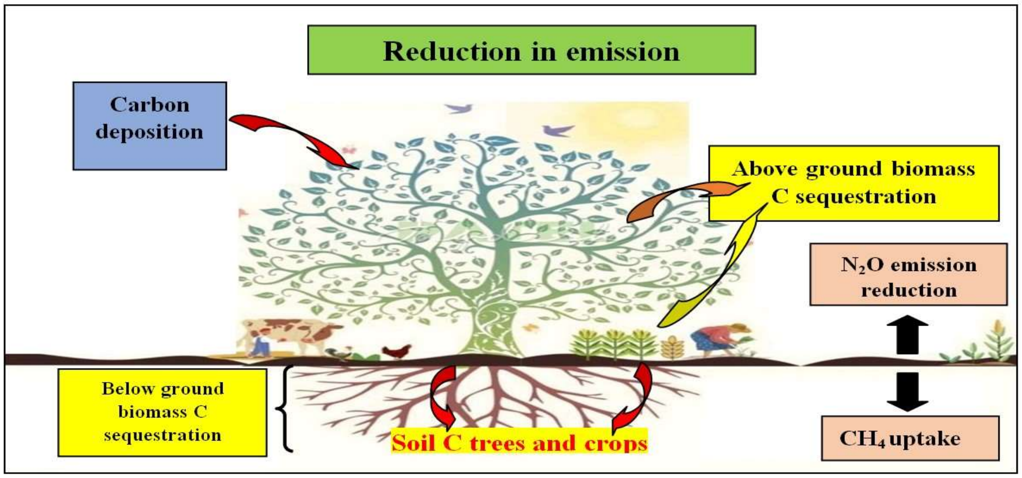

Figure 3: Net GHGs mitigation in Agroforestry

Reduced soil disturbance and greater macroporosity might possibly lead to increased CH_4 in agroforestry compared conventional agricultural fields, but the effect may be only slight and vary with the detailed disturbance patterns under agroforestry and normal agriculture. These results and interactions suggest that, in principle, agroforestry could possibly either intensify or mitigate soil GHG emissions to a small extent, and it is important to gain a comprehensive understanding of total soil GHG emissions in agroforestry systems. Agroforestry system reduces the GHGs emission such as CH_4 and N_2O from soils (Kim *et al.*, 2009).

Agroforestry: Means for adaptation

Options for agroforestry may offer a way to increase the sustainability of smallholder farming systems by diversifying production methods. From the perspective of smallholder farmers, the increasing interannual unpredictability in rainfall and temperature is the most concerning aspect of climate change. There are several clear benefits to tree-based systems for sustaining output throughout wetter and drier years. Finally, products produced by tree-based production methods frequently have more value than crops grown in rows. In order to mitigate revenue risks brought on by climate fluctuation, the production system may be diversified to incorporate a sizable tree component.

Research into the contributions of agroforestry in buffering against climate variability is not well advanced. Agroforestry for climate adaptation at the farm level and enhanced resilience at the landscape level can take many forms. Agroforestry, for instance, may lessen air pollution and improve both the warming and cooling of the environment, resulting in a dependable microclimate for cattle and crops. Moreover, agroforestry can also help with climate change adaptation and mitigation by enhancing carbon storage, reducing deforestation, protecting biodiversity, producing cleaner water, and reducing soil erosion, which improves the ability of agricultural lands to withstand floods and drought events.

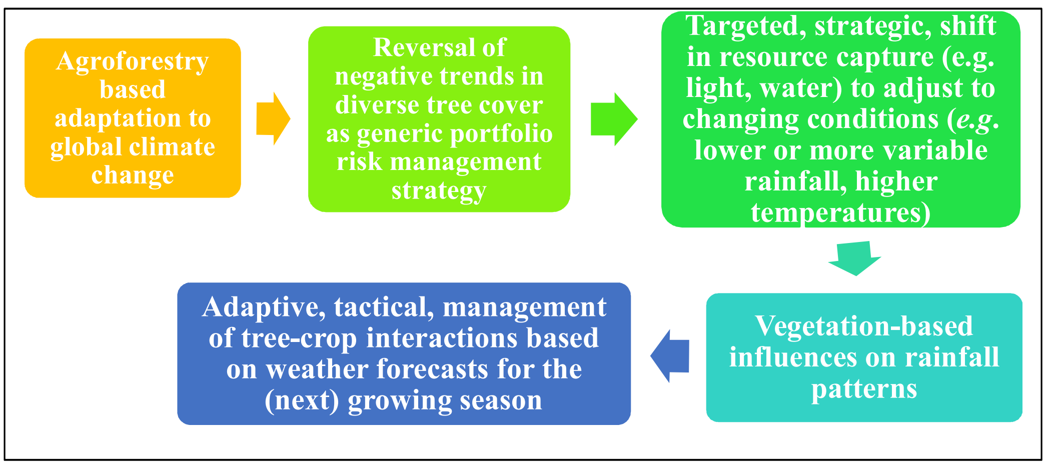

Figure 4: Agroforestry based adaptation to global climate change

(Source: Noordwijk *et al.*, 2021)

Globally, ongoing adaptation activities are still fragmented, gradual, sector-specific, difficult to monitor and/or track, and mostly concerned with planning as opposed to implementation. Agroforestry-specific adaptation initiatives suffer the same difficulties. According to agricultural adaptation techniques, farmers should consider other crop varieties, alternative means of subsistence such as planting trees, or relocation (Rippke *et al.*, 2016).

Agroforestry: Role in environment resilience

Resilience is the ability to become less sensitive to shocks and disruptions while preserving functionality. Through the regulation of water flows and the agroforestry's ability to buffer microclimates, agroforestry may significantly increase a community's ability to withstand unpredictable climatic dangers. Crop diversification, long rotation systems for soil conservation, home gardens, boundary planting, perennial cropping, hedgerow intercropping, live fences, enhanced fallows, mixed stratum cropping, etc. are all examples of agroforestry land management practises (Mbow *et al*., 2014). By decreasing soil erosion, mitigating non-point pollution, preserving wildlife habitats, and performing other various ecosystem services, such microclimate management helps conserve biodiversity. This makes it easier to adapt quickly to changes in ecological conditions and preserve and replenish both biotic and abiotic natural resources.

Crop performance is also impacted by microclimate improvement since it serves as a buffer against climatic extremes that have an influence on crop development. Additional trees shadowing protects crops from extreme temperature changes, keeping them closer to their ideal circumstances. By lowering incident solar radiation, air and soil temperatures, improving the soils water status, and increasing humidity, the dispersed plant cover facilitates the establishment of undergrowth (Mbow *et al*., 2014). Agroforestry systems also mimic natural ecosystems and have high levels of biodiversity thanks to the higher plant diversity in the spatial and temporal distribution of crops, particularly the rise in functionally significant taxa like insectivorous birds, seed-dispersing birds, pollinators, and amphibians that provide biocontrol services (Lin, 2011). The results of recent case studies indicate that in agroforestry systems, a high degree of species variety supports a better overall ecosystem resilience (Bélair, 2010).

Agroforestry systems can also be considered as important buffer zones around reserves reducing edge effects and increasing connectivity among forests. Trees are also identified as stored capital and these tree banks greatly reduce the vulnerability not only to environmental shocks but also economic and social shocks as well. Multipurpose trees in integrated approach enhance the benefits reap by agroforestry.

Dialogue on agroforestry systems and global climate

Agroforestry systems are a crucial tool for climate change mitigation and can assist both developed and developing countries in achieving policy synergy between technologies, landscapes, rights, and markets, as well as better localising Sustainable Development Goals (SDGs), restoring multifunctional landscapes, and mitigating climate change. They can also help with reforestation goals in line with the Bonn Challenge and the UN decade on restoration (2021-2030), as well as enhancing food and water security. The United Nations Framework Convention on Climate Change (UNFCCC) has emphasised the growing need for mainstreaming and implementing sustainable land management approaches, specifically agroforestry systems, along with other well-known international environmental and scientific organisations (IPCC, 2019). International organisations including the UNFCCC, the Food and Agriculture Organisation (FAO), the Convention on Biological Diversity (CBD), and the World Bank have all given agroforestry systems significant respect (Buttoud, 2013).

The relevance of agroforestry systems in reducing climate change was first acknowledged internationally through the Kyoto Protocol (Table 1). Since then, there has been a rise in interest around the globe in employing agroforestry systems to improve carbon sequestration (Atangana, 2014).

Table 1: Agroforestry systems key agreement and reports

Treaty	Assessment
Kyoto Protocol - 2005	Includes agroforestry as an important sustainable land management approach for climate change adaptation and mitigation
Reduced Emissions from Deforestations and Forest Degradation (REDD)	Agroforestry potential to support indigenous communities for livelihood benefits while mitigating climate change demonstrated
IPCC Third Assessment Report (2001)	Prospects of agroforestry for providing solutions to myriad issues while at the same time delivering a variety of social, financial and environmental profits for human well-being acknowledged
IPCC Special report Climate and Land (2019)	Agroforestry quoted as an emerging vital solution to climate adaptation and mitigation through efficient land management

(Source adapted from Dhyani *et al.*, 2021)

Understanding the significance of agriculture, forestry, and other land-use sectors in climate change adaptation and mitigation has helped numerous nations make significant progress in improving their national planning as a result of Reduced Emissions from Deforestation and Forest Degradation (REDD). Nine out of the 17 Sustainable Development Goals (SDGs)—including SDG 15 (life on land), SDG 13 (climate action), SDG 12 (responsible production and consumption), SDG 2 (zero hunger), SDG1 (no poverty), SDG 3 (good health and well-being), SDG 8 (decent work and economic growth), SDG 5 (gender equality), and SDG 10 (reduce inequalities)-can be achieved through the use of agroforestry systems.

Agroforestry systems effects on agricultural output

Agroforestry practises have the innate ability to increase soil fertility. Leguminous plants' biological nitrogen fixing and the rise in soil organic matter are the key contributors to this. In contrast to monoculture systems, trees on farms also enable more efficient nutrient cycling, enrich the soil with nutrients and organic matter, and enhance the structural characteristics of the soil (Lott *et al*., 2009). Sustainable agriculture is severely hampered by the gradual decline in soil fertility caused by several factors (Pandey, 2002). The most harmful type of soil degradation is topsoil erosion, which is likely to be made worse by ongoing clearance of agricultural leftovers and surface litter. Discussions on food security have turned to sustainable agroforestry techniques due to the scarcity of mineral fertilisers and the underperformance of present agricultural programmes. Therefore, trees assist in recovering nutrients, preserving soil moisture, and improving soil organic matter by water tapping and preventing nutrient leaching (Duguma and Hager, 2011).

The potential of agroforestry to reduce the yield gap varies depending on the biophysical and human context. There are several effective agroforestry techniques, including trees that enhance soil, quickly expanding trees for fuel wood, native fruit trees to add to nutrition and revenue, and trees that can provide medicinal plant products. (Molua, 2005). In actuality, it is necessary to distinguish between straightforward agroforestry systems (such hedgerow, intercropping, and alley cropping systems) and sophisticated agroforestry systems that mimic the natural forest ecosystems while being incorporated into agricultural management systems (Rice, 2008). The potential for agroforestry practises to produce assets for farmers, opportunities for climate change mitigation, and potential to promote sustainable production that increases agro ecosystem diversity and resilience all contribute to the interest in researching agroforestry in a changing climate.

CONCLUSION

Climate change is the most severe problem that we are facing today in agriculture production and human health. The natural resources such as land, water, and vegetation occupy center-stage for the welfare and development of people. Agroforestry options may provide a means for diversifying production systems and increasing the sustainability of smallholder farming systems. Agroforestry enhance the uptake of CO_2 or reduce its emission and has the potential to remove a significant amount of CO_2 from the atmosphere, if the trees are harvested, accompanied by replanting of same and/or other area, and sequestered carbon is locked through non-destructive use of such wood. Now it has been proved that agroforestry system are promising land use system to increase aboveground and soil C stock and to mitigate greenhouse gas emissions.

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Chapter - 8

Microbial Biosurfactants as a Biological Blueprint for Amelioration of Polluted Soils

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The contamination of soils due to various pollutants poses significant challenges to the environment and human health. Traditional remediation approaches have limitations in terms of efficiency, cost, and potential secondary environmental impacts. In recent years, microbial biosurfactants have emerged as a promising tool for the amelioration of polluted soils. This chapter provides an overview of the role of microbial biosurfactants in soil remediation and explores their potential as a biological blueprint for sustainable and eco-friendly solutions. The chapter discusses the mechanisms of action of biosurfactants, their production by microorganisms, and their applications in the remediation of different types of soil contaminants. Moreover, it highlights the advantages and challenges associated with biosurfactant-based remediation strategies and presents future prospects for their implementation on a larger scale. Overall, this chapter aims to emphasize the importance of microbial biosurfactants in addressing soil pollution and fostering a more sustainable approach to soil remediation.

Keyword: *Human health, microbial biosurfactants, sustainable, soil remediation*

INTRODUCTION

Soil pollution is a significant environmental issue that has gained widespread attention due to its detrimental effects on ecosystems, agriculture, and human health. It refers to the contamination of soil with substances that are harmful or toxic to living organisms, including plants, animals, and microorganisms. Soil pollutants can originate from various sources, including industrial activities, agricultural practices, improper waste disposal, mining operations, and urbanization. These pollutants can persist in the soil for long periods, leading to long-term environmental degradation.

Table 1: Types of soil pollution and its example

Sl. No.	Types of soil pollution	Examples:
1.	Industrial wastes	Pulp and paper mills, chemical fertilizers, oil refineries, coal and mineral mining industries, etc.
2.	Urban wastes	Garbage and rubbish materials like plastics, glasses, metallic cans, fibres, paper, rubbers, street sweepings, fuel residues, etc.
3.	Agricultural practices	Fertilizers, pesticides, herbicides and weedicides
4.	Radioactive pollutants	Radio nuclides, Radioactive waste include Strontium90, Iodine129, Cesium-137 and isotopes of Iron

Table 2: Effects of Soil Pollution and its result

Sl. No.	Effect of Soil pollution on	Result
1.	Health of Humans	Crops and plants grown in polluted soil absorb a large portion of the pollutant and when consume it, it causes minor and terminal illnesses
2.	Growth of Plants	The fertility of the soil gradually declines, rendering the land unsuitable for agriculture and the survival of any local vegetation.
3.	Decreased Soil Fertility	Toxic chemicals in the soil can reduce soil fertility, resulting in a decrease in soil yield
4.	Toxic Dust	The release of toxic and foul gases from landfills pollutes the environment and has serious consequences for some people's health
5.	Changes in Soil Structure	The death of many soil organisms (for example, earthworms) in the soil can cause changes in soil structure

Microbial biosurfactants: A promising alternative

Microbes have untapped potential, which makes them effective alternatives agents for strengthening agro-ecosystems and soil health. Due to their processes of microbial mitigation and environmental adaptation, these microfloras have a great potential to increase resistance and they are suitable agents for fending against toxic aberrations in soils (Laishram *et al.*, 2023). Biosurfactants are the surface-active biomolecules produced by bacteria, fungi, and yeast. Basically, these microorganisms produce different biosurfactants for various purposes; for instance, rhamnolipids increase the solubility of hydrophobic hydrocarbons, cause changes in microbial surface properties, and enhance the bioavailability of potential hydrophobic carbon sources. Unlike the chemically synthesized surfactants, biosurfactants are generally categorized based on their microbial origin and chemical composition (Vijayakuma & Varatharajan, 2015). Chemically, biosurfactants are categorized into glycolipids (rhamnolipids), trehalolipids, sophorolipids, lipopeptides and lipoproteins (surfactin, lichenysin), fatty acids, phospholipids and neutral lipids, polymeric, and particulate biosurfactants. Owing to their safe properties such as, low toxicity, high degree of biodegradability, high foaming capacity, and optimal activity at extreme environmental conditions (Singh & Cameotra, 2004), biosurfactants have recently received attention for their different applications in various fields (food industry, removal of oil and petroleum contamination, bioremediation of toxic pollutants and biopesticides). Currently, the interest in the use of biosurfactants as biopesticides has been growing fast because of their environment-friendly characteristics and high degree of degradability. Thus, to reduce the adverse effects of synthetic pesticides on the environment and human health, biosurfactants could be one of the promising alternative options in the management of agricultural pests.

Table 3: Main classes of biosurfactants and respective producer microorganisms (Salihu *et al.*, 2009)

Class/type of biosurfactant	Microorganisms
Glycolipids	
Rhamnolipids	*Pseudomonas aeruginosa*
Sophorolipids	*Torulopsis bombicola, T. apicola*
Trehalolipids	*Rhodococcus erythropolis, Mycobacterium sp.*
Lipopeptides and lipoproteins	
Peptide-lipid	*Bacillus licheniformis*
Viscosin	*Pseudomonas fluorescens*
Serrawettin	*Serratia marcenscens*
Surfactin	*Bacillus subtilis*
Subtilisin	*Bacillus subtilis*
Gramicidin	*Bacillus brevis*
Polymyxin	*Bacillus polymyxia*
Fatty acids, neutral lipids and phospholipids	

Fatty acid	*Corynebacterium lepus*
Neutral lipids	*Nocardia erythropolis*
Phospholipids	*Thiobacillus thiooxidans*
Fatty acid	*Corynebacterim lepus*
Polymeric surfactants	
Emulsan	*Acinetobacter calcoaceticus*
Biodispersan	*Acinetobacter calcoaceticus*
Liposan	*Candida lipolytica*
Carbohydrate-lipid-protein	*Pseudomonas fluorescens*
Mannan-lipid-protein	*Candida tropicalis*
Particulate surfactant	
Vesicles	*Acinetobacter calcoaceticus*

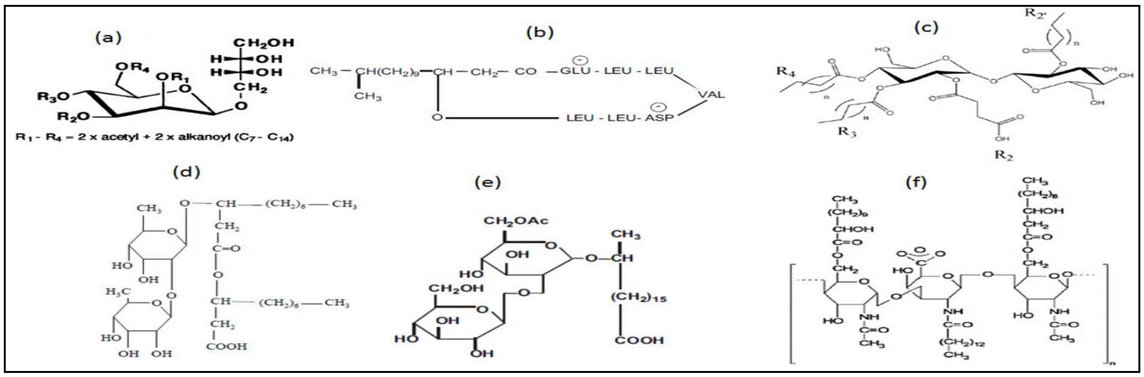

Figure 1: Chemical structures of some common biosurfactants (a) Mannosylerythritol lipid (b) Surfactin (c) trehalose lipid (d) Sophorolipid (e) Rhamnolipid (f) Emulsan. (from An investigation for potential paper) (Chavez *et al*., 2005)

Physiochemical properties and Functions of Biosurfactants

Surface and interface activity: Surfactant helps in reducing surface tension and the interfacial tension. Surfactin produced by *B. subtilis* can reduce surface tension of water to 25 mN mG1 and interfacial tension water/hexadecane to less than 1 mN mG1 (Cooper *et al*., 1981). The rhamnolipids produced by *P. aeruginosa* decreased surface tension of water to 26 mN mG1 and interfacial tension of water/hexadecane to value less than 1 mN mG1 (Syldatk *et al*., 1985). In general, biosurfactants are more effective and efficient and their Critical Micelle Concentration (CMC) is about several times lower than chemical surfactants, i.e., for maximal decrease on surface tension, less surfactant is necessary (Desai & Banat, 1997).

Temperature and pH tolerance: The biosurfactant production from extremophiles has gained attention in last decades for their considered commercial interest. Most of the biosurfactants and their surface activity are resistant towards environmental factors such as temperature and pH. Lichenysin from *Bacillus licheniformis* was found to be resistant to temperature up to 50°C, pH between 4.5 and 9.0 and NaCl and Ca concentrations up to 50 and 25 g LG1, respectively (McInerny *et al*., 1990). Another biosurfactant produced by *Arthrobacter* protophormiae was found to be both thermostable (30-100°C) and pH (2 to 12) stable (Singh & Cameotra, 2004). Since, industrial processes involve exposure to extremes of temperature, pH and pressure, it is necessary to isolate novel microbial products that able to function under these conditions (Cameotra & Makkar, 2004).

Biodegradability: Microbial derived compounds can be easily degraded when compared to synthetic surfactants (Mohan *et al*., 2006) and are suitable for environmental applications such as bioremediation/biosorption (Mulligan *et al*., 2001). The increasing environmental concern forces us to search for alternative products such as biosurfactants (Cameotra & Makkar, 2004). Synthetic chemical surfactants impose environmental problems and hence, biodegradable biosurfactants from marine microorganisms were concerned for the biosorption of poorly soluble polycyclic aromatic hydrocarbon, phenanthrene contaminated in aquatic surfaces (Olivera *et al*., 2003). The blooms of marine algae, Cochlodinium can be controlled by using the biodegradable biosurfactant sophorolipid with the removal efficiency of 90% in 30 min treatment (Lee *et al*., 2008).

Low toxicity: Although, very few literatures were available regarding the toxicity of biosurfactants, they are generally considered low or non-toxic products and are appropriate for pharmaceutical, cosmetic and food uses. Poremba *et al*. (1991) demonstrated the higher toxicity of the chemical-derived surfactant (Corexit) which displayed a LC50 against *Photobacterium phosphoreum* and was found to be 10 times lower than of rhamnolipids. Flasz et al. (1998) compared the toxicity and mutagenicity profile of biosurfactant from Pseudomonas aeruginosa and chemically derived surfactants and indicated the biosurfactant as non-toxic and non-mutagenic. The low toxicity profile of biosurfactant, sophorolipids from *Candida bombicola* made them useful in food industries (Cavalero & Cooper, 2003).

Emulsion forming and emulsion breaking: Biosurfactants may act as emulsifiers or de-emulsifiers. An emulsion can be described as a heterogeneous system, consisting of one immiscible liquid dispersed in another in the form of droplets, whose diameter in general exceeds 0.1 mm. Emulsions are generally two types: oil-in-water (o/w) or water-in-oil (w/o) emulsions. They possess a minimal stability which may be stabilized by additives such as biosurfactants and can be maintained as stable emulsions for months to years (Velikonja & Kosaric, 1993). Liposan is a water-soluble emulsifier synthesized by *Candida lipolytica* which have been used to emulsify edible oils by coating droplets of oil, thus forming stable emulsions. These liposans were commonly used in cosmetics and food industries for making oil/water emulsions for making stable emulsions (Cirigliano & Carman, 1985).

Antiadhesive agents: A biofilm can be described as a group of bacteria/other organic matter that have colonized/accumulated on any surface (Hood & Zottala, 1995). The first step on biofilm establishment is bacterial adherence over the surface was affected by various factors including type of microorganism, hydrophobicity and electrical charges of surface, environmental conditions and ability of microorganisms to produce extracellular polymers that help cells to anchor to surfaces (Zottala, 1994). The biosurfactants can be used in altering the hydrophobicity of the surface which in turn affects the adhesion of microbes over the surface. A surfactant from *Streptococcus thermophilus* slows down the colonization of other thermophilic strains of *Streptococcus* over the steel which are responsible for fouling. Similarly, a biosurfactant from Pseudomonas fluorescens inhibited the attachment of Listeria monocytogenes onto steel surface (Chakrabarti, 2012).

Mechanism of action in amelioration of polluted soils

Application in microbial enhanced oil recovery (MEOR): Oil spills cause devastating effect on aquatic life on marine environment. Chemically synthesized surfactants had been reported for their toxicity on aquatic organisms, so were, treated them unsuitable for remediation (Bach *et al*., 2003,). One of the inherent alternatives for this purpose was to find the biomolecules which had surface activity as well as the emulsifying activity along with the low Critical Micelle Concentration (CMC) characteristics. Due to the high cost of chemical tension active agents hinders the widespread use of surfactants in oil recovery processes (Juwarkar *et al*., 2007). Thus, to reduce the interfacial tension between oil/water and oil/rock, biosurfactants have been employed which leads to a reduction in the capillary forces that impede oil from moving through rock pores. The biosurfactants emulsify the hydrocarbons in water to form various mixtures and make them water soluble. Lichenysins, rhamnolipids and surfactin are the few surfactants which are found to be successful in the remediation of the oil contamination (Hashim *et al*., 2011). Hydrocarbonoclasticity bacterial consortium has a wide range of degradation capabilities on both aliphatic as well as aromatic fractions of crude oil. Many bacterial species that produce biosurfactants had been described for the microbially enhanced oil recovery *in-situ* applications that belong to *Bacillus* sp. because of their thermal and halotolerance ability. A typical Bacillus strain was grown and produced lichenysin by both anaerobic and aerobic processes at relatively high temperatures ranging from 40 -60°C. Different processes can be approached to exploit the biosurfactant producing strains in oil recovery applications (Kitamoto *et al*., 2002).

Application in heavy metal contaminated soil: The soil contamination by heavy metals is a serious problem for the life and health of living organisms include human because of their potential toxicity, reactivity and mobility in the soil. A number of technologies are currently used to remove potentially toxic metals cations such as Pb^{2+}, Zn^{2+}, Cr^{3+}, Cd^{2+} and Hg^{2+} (Miller, 1995) from soil and bioremedia-tion is one of them. However, in contrast to bioremediation of organic substances, metals cannot be biodegraded. Another difference in their remediation is fact that organics usually occur in the soil in the form of neutral molecules and heavy metals as cations. Such anionic biosurfactants as e.g. rhamnolipids with caroboxylic group or surfactin with two negative charges on the aspartate and the glutamate residues are cable of binding metals. But, when removing heavy metals from the soil, it is especially important to select the proper complexing agent due to the selectivity of biosurfactants to metals present both in soil solution and those associated with solid soil particles (Miller, 1995). As with the bioremediation of hydrophobic substances, there are differences between the mechanism of action of low and high-molecular weight surfactants in metals remediation. Bacterial exopolysaccharides (e.g. emulsan) have been shown to bind different metals. But such complexation is less effective than complexation by low-molecular mass biosurfactants probably due to the large molecule size of extracellular bioemulsifiers (Miller, 1995). Biosurfactants can enhance the mobility of heavy metals in two different ways – by lowering interfacial tension and by forming micelles (Wang & Mulligan, 2004). Initially, at low concentration ZPC molecules adsorb at metal–soil and soil–water interface because of their amphiphilic structure. In this way, they improve soil wettability as well as reduce interfacial tension and thus the strength of binding metal cations to soil particles. At the end desorption of the metal from soil particles and its complexation by the biosurfactant micelles is observed (Mulligan, 2017). Forming the micelles stabilize metal-biosurfactant

Application of biosurfactants for pesticide remediation: Pesticide contamination is a significant problem. The use of biosurfactants for pesticide biodegradation has recently gained popularity. The biosurfactant market is anticipated to grow as the pesticide business grows and consumers become more health-conscious (Rawat *et al*., 2020). The most crucial role that biosurfactants play is the dissociation of toxic pesticide molecules from the soil or water molecules, thus making it bioavailable for the microbes to speed up the remediation process. Desorption from soil particles leads to a reduction in surface tension, thus enhancing the mechanism of degradation (Singh *et al*., 2007). The probable interaction used for pesticides bioremediation by biosurfactants includes electrostatic interactions, counter-ion binding, ion exchange, and precipitation-dissolution (Banat *et al*., 2010). Biosurfactants enhance the surface area of hydrophobic pesticides, increasing their solubility in soil and water by inducing emulsification of pesticide molecules. The thumb rule of bioremediation is that the more the amount of pesticide that is water-soluble, the greater the amount of pesticide bioavailable to microorganisms. Surface-active polar flocculating molecules such as biosurfactants, which produce emulsions at and above their critical micellar concentration, may enhance the separation of hydrophobic pesticides from the aqueous phase by creating emulsions at and above their critical micellar concentration (CMC). When pesticides are released into the environment, they become more bioavailable to possible degraders, which may help alleviate the worry about pesticide contamination of soil and water bodies (Zhou *et. al*., 2011). As a result, the soil becomes free of pollutants, productive, and suitable for crop cultivation (Fenibo *et. al*., 2019). Rhamnolipids are the most widely used biosurfactants in industrial and environmental clean-up applications. The potential of rhamnolipid in bioremediation has been extensively studied in *Pseudomonas* and *Burkholderia* species (Varjani and Upasani, 2016).

Future prospective of biosurfactants

Development of Novel Biosurfactants: Researchers are actively exploring the identification and development of novel biosurfactants with improved properties, such as higher stability, broader range of contaminant compatibility, and enhanced biodegradation capabilities. Through bioprospecting and genetic engineering techniques, new biosurfactants can be discovered or engineered to address specific challenges associated with different types of pollutants and soil conditions.

Tailored Biosurfactant Formulations: Future research will focus on formulating biosurfactants specifically tailored for different types of soil contaminants. This involves optimizing the composition and concentration of biosurfactant blends to maximize their effectiveness in mobilizing, solubilizing, and degrading specific pollutants. Tailored formulations can enhance the bioavailability of contaminants and improve the overall efficiency of soil remediation processes.

Integration with Advanced Technologies: The integration of biosurfactants with advanced technologies, such as nanotechnology, electrokinetics, and molecular biology tools, holds great potential. By combining biosurfactants with these technologies, researchers can develop innovative approaches for targeted contaminant delivery, controlled release, and enhanced biodegradation. This integration can also facilitate the development of in-situ and on-site remediation techniques for polluted soil.

Field-Scale Applications and Case Studies: Further studies are needed to demonstrate the practicality and efficacy of biosurfactant-based remediation at larger contaminated sites. Field-scale applications and case studies will provide valuable insights into the real-world challenges and successes of biosurfactant-assisted soil remediation. These studies can help refine and optimize the implementation strategies, dosage requirements, and cost-effectiveness of biosurfactant-based approaches.

Ecotoxicological Assessment: The environmental impacts of biosurfactant application in soil remediation need to be further investigated. Future research should focus on comprehensive ecotoxicological assessments to evaluate the fate, persistence, and potential effects of biosurfactants on non-target organisms, soil microbiota, and overall soil ecosystem health. Understanding the ecological implications of biosurfactant use is crucial for ensuring the sustainability and long-term benefits of soil remediation practices.

Regulatory Frameworks and Industrial Adoption: The development of regulatory frameworks and guidelines specific to biosurfactant use in soil remediation is essential for widespread adoption. Clear regulations, standards, and policies will facilitate the integration of biosurfactants into existing soil remediation practices and encourage industrial stakeholders to embrace these eco-friendly alternatives. Collaboration between academia, industry, and regulatory bodies will be crucial for advancing the use of biosurfactants in polluted soil amelioration.

CONCLUSION

The future perspectives of biosurfactants for the amelioration of polluted soil are bright. Continued research and innovation will drive the development of novel biosurfactants, tailored formulations, and integration with advanced technologies. Field-scale applications, ecotoxicological assessments, and regulatory frameworks will contribute to the practical implementation and acceptance of biosurfactant-based soil remediation approaches. By harnessing the potential of biosurfactants, we can pave the way for sustainable and effective solutions to address soil pollution and restore environmental health.

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Chapter - 9

Principles of Quality Seed Production in Vegetable Crops

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The quality, productivity, and sustainability of vegetable seed production is improved by putting suitable controls at each stage, right from parental selection to seed processing and storage by utilizing the latest technology. The adoption of best practices in seed production, such as crop management, disease control, and post-harvest handling are made easier through training programmes, workshops, and knowledge-sharing platforms. This assures a steady supply of high-quality seeds for farmers. This chapter focuses on the importance of information transmission and capacity building among seed producers and farmers for quality seed production in vegetables.

Keywords: *Seed quality, genetic principles, agronomic principles, seed certification*

INTRODUCTION

Embryo is the first stage of an organism's development. A mature ovule that contains an embryo, a miniature plant, and food reserves inside of a protective coat is called a seed. Embryonic development is the phase of life cycle that starts just after the pollen fertilizes the female egg cell in sexually reproducing plants (Agarwal, 2018).

Seed production is an integral part of agriculture, responsible for the creation, propagation, and distribution of seeds to farmers. The increased productivity of vegetable crops in India is mostly attributable to the government and private sector's supply of high quality seeds. Recent trends and technologies like, improved irrigation systems and modern production techniques also contribute to higher vegetable crop output (Koundinya and Kumar, 2014). However, the depletion of natural resources, deterioration of soil quality, and the increased pollution levels pose a challenge to the sustainable production of vegetables. This issue can be resolved by a number of different approaches like using seeds from high yielding, genetically improved varieties and hybrids that are adapted to a wider range of agro-ecological conditions, efficient resource management, and efficient pest management methods (Rashid and Singh, 2000).

The process of producing quality seeds demands a high level of technical expertise and thus the process must be standardized and tailored according to specific crops. Knowledgeable about the genetics and agronomy of seed production is also a pre requisite for producers in order to avoid contamination. Hence, to preserve the desired level of varietal purity, certain guidelines and principles must be observed and maintained during seed production, harvesting, and post-harvest stages.

Principles of seed production

The fundamentals of seed production include a number of procedures and factors intended to produce high-quality seeds. Some of these fundamental ideas are described as follows:

Genetic principles

The production of genetically pure seed is costly process requiring high level of technical expertise. The breeder or producer must have thorough knowledge of the underlying genetic concepts for maintaining varietal purity of the seeds. To prevent the genetic deterioration of a crop variety, different interventions must be used depending on the crop's flowering pattern, floral structure, pollination behaviour, genetic constitution, photo and thermo sensitivity and the need for special stimuli with regard to floral initiation (Kumar *et al.,* 2023).

Control of seed source

Production of high-quality seeds is greatly influenced by genetic principles. These guidelines include a range of concepts of plant breeding and genetics that help produce high-quality seeds. There are four classes of seed which is defined by Association of Official Seed Certification Agency (AOSCA):

1. **Breeder's seed**: Breeder's seed is a type of seed or vegetative propagating material that is directly under the control of the original or officially authorized plant breeder of the breeding programme or institution, who produced the variety and whose name is listed on the variety's release registration. Breeder's seed is genetically pure to ensure that the foundation seed class of the following generation will adhere to the established requirements of genetic purity.
2. **Foundation seed**: Foundation seed is progeny of breeder seed, or it may be created from another foundation seed that is directly linked to breeder seed.
3. **Registered seed**: Registered seed is the offspring of foundation seed that has been managed in accordance with the requirements laid forth for the specific crop being certified in order to preserve its genetic integrity and uniqueness.
4. **Certified seed**: It is the offspring of foundation seed created by licensed seed producers under the watchful eye of organizations that certify seeds in order to maintain minimum requirements for seed quality (Hazra and Som, 2016).

Table 1: Tag colour of different seed classes

Seed class	Tag colour
Breeder's seed	Golden yellow
Foundation seed	White
Registered seed	Purple.
Certified seed	Blue

(Source: Agarwal, 2018)

Crop rotation: To reduce the possibility of plant material or dormant seeds lingering from the previous crops that are likely to cross-pollinate or produce admixture with the intended seed crop, satisfactory intervals between related or comparable crops are necessary. Crop rotation also enhances plant nutrition, preserves the physical state of the soil, and reduces the danger of soil-borne pests and diseases in addition to these other benefits. Therefore, it is important to pay attention to how long it has been since a comparable crop was produced in the same soil.

Isolation: Eliminating the chance of cross-pollination between various cross-compatible plants is a crucial step in the seed producing process. Adequate separation helps prevent mixing during harvest and the spread of pests and diseases from different host plants in addition to cross-pollination (Kumar *et al.,* 2023). It is important to comprehend isolation distance guidelines in the context of the environment where the crops are cultivated.

The degree of out crossing can be influenced by a number of factors, including

a) Varietal traits like flower structure
b) Environmental elements like wind and temperature
c) Pollinator species and their behaviour on the flowering
d) Isolation distance
e) The presence of barrier plants
f) Planting patterns like row or block plantings
g) Number of varieties planted or number of plants of each variety
h) Number and kind of other pollen sources
i) Regional or bioclimatic factors (Hazra and Som, 2016).

It is possible to separate vegetable seed crops based on distance and time.

a) **Isolation by time**: Within each farm of a multiplication station, this kind of isolation is conceivable. If the rotational criteria are followed, this system's seed production is set up such that cross-compatible types can be cultivated in succeeding years or seasons.

b) **Isolation by distance**: When temporal isolation is not an option, isolation by distance should be used instead. The kind of crop pollination heavily influences isolation distance. For the production of certified seed, it is often necessary to maintain an isolation distance of at least 1000-1600 metres between insect-borne, highly cross-pollinated vegetable crops like onion, radish, cabbage, cauliflower, broccoli, Brussels sprouts, etc. and wind-pollinated vegetable crops like spinach, beetroot, palak and sweet corn. However, because their pollen is heavier, a relatively short isolation distance of 400–500 metres is needed for the highly cross-pollinated cucurbits. The distance of isolation also changes depending on the class of seeds that will be produced. Because of the strict requirements to preserve high genetic purity, isolation distance is higher for foundation than certified seed production.

Rouging of seed crop

The procedure of rouging involves eliminating off-types plants from the seed crop. The possible cause of genetic contamination of seeds is the presence of off-type plants in the seed crop (Laverack and Turner, 1995). In addition to off-type plants, unhealthy and unusual plants must also be taken out. Thus, it is one type of selection that is used in the breeding of seeds. There is no such thing as "variety maintenance" since varieties are never static and are continuously changing. Instead, selection is always taking place, whether or not we are actively involved in it. Genetic variables (mutations, genetic drift owing to population growth, sporadic crossings, etc.) and environmental and biotic factors (climate, weather, soil, diseases, pests, etc.) all contribute to the variety's ongoing transformation. Rouging must thus be conducted continuously to retain desired varietal traits. In order to prevent the unwanted characteristics from transferring to the seed, plants should ideally be rouged before flowering. When rouging, the entire plant is examined, not only the fruit or seed. When rouging plants, particular focus is placed on the plant's vigour, growth form, true-to-type, flower colour, foliage colour, leaf shape, and resistance to disease and insects. Productivity, fruit size, colour, and form need to be taken into account when fruit production starts. The seed itself can then be rouged once more. Depending on the type of vegetables, the purity of the seeds sowed, the characteristics of the previous crop, etc., the number of rouging which is needed for the seed crop varies (Rashid and Singh, 2000).

When necessary, roping is carried out throughout the growth season, from the seedling through the fruiting stage. Off-type plants in the seed crop should be rouged out at various times of the day by moving around the plot in various directions. As soon as the off-types are apparent, rouging should generally be performed in three stages:

a. Vegetative stage
b. Flowering stage
c. Maturity stage.

Regular supervision by qualified personnel is crucial, and the supervisor of seed production must be familiar with the distinct, uniform, and stable (DUS) characteristics of each variety or paternal line of the hybrid, on the basis of which adequate rouging should be carried out.

Grow-out test

Grow-out tests for genetic purity should be conducted frequently on varieties or parental lines of a hybrid that is being raised for seed production to ensure that they are being kept in their true form.

Agronomic principles

Apart from genetic principles there are some agronomic principles too which are applied in quality seed production. They are listed as follows:

Selection of suitable area for seed production

A crop variety used to produce seeds in a certain location must be suited to the photoperiodic and climate variables present there. Seed production is better suited to areas with moderate rainfall and humidity than those with high rainfall and humidity. For the induction of blooming and pollination, the majority of crops require a dry, sunny period with a moderate temperature (Neenu *et al.,* 2013). Excessive rainfall during flowering can decrease seed production and may cause illnesses to spread to other crops, including onions. Pollen abortion could occur if temperatures are too high when flowers are blooming. Unless a particular crop is properly designed to thrive and generate seed under these conditions, it is generally recommended to avoid producing seeds in places with excessive temperatures.

In case of vegetables; for the initiation of the seed stalk, vernalization is necessary for biennial crops like cabbage, cauliflower of group III and group IV, broccoli, Brussels sprouts, kale, European radish, carrot, beetroot, long day onion, leek, etc. These should be produced as seeds in regions with short days and low temperatures favourable to vernalization.

Field preparation

Making flat or elevated seed beds and getting rid of any weeds and stray plants constitute field preparation. During tillage operations, a well-tilled seed bed aids in better germination, excellent stand establishment, and the elimination of possible weeds. Equipment used during field activities has to be cleansed of dirt, leftover weed or crop seeds before entering the site to prevent contamination of the area with other crop or weed seed. It is possible to use the stale seedbed approach, in which the seed beds are created approximately a week before they are to be seeded. In order to reduce weed competition in the seedbed before the seed crop is spread, this enables the weed seeds to germinate first (George, 2011).

Selection of variety

The correct variety must be chosen in order for a seed producing industries to succeed. When choosing a variety to produce seeds, the following factors should be taken into account.

- The variety that will be used to produce seeds has to be adjusted to the photoperiod and environmental conditions present in the production locations.
- Genetic purity is required for the variety.
- The diversity ought to produce a lot.
- The variety should also have other appealing qualities, such as consumer preference, resistant to pests and diseases, etc.

Source of seed

The seed must always come from a recognized official agency and be of recognized purity and proper class. While purchasing the seeds, the following elements should be carefully considered.

- The seed belongs to the right class. Breeder's seed class seed is needed for raising a foundation seed crop, and foundation seed class seed is needed for sowing when raising a certified seed crop.
- If the acquired breeder's/foundation seed bags' tags and seals are undamaged.
- The fact must be taken care that the validity period is still in effect.

Control of weeds

Weeds compete with seed crops for nutrients, moisture, sunshine and space, which decrease production and lower quality standards. A number of illnesses may potentially be carried by weed plants in the seed field or neighbouring locations.

Control of diseases and pests

Growing a healthy seed crop also requires effective disease and insect management. In addition to having lower yields, ill and insect-damaged plants always produce seed of inferior quality. Numerous illnesses are both systemic and seed-borne in origin. If not checked, the resulting seed will transmit the pathogens' spores (inoculums) and result in the production of unhealthy plants in the following generation. By employing disease-free planting material, manufacturing seed in isolated, disease-free areas, and using suggested plant protection techniques, disease-free seed may be produced. Insects may be controlled in the field by using pesticides, and in storage by keeping everything clean, fumigating the area, and treating the seeds. Additionally, efficient in preventing cross-infestation while in storage is the use of insecticide-impregnated seed packaging materials.

Nutrition

The healthy growth of plants and seeds depends on a variety of plant nutrients, including nitrogen, phosphorus, potassium, boron, molybdenum, zinc, and sulphur. The best use of nutrients produces the highest yields, the best seed quality and better expression of plant type.

Seed treatment

In order to ensure healthy seedling establishment and the management of soil- and seed-borne diseases, seed treatment helps to increase the planting value. The final stage in conditioning seed before bagging is the application of seed treatment, which is a specialized procedure. For this aim, a variety of systemic and contact fungicides and insecticides are available. Chemicals are chosen based on the type of protection required. The phrase "seed treatment" refers to both goods and operations. The growing environment for the seed, seedling, and young plant can be improved by the use of specialized goods and practices. The intricacy of seed treatment ranges from a simple dressing through coatings and seed pelleting.

a) Seed Dressing: The most popular technique for treating seeds is seed dressing. A dry formulation is applied to the seed, or it is wet treated with a slurry or liquid formulation. The most effective dust for most vegetable crops is Captan or Thiram 75% dust at 2-3 g/kg of seed. In order to protect seeds against pests during storage, non-toxic plant materials can be used, such as tobacco powder, neem powder, turmeric powder, etc.

b) **Seed Pelleting**: The most advanced seed treatment method, seed pelleting modifies the physical form of a seed to improve growing capacity and handling. The most expensive use is pelleting, which calls for specialised equipment and methods.

c) **Seed coating**: To improve adhesion to the seed, a specific binder is used with a formulation. Technology-advanced treatment is needed for coatings.

Harvesting drying and storage of seeds

It is crucial to harvest the seed crop when it will produce the most seeds of the highest quality and production. Typically, seeds are collected when they have a moisture level of 15-20% or less (Selvakumar, 2014). The pods of legume vegetables are picked when they are sufficiently dry, while cole crops are taken when the siliqua becomes yellow (Hazra and Som, 2016). The seeds are washed and dried after extraction. Drying seeds to an acceptable moisture content level is important to maintain seed viability and vigour. Sunlight, chemical desiccants, and mechanical driers can all be used to dry seeds. For the seeds to remain healthy and viable, the drier's air temperature shouldn't rise over 38°C. Sensitive seeds, such as onion, carrot, and leek, require drying at temperatures lower than 27°C. Threshing is finished for dry fruits after they are fully dried. When there is a minimal amount, it is done manually. Using a wooden stick, dried material (such as cereal grains, legume pods, leafy vegetables, etc.) is pounded in order to extract seeds and/or fruits. Threshing machines are employed on a huge basis. In order to prevent mechanical injuries and mechanical mixes, they should be completely cleaned before use. To remove the seeds from completely ripe tomato and brinjal fruits, cut the fruit into pieces, then ferment it and wash it to separate the seeds from the pulp. The seeds are then either dried in a dryer or partially shaded by open sunlight. The seed lot is also cleaned to remove any physical impurities such as inert matter, dust, stones, leaves etc. Clean and dried seeds should be placed in neat, clean sacks or bags and kept in a tidy, cold go-down for short-term storage (Toole, 1942).

Table 2: Isolation requirements for various vegetable crops

Crops	Minimum isolation distance (m)			
	Varieties or OPs		Hybrids	
	Foundation	Certified	Foundation	Certified
Amaranth	400	200	-	-
Asparagus	500	300	-	-
Beetroot, radish, turnip, spinach	1600	1000	-	-

Brinjal	200	100	200	200
Carrot	1000	800	1000	800
Cowpea, beans, dolichos	50	25	-	-
Cauliflower, cabbage, knol-khol, Chinese cabbage	1600	1000	1600	-
Cucumber, bitter gourd, muskmelon, bottle gourd pumpkin, sponge gourd, ridge gourd, snake gourd, snap melon, winter squash, summer squash, watermelon	1000	500	1500	1000
Fenugreek, garden pea	10	5	-	-
Indian squash, long melon	1000	500	-	-
Ivy gourd, pointed gourd	20	20	-	-
Lettuce	100	50	-	-
Okra, chilli, capsicum	400	200	-	-
Onion	100	500	1200	600
Tomato	50	25	200	100

(Source: Hazra and Som, 2016)

Seed cerification

Seed certification is a procedure which makes sure that the seeds being offered are pure and of the highest caliber. To confirm that the seeds fulfil particular criteria and regulations, it entails a number of inspections, testing, and processes. By giving consumers and farmer certainty about the calibre and validity of the seeds they buy, seed certification serves to safeguard both groups (Parimala *et al.,* 2013).

- Field standards: These requirements are used in standing crops to preserve both seed health and genetic integrity. In addition to the amount of area needed, other crop plants, isolation distance, weeding for troublesome species, ill crop plants, and rouging for off kinds are crucial. The crop is certified if it satisfies the established field criteria. Simply meeting "field standards" does not imply that the crop has been approved in its entirety. 'Seeds standards' must be met. The crop is eventually recognized as foundation or certified seed if it satisfies all requirements.
- Seed standards: These consist of inert matter, weed seeds, other crop seeds, seed of other varieties, proportion of pure seeds, germination percentage, and moisture content. Depending on the crop, a minimum range of 55–70% germination is typically prescribed. It ranges from 55 to 70 % for seeds of various vegetable crops,

60 to 65 % for cole crops, and 70% for legume seeds. More than 13% moisture shouldn't be present in seeds.

CONCLUSION

A key element of agricultural systems that affects crop performance, productivity, and overall food security is the development of high-quality seeds. Parental selection, seed processing, storage, and certification are only a few of the crucial steps in the multifaceted process of producing high-quality seeds.

To produce standard progeny with better features, it is crucial to carefully choose superior paternal lines. In order to produce high-performing offspring, factors including disease resistance, yield potential, and environmental adaptation must be taken into account. Effective isolation techniques must also be used in order to retain genetic purity and stop unintended cross-pollination, protecting the seed stock's integrity.

The viability and quality of seeds are strongly impacted by seed processing and storage practices. It is essential to thoroughly clean, dry, and remove contaminants from collected seeds in order to avoid possible contamination and preserve the highest level of seed quality. To keep seeds from deteriorating, maintain their ability to germinate, and increase their lifetime, it is essential to maintain the proper storage conditions, which include controlling moisture and temperature.

Testing and certification of seeds are reliable methods for determining and assuring the quality of seeds. Objective evaluations of the characteristics of seed quality are provided by rigorous laboratory testing processes, which include germination rate, purity, and vigour tests. Instilling trust and promoting fair trade practices, certification programmes run by authorized organizations provide assurance to farmers and consumers regarding the authenticity and quality of the seeds being offered.

A key priority for sustainable agriculture and global food security is investing in the development of high-quality seeds. Researchers, breeders, and farmers may collaboratively increase agricultural output, resilience, and the availability of high-quality seeds by giving careful attention to every step of the seed production process. By reducing the danger of pests and illnesses, fulfilling the rising demand for nutrient-dense foods, and creating a more sustainable and safe food supply chain for future generations, these initiatives help the world.

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Chapter - 10

Arsenic Toxicity in Soil, Water and Plants

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INTRODUCTION

Arsenic (As) is a heavy metal whose name is derived from the Greek word 'arsenikon' (meaning = potent). As (Arsenic) is a non-essential, non-metallic carcinogenic element that exists in a variety of situations and is extremely poisonous to all life forms, including plants. Arsenic (As) is found in abundance in the earth's crust. It can be found in over 200 distinct minerals, the most prevalent of which is arsenopyrite. Natural As accounts for roughly one-third of the As in the Earth's atmosphere. As and its compounds have been classified as a Group 1 human carcinogen by the US Environmental Protection Agency (EPA) by the International Agency for Research on Cancer (IARC). Agency for Toxic compounds and Disease Registry ASTDR listed Arsenic as first among the 20 priority dangerous compounds. The release of As into the environment is either naturally through weathering of As-rich minerals in the Earth's critical zone and volcanic activity or the use of wood preservatives, mining, excessive use of As-based fertilisers and pesticides in agriculture, and irrigation with As-contaminated groundwater. As can occur in four different oxidation states in soil and water: As(-III), As(0), As(III), and As(V) where As(III) and As(V) are most commonly found. There are both organic like monomethyl arsonic acid, arsenobetaine, and arsenosugars) and inorganic As species present, with As(V) being more poisonous and mobile. Arsenate (As(V)) and arsenite (As(III)) are highly poisonous and mobile in the natural environment; As(III) is prevalent in reduced circumstances, and As(V) is dominant in oxidised settings. According to a 2015 analysis, arsenic is a strong carcinogen that has been linked to skin, lung, kidney, bladder, and liver cancer. It has been observed that if exposed for a short length of time, symptoms may include vomiting, stomach pain, encephalopathy, and bloody diarrhoea. Long-term contact can cause skin thickening, darkening, gastrointestinal pain, diarrhoea, heart problems, numbness, and cancer.

Two common forms of Inorganic Arsenic

1. Arsenate [As(V)]
2. Arsenite [As(III)]

Two forms of inorganic arsenic, are rapidly absorbed by plant root cells. As(V) is easily transformed to As(III), the more poisonous of the two forms, once within the cell. Both As(V) and As(III) impair plant metabolism, although in different ways. As(V) is a phosphate chemical analogue that can disrupt at least some phosphate-dependent parts of metabolism. Phosphate transport proteins can transfer As(V) across cellular membranes, causing phosphate supply imbalances. During phosphorylation processes, it can compete with phosphate, resulting in the creation of As(V) adducts, which are frequently unstable and short-lived.

As accumulates mostly in the root system, it causes numerous physiological changes, interferes with metabolic processes, slows plant growth, and, eventually, reduces crop output. Arsenic contamination in rice grains has also been detected in various rice cultivars tested in Bangladesh. These harmful metals are widely found more in southern Asian nations such as Bangladesh, Cambodia, India, Nepal, and Vietnam.

Arsenic content in soil

Depending on the parent material of the soil, different soils have various background of As concentrations; in most circumstances, the baseline soil As content might range from 5 to 10 mg kg1. An average As concentration of 7 mg kg1 has been observed for European topsoil. Peats and bog soils, on the other hand, are considerably more enriched with As, with average soil As concentrations of up to 13 mg kg1. Acid sulphate soils are among the soils with comparatively higher As levels. Because of different human activities, the United States Environmental Protection Agency's (USEPA) recommended allowable soil As content of 24 mg kg^{-1} has been exceeded in several nations across the world. Arsenic concentrations in non-affected soils typically range from less than 10 mg kg^{-1} to as much as 30,000 mg kg^{-1} in contaminated soils. Arsenic in agricultural soils has a permissible limit of 20 mg/kg soil, but 5-ppm arsenic in soil has been found to be harmful to sensitive crops. Despite its low crustal abundance (0.0001%), As is abundant in nature and is frequently associated with metal ores such as copper, lead, and gold. In aerated soils utilised for crops such as wheat, maize, and most vegetables, the predominant element is As (V), which is likely to be in the solid phase. As a result, in such soils, groundwater utilised for irrigation is rapidly absorbed by iron hydroxides, rendering it essentially unavailable to plants. Arsenic is mostly prevalent as As(III) in anaerobic soil conditions such as those found in flooded paddy fields and is dissolved in soil-pore water (the soil solution). It is thus more accessible to plant roots.

Arsenic concentration in water

Many countries around the world are dealing with As contamination of groundwater, including Bangladesh, India, China, Pakistan, Chile, Argentina, Mexico, Poland, New Zealand, Canada, Hungary, Taiwan, the United States, and Japan. Approximately 59 districts in West Bengal, India, a large population in Bangladesh, and several areas in Pakistan's Sindh and Punjab provinces rely on As-contaminated groundwater for irrigation and drinking. Because As has been discharged geologically into aquifers, groundwater As levels in some countries have exceeded 3000 g L^{-1}. According to World Health Organisation (WHO) standards, the permissible limit of As in drinking water is 10 g L^{-1}, which is observed globally with deviations in several South and Southeast Asian nations. According to WHO standards for As in drinking water, more than 200 million people worldwide are at danger of As poisoning, with around 100 million at risk in South and Southeast Asia alone. As concentrations in seawater are typically less than 2 g L^{-1}. As concentrations in freshwater sources such as lakes, rivers, and streams range from 0.15 to 0.45 g L^{-1} depending on the source and geochemical features of the region. Lake waters often have lower As concentrations than river waters. The majority of As-contaminated sites are found around big deltas and in the vicinity of major rivers that originate in the Himalayan mountain range. The Bengal delta has the highest As concentration, with more than 88% of the 45 million people suffering by high (>50 g L^{-1}) As poisoning.

Arsenic uptake from soil to plant

Arsenic concentration in plants is typically less than 1.0 mg kg1 dry weight (DW). It has been reported that As concentrations of 0.1% on a DW basis in various plant species growing on As-contaminated soil. Plants accumulate As in the root and transfer to the shoot, which can be active (requires energy) or passive (does not require energy). With the help of several transporter proteins, plants may take up As in its inorganic form, and the fundamental driving factor for As absorption is a concentration gradient between source and sink. The method of As uptake by plants differs depending on the chemical species of As. It has been revealed that As(V) enters the plant cell via several Pi channels. This is due to the fact that P is chemically similar to As(V). The presence of As(V) in the growth medium or a lack of P leads to increased co-transport of As(V) and Pi. The key components of P channels involved in As(V) uptake by plants are several Pi transporter proteins (PHT). Plants have been found to exhibit both high-affinity and low-affinity P transporters. PHT1 proteins play a role in high-affinity transport. The protein implicated in low-affinity transport, on the other hand, is still unknown. Some investigations, however, have suggested that some PHT1 proteins may generate low-affinity activity. Plants, on the other hand, absorb As(III) through a variety of nodulin-26-like intrinsic proteins (NIPs). According to reports, PHT transporters are unidirectional, but NIP transporters are bidirectional. As a result, depending on the difference in As concentration, As(III) can travel in both directions between plant cells and growing medium.

On the other hand, because of the similarities between As(III) and Si, it has been reported that As(III) uses silicon transporters in plants. It has been shown that when plants are deficient in Si, the expression of the influx Si transporter (Lsi1) rises. Lsi1 and efflux Si transporters (Lsi2) are primarily responsible for Si build up in plants. The Lsi1 and Lsi2 transporters are found on the proximal and distal sides of epidermal and endodermal cells, respectively, and aid in As trafficking between cells and tissues as in Fig no. 1.

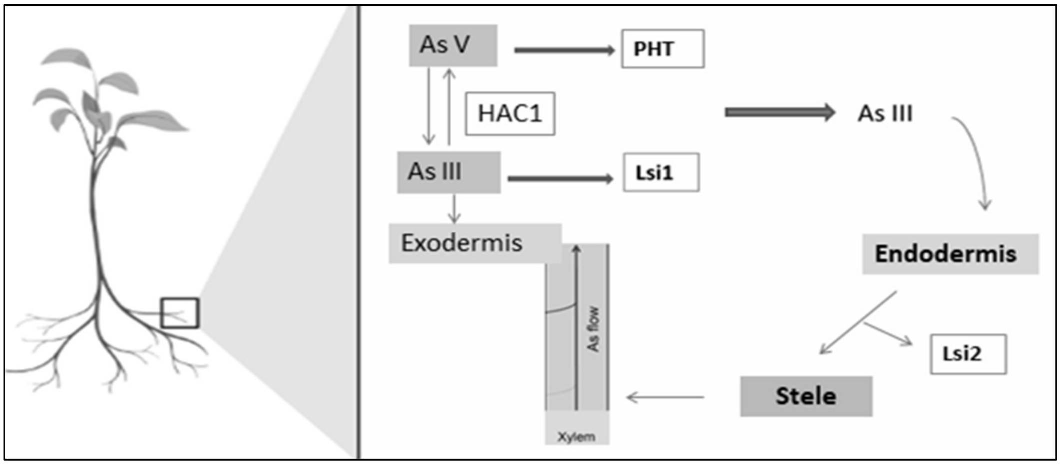

Figure 1: Arsenite (AsIII) and arsenate (AsV) uptake and As vacuolar sequestration in roots. AsIII and AsV are taken up by rice roots via phosphate transporters (PHT). AsV is reduced to AsIII by arsenate reductase HAC1. AsIII influx transporter Lsi1 and AsIII efflux transporter Lsi2 play a critical role in As uptake and As transport to root xylem for translocation respectively

As absorption by plants is also influenced by distinct physiological/tolerance mechanisms that occur in different plant tissues under As stress. Indeed, As stress can cause a variety of harmful effects at the cellular and molecular levels inside plants. To cope up with As toxicity, plants have a variety of tolerance mechanisms that entail physiological and biochemical changes. These physiological and metabolic changes also affect plant metal uptake and root-shoot transmission. Reduced metal uptake by plants, for example, has been suggested as a tolerance mechanism by which plant cells can tolerate metal toxicity. Thus, physiological changes inside plants can influence As uptake.

Symptoms of arsenic toxicity in plants

- Changes in adenosine triphosphate (ATP), chlorophylls, and the photosynthetic system caused by arsenic (As) pollution are the most common symptoms in As-stressed plants
- Interveinal necrotic and white chlorotic signs.
- Arsenic wreaks havoc on the chloroplast membrane and disrupts the functioning of the essential photosynthesis process.
- Plants developing under As stress show a considerable drop in pigment production due to a lack of adaptive modifications to high As levels, as well as a lowered rate of CO_2 fixation and functional activity of photo system II (PSII).

- Toxic heavy metals have the ability to interact with various important biological macromolecules, including nuclear proteins and DNA, resulting in an increase in reactive oxygen species (ROS).
- Chlorosis of the shoot, lipid peroxidation, and protein degradation40, as well as sterility of the florets / spikelets, resulting in a lower grain yield.

Physiological effects of arsenic on plants

As may significantly hinder plant growth by delaying or stopping cell expansion or biomass build up when it moves through shoots. By lowering fertility and the growth of reproductive organs, As can decrease a plant's ability to reproduce. As a result, the yield-related parts of plants are also hindered, which lowers yield or fruit production. There are numerous ways that arsenic can be often absorbed by roots, moved through the xylem from the root to shoots, subsequently accumulated to the seeds and plant aerial parts. As treatments exhibited noticeably lower germination rates as well as shoot and root lengthening. Higher As concentrations can stifle growth since it interferes with metabolic processes, which frequently result in plant death. As also decreased biomass production, root length, and leaf number.As plants treated with irrigation water only, various growth metrics, such as root length, fresh and dry weight, and shoot length, fresh and dry weight, were drastically reduced. Additionally, P, K, S, Ca, and Mg nutrient accumulation in the shoot was decreased by irrigation water.

Photosynthesis, respiration, transpiration, and plant metabolic processes are substantially affected in other ways by arsenic toxicity, which can actively react with enzymes and proteins and disrupt biochemical functions of cells. Arsenic is the cause of the production of reactive oxygen species (ROS) inside the cell, which can lead to protein and lipid oxidation and have a negative impact on cellular and subcellular organelles as well as DNA damage.

Plant organs exhibit a variety of secondary stresses when exposed to toxic metal stress; water or osmotic stresses are frequent among them. When faced with these kinds of challenges, plants will react in a variety of ways to preserve the water status. Plants can adapt to As exposure through osmotic adjustment, water content management, or water potential. As(III) led to a greater drop (78%) in stomatal conductance. Plants that were exposed to varied concentrations of As (V) had better protein and soluble sugar production and accumulation. As well as a 48% rise in protein and a 172% increase in soluble sugar, an increase in As also significantly boosted the accumulation of proline and glycine betaine. When As levels are high enough, it can cause essential metabolic processes to malfunction, which can be fatal. The majority of plants have defences that keep the majority of their As burden in the roots. But some of the As is transferred to the plant's shoot and other tissues in a genotype-dependent manner.

Plants exposed to As experience cellular membrane breakdown that results in electrolyte leakage. Malondialdehyde, a by-product of lipid peroxidation, is frequently increased in the presence of membrane damage, indicating the importance of oxidative stress in As toxicity. Cell membranes are damaged by arsenic poisoning, and it is well known that chloroplast membranes are particularly vulnerable to As-induced harm. Literature demonstrates that As stress caused changes in the chloroplast membrane organisation, including swelling and rupture of the thylakoid membrane. Additionally, As toxicity lowered carotenoids and altered the chloroplast membrane. Chloroplasts undergo dilapidation and internal membrane alteration as a result of arsenic toxicity, which negatively impacts the photosynthetic pigments and the rate of carbon assimilation. As has a negative impact on the Chl a and Chl b contents, PSII's maximum and actual photochemical efficiencies, the quantum yield of CO assimilation, non-photochemical quenching, net photosynthesis rate, stomatal conductance to water vapour, and internal CO concentration. Starch, sucrose, and glucose concentrations were all reduced as a result of As toxicity. Under As stress, electron flow through thylakoid membranes may be decreased. As decreases the ability to create ATP and nicotinamide adenine dinucleotide phosphate (NADPH) in the carbon fixation processes centre. Uncoupling of thylakoid electron transport from ATP synthesis may occur when P is replaced by As (V) during photophosphorylation. The breakdown of chlorophyll under As stress may be the cause of photosynthetic limitation. Under As stress caused reduction of the ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) large subunit, which led to down regulation of RuBisCO and chloroplast. Also, the net photosynthetic rate, electron transport rate, and PS II efficiency all decreased. The phosphorylation of ADP to ATP in the mitochondrial inner membrane and plastid thylakoid membrane is a crucial Pi-requiring process in plants. However, in the presence of As(V) and/or a Pi deficit, a mitochondrial enzyme may produce ADP-As(V) during this process. ADP-As(V) synthesis or phosphorylation of ADP to ATP have both been described as chemically analogous processes in the past.

Biochemical Effects of Arsenic on Plants

Chloroplast, mitochondria, and peroxisome are just a few of the metabolic pathways that can continually produce ROSs as a by-product of their regular aerobic metabolism. It is well known that these overly produced ROSs can damage DNA, inactivate enzymes, oxidise proteins, lipids, and carbohydrates in an unspecific manner.

The formation of reactive oxygen species (ROS), such as superoxide radicals (O-2), hydroxyl radicals (OH), and hydrogen peroxide (H_2O_2), is the most hazardous metabolic consequence of As at the subcellular level. These ROS pose a serious threat to plant metabolism and have the potential to irreparably harm essential macromolecules such lipids, proteins, carbohydrates, and DNA. It has been noted that As(V) to As(III) conversion is related to the production of ROS in plants. By raising the activities of the antioxidant enzymes, plants defend themselves against oxidative damage brought on by the production of ROSs. Superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR), and ascorbate peroxidase (APX) are some of the enzymes involved in the detoxification of ROS. Proline is a well-known osmoprotectant and one of the non-enzyme antioxidants that is extensively accumulated in plants under As stress. It acts as a cell wall plasticizer, aids in maintaining the minimal amount of water required for cell function, and shields plants from ROS-mediated harm.

According to studies, arsenic interferes with biochemical and metabolic processes in plants growing in As-contaminated soils, impairing nutrient uptake, having a negative impact on the photosynthetic apparatus, interfering with plant water status, interacting with the functional groups of enzymes, and replacing essential ions from adenosine triphosphate (ATP).

Arsenic-induced reactive oxygen species (ros) generation

O_2 generation is mostly found in complex-I and complex-III of the electron transport chain (ETC) inside mitochondria. O_2 is mostly used in two pathways: 95% of the total O_2 is used by cytochrome oxidase to create H_2O, and other O_2 is directly reduced to O_2^- in the flavoprotein dehydrogenase segment. O_2 is converted to O_2^- at the respiratory chain's ubiquinone cytochrome region. Additionally, during photosynthesis, O_2 is produced in the chloroplast, which receives electrons travelling via PS-I and PS-II to produce O_2. Only a small part of the total carbon is fixed into CO_2 under As (or other) stress, which causes a drop in Calvin cycle carbon reduction and a rise in oxidised NADP+ levels. When ferredoxin is over-reduced during photosynthetic electron transfer, this oxidised form of NADP+ can act as the electron acceptor. As a result, the Mehler reaction, also known as the electron transfer from PS-I to O_2, can transfer electrons from O_2 to generate O_2^-. This starts a series of events that quickly produce oxygen radicals.

In addition, there are two different ways for peroxisomes to create O_2: either in the matrix, where xanthine oxidase catalyses the conversion of xanthine and hypoxanthine into uric acid, or in the membranes, where small amount of ETC is active. Monodehydroascorbate reductase has the ability to contribute to O_2^- generation in membranes. H_2O_2 is created in peroxisomes by a number of different activities, including the photorespiratory glycolate oxidase reaction, oxidation of fatty acids, flavin oxidase activity, and O_2^- radical disproportionation.

For the physiological, biochemical, and metabolic activities occurring inside the plants, the increased creation of ROS is extremely hazardous. The majority of reports claim that they cause a variety of cellular damages at high concentrations and alter the redox status of cells, which can act as a signalling molecule. As a result, ROS's functionality and/or effects would only depend on its concentration. According to several research, As(V) is converted to As(III) in plants, which increases ROS production. Other significant mechanisms for the production of ROS in plants include the leaking of electrons during the reduction of As(V) to As(III), as well as the inhibition of crucial enzymes.

Molecular effects of arsenic on plants

Excessive ROS lead to DNA damage, non-specific oxidation of proteins, lipids, and carbohydrates. The excessive production of ROS caused by arsenic exposure has been widely reported to cause genotoxic reactions in both plants and animals. Numerous studies have suggested that the initial link between Arsenic genotoxicity and the generation of ROS during its biotransformation. DNA is vulnerable to ROS attack because rings of both pyrimidine and purine contain unsaturated bonds. DNA degradation can be brought on by ROS attack, inactivation of DNA repair mechanisms, or a combination of both. Therefore, the ROS produced can result in DNA-protein adducts, DNA and oxidative base damage, chromosomal aberrations, sister chromatid exchange, the formation of micronuclei, aneuploidy, and deletion, as well as the breakup or exchange of chromatids or chromosomes, the formation of apyrimidinic/apurinic sites, and DNA-protein cross-links (Cadet *et al*., 2013; Woźniak *et al*., 2003). Among four bases of DNA, guanine is shown to be the preferred target for ROS and after its oxidation it is converted into several stable compounds like 8-hydroxyguanosine, 8-hydroxyguanine and 8-hydroxy-2-deoxyguanosine (8-OHdG) (De Vizcaya-Ruiz et al. 2009). In particular, the 8-OHdG is a highly mutagenic miscoding lesion that leads to a G: C to T: A transversion mutation in DNA. Its accumulation has already been observed in Arsenic- affected animal tissues, but not yet in crop plants. Similar to double-strand breaks, single-strand breaks in DNA can be caused either directly or indirectly by ROS during the base excision repair process. Additionally, it is known that As can substitute for P in DNA's phosphate-groups, producing toxic organo-arsenical compounds that are difficult for plants to metabolise.

Additional potential causes of As-induced genotoxic effects in affected plant tissues include shortening of telomeres and inhibition of DNA repair processes, such as nucleotide excision repair and base excision repair.

According to reports, the disappearance of typical RAPD bands may be related to instances of DNA damage, such as point mutations or chromosomal rearrangements brought on by genotoxic substances. Similarly in some findings the frequency of RAPD band loss increased in *Oryza sativa* seedlings as As exposure levels and exposure times increased (Ahmad *et al*., 2012).

Detoxification mechanisms of arsenic in plants

1. **Reducing the rate of assimilation of arsenic**

   By reducing the rate of As absorption infiltration, one can develop resistance to As. Some plants, like *Holcus lanatus* and *Cytisus striatus*, have evolved to grow preferentially on soils with high levels of As contamination. High-affinity phosphate/AsV transport is constitutively suppressed in as hyper tolerance. In comparison to non-adapted plants, this constitutive suppression of high-affinity phosphate transporter activity results in a considerable reduction in the rate of As absorption. When the external phosphate status is high, the phosphate/arsenate transporter has a higher affinity for phosphate, which allows it to be absorbed more efficiently than arsenate. Because of this, non-resistant plants can become more resistant to arsenate by increasing their phosphorus status, which in turn suppresses the uptake of phosphate and arsenate and lowers levels of arsenate accumulation.

2. **Change and volatilization of deposited As**

Alternative techniques for decreasing overall As buildup via effluxing or volatilizing As has been observed in bacteria and yeast, and new discoveries point to the existence of these mechanisms in plants as well. Various bacteria, fungi, and individuals use S-adenosylmethionine-dependent methyltransferase to change arsenite into the gaseous trimethylarsine (TMA) (Messens and Silver 2006). From the eukaryotic algae *Cyanidioschyzon merolae*(Qin et al. 2009) identified two genes that encode As(III) methylases (CmarsM7 and CmarsM8) and showed that the purified enzymes could convert AsIII to TMA. Additionally, the expression of the CmarsM gene and its homolog arsM from the soil bacteria *Rhodopseudomonas palustris* led to the formation of TMA and enhanced tolerance to As in arsenite hypersensitive *E. coli* (Qin et al. 2006, 2009). Two submerged plants, *Ceratophyllum demersum* and *Elatine triandra,* were also found to contain an unidentified substance, most likely an arsenosugar (Zheng et al. 2003). Since organic methylated As species are often less hazardous than inorganic ones, these results offered strong evidence in favour of the hypothesis that As methylation may be a common mechanism of tolerance against inorganic As.

3. **Function of proline in plant As detoxification**

A well-known osmoprotectant called proline is heavily accumulated in plants under a variety of stress circumstances. It stabilises the cell wall and maintains the minimal amount of water needed by cells and cell membranes. By acting as a singlet oxygen quencher and OH scavenger, proline defends plants against ROS-mediated damages and maintains the structural integrity of proteins, DNA and cellular membranes. It is a crucial amino acid which participates in signalling mechanisms that control the plant growth.

A proline-proline cycle was revealed by (Signorelli et al. 2013) to play a key role in scavenging OH radicals. Proline participates in this cycle by first abstracting one H atom and capturing an OH ion, then by abstracting another H atom and capturing another OH to capitulate pyrroline-5-carboxylate. Therefore, pyrroline-5-

carboxylate is recycled back to proline under the control of pyrroline-5-carboxylate reductase, with the concurrent oxidation of NADPH. According to reports, plants that can tolerate metals over-accumulate proline, which gives them the ability to change their osmotic pressure in response to water stress. Thus, proline use effectively controls cellular osmotic potential and is essential for maintaining plant development under stress.

Proline can lessen the toxicity of As through a number of methods such as:

a) By altering the cell wall structure and safeguarding plasma membranes, it is possible to decrease As uptake.
b) By directly reducing As-induced ROS production
c) By enhancing the activities of several antioxidants, which helps to reduce ROS damage indirectly.
d) By altering the expression of genes associated to stress

Singh *et al*. 2017 reported exogenously added proline to *Solanum melongena* seedlings grown in hydroponics and subjected to varied As(V) concentrations. They noticed that the application of proline decreased the toxicity of As by lowering plant absorption. Additionally, increased antioxidant activity that decreased oxidative damage to seedlings was linked to enhanced plant growth under As stress.

4. **Function of salicylic acid in detoxification of arsenic**

A phenolic compound known as salicylic acid which is an endogenous plant growth regulator, works in physiological activities like photosynthesis, growth, nitrate metabolism, blooming and ethylene production. It not only plays a critical part in determining and signalling defense responses to pathogenic infections, but it also contributes to a number of other unfavorable situations. Salicylic acid may also have a role in the signalling of abiotic stress in plants and their reactions to toxins like As. According to (Singh *et al*., 2017) exogenous application of SA to rice plants under As stress showed great promise for lowering As toxicity by raising endogenous concentrations of both SA and NO. The increased nitrate reductase activity was thought to be the cause of the elevated NO concentration. Additionally, decreased arsenic uptake was caused by the OsLsi2 gene being down regulated in response to SA and NO supply. Salicylic acid functions in plants under stress from arsenic (As) by controlling transporters, limiting As translocation to shoots, preserving the cell's redox balance, reducing chlorosis by promoting shoot iron (Fe) concentrations, scavenging reactive oxygen species (ROS), and stabilizing the membrane through increased NO and antioxidant enzyme production, salicylic acid promotes tolerance against As.

5. Function of Nitric Oxide in Detoxification of Arsenic

A gaseous free radical called nitric oxide (NO) is used by plants as an intra and intercellular signalling agent and can control a number of cellular reactions in both normal and stressed circumstances. Exogenous NO addition may shield plants from As and other harmful metals. When applied to rice plants under As(III) stress, nitric oxide dramatically reduced root As absorption and its translocation to shoots. Additionally, through enhancing Fe uptake it lessened As-induced chlorosis. Pre-treating plants with NO as an antioxidant has been shown to totally scavenge ROS and increase tolerance to As. Nitric oxide increases resistance to As by decreasing As uptake by controlling different transporters, decreasing chlorosis by raising iron (Fe) concentrations in shoots, causing As to be sequestered in vacuoles through increased PC synthesis, and reducing ROS-mediated oxidative stress by increasing the activities of antioxidant enzymes. Nitric oxide induces As vacuolar sequestration through enhanced PC (Phosphatidylcholine) synthesis, reduces ROS-mediated oxidative stress through enhanced antioxidant enzyme activities and reduces chlorosis by increasing iron (Fe) concentrations in shoots.

CONCLUSION

Even though significant efforts have been made to understand the mechanisms of As-induced injury at different stages of plant development, our knowledge of the matter is still far from complete. In addition, As is known to inhibit and/or reduce a number of earlier developmental processes, including seed germination, root/shoot growth, and others, which take place during the early stages of seedling development. There is no doubt that exposure to As has a negative impact on crop plants, causing inhibitory reactions in general growth processes, photosynthetic efficiency, and biomass accumulation. Arsenic can cause oxidative stress by increasing the production and/or ineffectively removing ROS, which can harm lipids, proteins, and nucleic acids. It can also interfere with a number of metabolic pathways either directly by acting as a competitive inhibitor of phosphate or indirectly by obstructing the actions of a few important enzymes. As a result, Arsenic toxicity has a negative impact on crop plant quality and productivity, as well as on the health and welfare of consumers like humans and animals. Through mechanisms like compartmentalization, polyphenol biosynthesis, metal binding proteins (PCs and MTs), and/or accumulation of compatible solutes like proline, glycinebetaine, mannitol, sugar, etc., plants have evolved strategies to counteract the toxic effects of Arsenic. Exogenous applications of proline, nitric oxide (NO) (sodium nitroprusside as a source of NO), salicylic acid (SA), phosphate, and potassium can significantly reduce the toxicity of arsenic. Additionally, the evidence arising from antioxidant defence system responses makes it abundantly clear that both enzymatic and non-enzymatic antioxidant defence systems play a significant role in protecting against arsenic-induced oxidative damage in plants.

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Chapter - 11

Uncovering the Nutritional Composition of Millets, Food Products and their Health Benefits

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Millets are a species of grass with small seeds in the Poaceae family that is commonly farmed around the world. They are known to be climate-change-resilient crops due to their high quantities of proteins, minerals, vitamins, and antioxidants. Proteins are necessary amino acids that cannot be synthesised by the body and are needed as a nitrogen supply during embryo development after germination. Millets have a high fibre content and are a staple crop in many parts of the world. They are adaptable grains that can be used to manufacture a wide range of foods, including millet flour. Millets are beneficial to your heart, weight loss, antioxidant activity, and may contain anti-cancer effects. They are high in nutrients, give prolonged energy, and include antioxidants like polyphenols and flavonoids. Millets are thought to be safe and have a number of health benefits. In terms of nutrients, millets outperform most non-millet grains. They are especially high in dietary fibres, minerals, antioxidants, phytochemicals, and polyphenols, all of which have broad-spectrum health benefits.

Keywords: *Anti-oxidants, health, millets, proteins*

INTRODUCTION

Millets are a type of grass with little seeds that belongs to the Poaceae family. They are grown as cereal crops because their edible seeds are widely used in human and animal nutrition. Millets have been cultivated for thousands of years and are widely grown around the world, particularly in semi-arid and desert settings. Millets are known to be climate-change adaptable crops because they can grow efficiently in low moisture, high temperature, and nutrient-depleted soils. In addition, millets possess several salient features such as high nutritive properties, minimum vulnerability to pathogens and tolerance to drought and salinity (Lata *et al.,* 2013). Millets, as crops with a shorter life cycle, are an appropriate staple crop for an expanding population. Most important millets such as pearl millet (*Pennisetum glaucum*), Sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), proso millet (*Panicum miliaceum*), foxtail millet (*Setariaitalica*) and kodomillet (*Paspalum scrobiculatum*).

The taxonomic classification of millets is as follows

- Kingdom: Plantae (Plants)
- Division: Magnoliophyta (Flowering plants)
- Class: Liliopsida (Monocotyledons)
- Order: Poales
- Family: Poaceae (Grasses)
- Subfamily: Panicoideae
- Tribe: Paniceae

Botanical description of millets

1. **Plant Structure**: Millets are annual grasses that grow to be 1 to 2 metres tall, though certain kinds can be shorter. They have stems that are slender, erect, and cylindrical, with nodes and internodes. The stems are typically firm and may be slightly purplish or greenish in colour.

2. **Leaves**: Millet leaves are alternating, long, and slender. They feature parallel venation and are linear or lanceolate in form. At each node, the leaf sheaths securely wrap around the stem, giving the plant a distinct appearance. The colour of the leaves can range from light green to dark green according on the species and type.

3. **Inflorescence**: Millets have inflorescences that can be compact or open panicles.The panicles are made up of spikelets organised in clusters along racemes, which are branches. Each spikelet is made up of one or more florets, or individual flowers. Millet species differ in the arrangement and size of their panicles.

4. **Flowers**: Millet flowers are small and lack petals, but they are surrounded by bracts, which are modified leaves. Although certain species may have cross-pollination processes, most blooms are self-pollinating. Millets are pollinated by the wind, and their blossoms release a lot of pollen.

5. **Seeds**: Millets' seeds are the most appetising portion of the plant. They are small and round or oval in shape, with colours ranging from white to yellow to brown to red according on the species and type. The seed coat can be smooth or rough, and it protects the endosperm, which is the starchy part of the seed.

Nutritional composition

Although foxtail millet and proso millet contain both glutenous and non-glutenous grains, millets in general provide highly nutritious, non-glutenous, and non-acid forming diets (Millets are referred to as "nutritious millets" or "Nutri cereals" because of their high levels of proteins, minerals, vitamins, and antioxidants, giving them a nutritional edge over non-millet cereals (Table 1). Millets are high in micro- and macronutrients, as well as dietary fibre and non-starchy polysaccharides with a low glycemic index. Because of their high proportion of resistant and slowly digesting starches, millets stand out among other starches as the optimum diet for patients with type 2 diabetes.

Table 1: Proximate compositions of millets grains in comparison with wheat and rice

Grain	Composition (per 100 g grain)							
	Protein (g)	Fat (g)	Ash (g)	Crude fiber (g)	Carbo-hydrate (g)	Energy (kcal)	Thiamin (mg)	Riboflavin (mg)
Pearl millet	11.8	4.8	2.2	2.3	67.0	363	0.38	0.21
Sorghum	10.4	3.1	1.6	2.0	70.7	329	0.38	0.15
Finger millet	7.3	1.3	2.7	3.6	72.0	336	0.38	0.21
Foxtail millet	12.3	4.3	3.3	8.0	60.9	351	0.42	0.19
Proso millet	12.5	3.1	1.9	7.2	70.4	364	0.59	0.11

Little millet	7.7	4.7	1.5	7.6	67.0	329	0.41	0.28
Barnyard millet	6.2	2.2	4.4	9.8	65.5	300	0.30	0.09
Kodo millet	8.3	1.4	2.6	9.0	65.9	353	0.33	0.10
Rice	6.8	0.5	0.6	0.2	78.2	362	0.41	0.04
Wheat	11.8	1.5	1.5	1.2	71.2	348	0.41	0.10

(Source: M. Muthamilarasan *et al.*, 2015)

1. **Proteins:** Peptide links connect the polymers of amino acids that comprise proteins. Proteins are a dietary source of amino acids, particularly necessary amino acids that the body cannot synthesise. Millets grains contain a high concentration of storage proteins, which are utilised as a nitrogen source during the early stages of embryo development after germination. Because these proteins are safe for human consumption, the amount of seed storage proteins is critical for nutrition. Seed storage proteins are classified into four classes based on their solubility properties: albumin (water soluble), globulin (soluble in diluted salt solution), prolamin (soluble in alcohol), and glutelin (extractable in diluted alkali or acid solutions) (Osborne, 1924). Dicots have large levels of albumin and globulin in their seed storage proteins, but monocots have higher levels of prolamin and glutelin (Utsumi, 1992). Prolamin accounts for nearly half of the total protein content of millets. According to a comparison of millets with non-millet cereals, proso millet has the greatest protein levels (12.5g/100 g), followed by foxtail millet (12.3g/100g). While rice contains just about 6.8 g of protein per 100 g, wheat contains a similar amount (11.8 g/100 g) to other non-millet cereals. The critical amino acids needed to avoid protein-energy malnutrition are also deficient in wheat proteins, but they are found in practically all millet proteins.
2. **Starch:** In agricultural plant seed endosperm, starch accumulates as the principal carbon and energy source for development, and it also serves as the primary carbohydrate component in human diets. Starch is degraded to simple sugars from two fractions when consumed: amylose and amylopectin. Based on digestibility, starch is divided into three types: quickly digestible starch (RDS), slowly digested starch (SDS), and resistant starch (RS) (Englyst, 1992). Due to the large

concentration of fast digestible starch in most non-millet cereals, glucose is released immediately after digestion, leading in a spike in blood glucose levels. Millets are high in slowly digestible starch and resistant starch, which resist digestion and are catabolized by the gut microbiota, resulting in a slow and steady release of glucose into the bloodstream, lowering postprandial glycemic and insulinemic responses, lowering plasma cholesterol and triglyceride levels, improving whole-body insulin sensitivity, increasing satiety, and decreasing fat storage (Higgins, 2004). Slowly digested starch (SDS) and resistant starch (RS) are thus significant dietary components for the prevention of dyslipidemia, type 2 diabetes, obesity, and coronary heart disease.

3. **Lipids:** In the diet, lipids provide fat and vital fatty acids. Millets contain a lot of linoleic acid, arachidonic acid, and linolenic acid, which are all important fatty acids. Millets contain a lot of linoleic acid, arachidonic acid, and linolenic acid, which are all important fatty acids. The lipid fraction in seeds is dominated by the germ and aleurone layers, and lipid bodies have been discovered to line the cell periphery (Rooney, 1991). These lipid structures encapsulate a storage triacylglycerol matrix that is enclosed by a half-unit membrane made up of a single phospholipid layer and a few key proteins (Léder, 2004). The germ layer provides approximately 80% of total lipid (Lorenz and Hwang, 1986). The highest lipid concentration (4.8) is found in pearl millet, while finger millet, foxtail millet, and kodo millet appear to contain less fat. Furthermore, pearl millet contains around 75% unsaturated fatty acids, with a particularly high amountof linoleic acid (46.3%) (Taira, 1984).
4. **Micronutrients:** Millets are high in vitamins and trace elements, which are required by the body to function normally. Proso millet has the highest thiamine content (0.59 mg/100 g), whereas little millet has the highest riboflavin content (0.28 mg/100 g). Rice and wheat contain 0.04 mg and 0.1 mg of riboflavin per 100 g edible portion, respectively (Table 1), which was significantly lower than other millets, particularly pearl millet, foxtail millet, and small millet. Table 2 summarises the trace element content of millets. Phosphorus is essential for the structural integrity of cell membranes and nucleic acids. Furthermore, phosphorus and calcium are engaged in critical molecular processes such as bone mineralization, energy production, cell signalling, and the regulation of acid-base balance. Almost all millets had high phosphorus levels, with foxtail millet having the highest (422 mg/100 g). Finger

millet is known for its high calcium content (398 mg/100 g). Magnesium is a cofactor for several enzymes and an active participant in enzymatic reactions, and kodo millet was found to have higher magnesium levels (166 mg/100 g). Similarly, copper (5.8 mg/100 g) and manganese (5.49 mg/100 g) are abundant in proso millet and finger millet, respectively. Iron levels in barnyard millet are higher (9.2.0 mg/100 g), followed by pearl millet (8.0 mg/100 g), kodo millet (3.6 mg/100 g), and others. Little millet had the highest zinc content (3.5 mg/100 g), followed by pearl millet (3.1 mg/100 g).

Table -2 Trace elements composition (mg/100 g dry matter) in millets grains

Grains	P	Mg	Ca	Fe	Zn	Cu	Mn
Pearl millet	379	137	46	8.0	3.1	1.06	1.15
Finger millet	320	137	398	3.9	2.3	0.47	5.49
Foxtail millet	422	81	38	5.3	2.9	1.60	0.85
Proso millet	281	117	23	4.0	2.4	5.80	1.20
Little millet	251	133	12	13.9	3.5	1.60	1.03
Barnyard millet	340	82	21	9.2	2.6	1.30	1.33
Kodo millet	215	166	31	3.6	1.5	5.80	2.90

(Source: M. Muthamilarasan *et al.*, 2015)

Unlocking the potential of millets for a variety of food products

Millets are versatile grains that can be used to make a variety of foods. Millets can be used to make the following popular foods:

1. **Millet Flour**: Millets can be processed into flour and used in place of wheat flour in a variety of recipes. Bread, pancakes, muffins, biscuits, and other baked items can all be made with millet flour.

2. **Millet Porridge**: By simmering millets in water or milk, they can be cooked into a porridge-like consistency. Millet porridge is a nutritious and substantial breakfast alternative that can be flavoured with spices, fruits, or sweeteners of choice.

3. **Millet Rice**: Millet rice can be made from millets and served as a side dish or used as a base for pilafs, stir-fries, and salads. Millet rice is a gluten-free alternative to regular rice that has a distinct texture and flavour.

4. **Millet Cereal**: Millet-based cereals can be made by processing millets into flakes or puffs. These cereals are delicious with milk or yoghurt and can be topped with fruits, nuts, or sweeteners for a nutritious start to the day.

5. **Millet Pasta**: Gluten-free pasta can be made with millet flour. Millet pasta has a somewhat nutty flavour and can be used in place of regular wheat-based pasta in a variety of pasta dishes.

6. **Millet Snacks**: Millets can be included into snack items such as crackers, chips, and bars. Millets, which are high in fibre, protein, and other nutrients, make these snacks a healthier alternative to commercially processed snacks.

7. **Fermented Millet cuisines**: Millets can be fermented to make traditional cuisines such as idli, dosa, and kanji. Fermentation improves the nutritional profile of millets by boosting nutrient bioavailability and digestion.

8. Millets, gluten-free grains that are extensively farmed in many regions of the world, can be used to make a variety of alcoholic beverages. Millets have gained appeal as an alternative to traditional grains such as wheat, barley, and rice due to their nutritious content. Here are some examples of alcoholic drinks made from millets:

   - **Millet Beer**: A traditional African beverage prepared from fermented millet grains, millet beer. Soaked grains are germinated, dried, and milled into flour, which is then fermented with water and yeast. The beer that results is often light, crisp, and slightly sour in flavour.

   - **Millet Wine**: Millet wine is a popular traditional Asian drink, particularly in China and India. It is created by fermenting cooked millet grains with yeast or a yeast/bacterial mixture. The taste and alcohol concentration of millet wine might vary depending on the fermentation procedure and the type of millet used.

   - **Millet Whisky**: As an alternative to regular barley-based whisky, some distilleries have begun creating whisky derived from millets. Millet whisky is made in the same way as barley whisky, involving malting, mashing, fermenting, distillation, and ageing. Due to the specific features of millets, millet whisky might have a distinct flavour profile when compared to regular whisky.

- **Millet Sake**: Sake, a Japanese rice wine, can also be made with millets rather than rice. Millet sake, also known as "awamori," is produced by fermenting millet grains with koji (a fermentation starter) and yeast. The end result can have a delicate and slightly sweet flavour.
- **Millet-based Craft Beers**: In recent years, craft breweries have experimented with millets to generate unique beer flavours. Millets such as sorghum, finger millet (ragi), and foxtail millet have been utilised in brewing as substitute grains, providing gluten-free options for beer drinkers.

These are just a few examples, and millets' adaptability allows for the development of many more food products. Millets are a gluten-free and healthy alternative to wheat and other grains, making them ideal for gluten-intolerant people or those wishing to diversify their diet.

Millets: Nature's superfood for optimal health

Millets are a type of grass with small seeds that has been cultivated for thousands of years as a staple food in many parts of the world, particularly Asia and Africa. Because of their distinct nutritional profile, they provide numerous health benefits. Here are some of the most important health benefits of millets:

1. **Nutrient-dense**: Millets are high in carbohydrates, dietary fiber, proteins, vitamins (especially niacin, thiamine, and vitamin B6), and minerals (including iron, magnesium, phosphorus, and potassium). These nutrients are essential for maintaining overall health and well-being.
2. **High in dietary fiber**: Millets are high in dietary fiber, particularly insoluble fiber. Fiber aids digestion, regulates blood sugar levels, and promotes satiety, all of which can help with weight loss. It also helps to maintain a healthy gut microbiome and lowers the risk of constipation, diverticulosis, and other digestive issues.

3. **Gluten-free alternative**: Because millets are naturally gluten-free, they are a good grain option for people who have celiac disease, gluten sensitivity, or follow a gluten-free diet. They can be used in place of wheat and other gluten-containing grains in a variety of recipes.

4. **Low glycemic index**: Millets have a lower glycemic index than refined grains like white rice and wheat. Lower glycemic index foods release glucose into the bloodstream more slowly, preventing blood sugar spikes. Millets are beneficial for people who have diabetes or want to control their blood sugar levels because of this property.

5. **Heart health**: The high fiber content and nutrient profile of millets contribute to heart health. Regular consumption of millets can help lower cholesterol levels, blood pressure, and the risk of cardiovascular disease.

6. **Weight management**: Because of their complex carbohydrates and fiber content, millets are nutrient-dense and provide sustained energy. They help control hunger and promote feelings of fullness, making them useful for weight management and preventing overeating.

7. **Antioxidant activity**: Antioxidants such as polyphenols and flavonoids are found in some millet varieties, such as finger millet (ragi). These compounds help to protect the body from oxidative stress and free radical damage.

8. **Potential anti-cancer properties**: Research suggests that certain millet varieties, including finger millet and pearl millet, possess anti-cancer properties. These grains contain phytochemicals that may help inhibit the growth of cancer cells and protect against certain types of cancers, such as colon and breast cancer.

It's important to note that individual nutritional needs may vary, and it's always best to consult with a healthcare professional or a registered dietitian before making significant changes to your diet or incorporating new foods.

Safe food for consumption: Achieving optimal health

Millets are generally regarded as safe for human consumption and have been consumed for thousands of years. They are important crops in many parts of the world, including Africa and Asia. However, as with any food, there are a few precautions to take.

1. Pesticide Residues: Using pesticides in millet cultivation may result in pesticide residues on the grains. To reduce this risk, ensure that millets are sourced from reputable suppliers who follow proper agricultural practices and regulations.
2. Allergies: Some people may have allergies or sensitivities to millets. Millets contain proteins, and like other grains, they can cause allergic reactions in people who are sensitive to them. If you have known grain allergies or sensitivities, you should consult a healthcare professional before incorporating millets into your diet.
3. Contaminants: Like other grains, millets can be contaminated by mycotoxins, heavy metals, or microbial contaminants. To reduce the risk, proper storage conditions and quality control measures are required.
4. Digestive Issues: Millets contain dietary fibers, such as insoluble fibers, which can be difficult for some people to digest. In sensitive individuals, this may cause digestive discomfort or gastrointestinal issues.
5. Improper processing, storage, or handling of millets can result in spoilage, mold growth, or insect infestation. Before using millets, store them in a cool, dry place and inspect them for signs of spoilage.

Millets are generally considered safe and have several health benefits, including being gluten-free, high in dietary fiber, and having a low glycemic index. However, if you have specific health concerns or dietary restrictions, you should always consult with a healthcare professional.

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Chapter - 12

Plant Growth-Promoting Rhizobacteria (PGPR): Enhancing Sustainability in Agriculture

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Microbes have a variety of functions in food production and agriculture, including fermentation, nutrient cycling, and organic material management. Plant growth-promoting rhizobacteria (PGPR) are microbial groupings that have the ability to colonize plant roots. The use of PGPR has been proven to be an environmentally acceptable approach to increasing agricultural yields by encouraging plant development either directly or indirectly. Plant growth-promoting rhizobacteria typically either indirectly promote plant growth and development by reducing the effects of various pathogens on plant growth and development in the form of biocontrol agents or directly promote plant growth by assisting in the acquisition of resources (essential minerals and nitrogen, phosphorus) or by modulating plant hormone levels. These helpful rhizobacteria groupings may reduce the world's dependency on harmful agricultural chemicals that harm agroecosystems. Additionally, in agriculture, PGPR can be a great tool to combat the destructive consequences of abiotic stress, such as excessive salinity and drought, and thus can become a key component in sustainable agricultural systems under changing climatic scenarios.

Keywords: *PGPR, sustainability, chelates, beneficial bacteria*

INTRODUCTION

The soil that surrounds the plant's roots contains a microbe 'store house' known as the rhizosphere. Plant growth-promoting microorganisms (PGPMs) in the rhizosphere, which include rhizobacteria, actinomycetes, fungi, arbuscular mycorrhiza fungi, and endophytes, can be symbiotic, or non-symbiotic. The root system functions as a chemical factory, generating and releasing phenolic chemicals used in rhizosphere interactions. Chemical substances and other techniques attract a huge number of microbial communities or populations to the plant's roots. The chemical makeup of plants and microorganisms differs. The chemical makeup of plants is also regulated by their physiological state. The rhizoplane and the root itself comprise the rhizospheric zone. The activity of PGPMs in stimulating rhizosphere growth is regulated and altered by the release of a variety of chemical compounds. The rhizoplane and root surface interact intensely with the rhizospheric soil to colonize soil-borne microbes and PGPMs. Microorganism populations in the rhizosphere are higher than in bulk soil but lower than in laboratory conditions. Rhizosphere bacteria compete for nutrient use during mobilization to preserve their beneficial effects on sustainable agriculture and the environment.

Plant growth promoting rhizobacteria

The main problem of using plant growth-promoting rhizobacteria (PGPR) in agriculture was inconsistent and unexpected results when the plants were grown in soil. The PGPRs microbial population largely improves plant health by modifying and producing plant growth regulator concentrations such as Indole-3-acetic acid, gibberellic acid (GA), and cytokinins. In this environment, auxins are the key important hormones that influence plant health and growth. The ability to produce ACC-deaminase (ACCD) decreases ethylene production in the growing plant's roots system, symbiotic nitrogen fixation, and antagonism activity by producing antibiotics, fluorescent, chitinases, pigments, siderophores, 1-3-glucanase, cyanide, zinc, phosphates, other micro, macronutrient solubilization and mobilization, and thus increasing plant growth.

Types of PGPRs

Extracellular PGPR (ePGPR): Existing in the rhizosphere, the rhizoplane, or the gaps between root cortex cells. *Arthrobacter, Agrobacterium, Azospirillum, Azotobacter,* *Burkholderia, Bacillus, Chromobacterium,Caulobacter, Erwinia, Flavobacterium, Micrococcus, Pseudomonas,* and *Serratia* are just a few examples.

Intracellular PGPR (iPGPR): Generally, found within the specialized nodular structures of root cells. *Allorhizobium, Mesorhizobium, Rhizobium* and *Bradyrhizobium* are members of the Rhizobiaceae family, as are endophytes and Frankia species.

Role of PGPR in agriculture

PGPR activates a number of pathways (both indirect and direct) that aid in plant growth. The rhizosphere contains just a small fraction of total bacteria, i.e., 2-5% of all bacteria in the region. PGPR has a distinct mode of action that is determined by the host plant. Some PGPR, such as *Frankia, Azotobacter,* and *Rhizobium sp*., have a high affinity for nitrogen fixation and fix nitrogen at rates of 50-150, 50-20-30, and 250 kg N/ha/year, respectively. Every year, these fertilizers are mixed into the soil to promote fertility and provide an adequate supply of important nutrients in the soil solution pool for plant uptake. Some PGPR strains are used in bio-remediation to handle biotic and abiotic stress, which are significant constraints in the soil that affect agricultural yield indirectly or directly. In poor, Cadmium (Cd)-polluted areas, Inoculation barely survives by binding the soluble Cd in the soil solution to generate a physiologically inaccessible complex form. Aside from that, this bacterial strain promotes root extension, increases production by 120%, and reduces Cd content in barley by a factor of two. When the *Bacillus megaterium* strain was infected with *Zea mays* (Maize), the root hydraulic conductivity improved, which is beneficial in salt-affected water absorption. Green gram inoculated with the *Pseudomonas aeruginosa* GGRJ21 strain increased plant growth and root proliferation under drought stress conditions via a number of mechanisms such as cell osmolyte sequestration, various antioxidant enzymes, and so on.

Growth promoting mechanism of PGPR

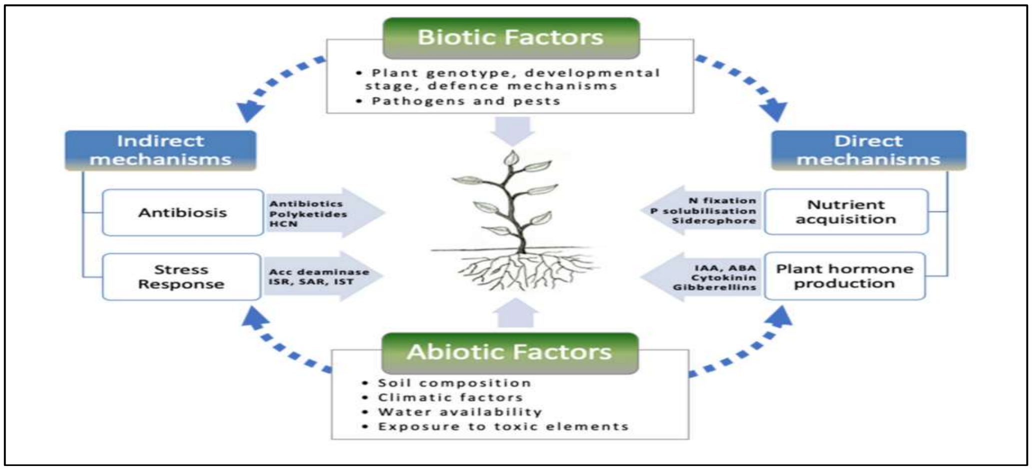

Fig. 1: Biotic and abiotic factors influencing plant–plant growth promoting rhizobacteria (PGPR) interactions in the rhizosphere

Direct Mechanisms

Biological fixation of nitrogen: Nitrogen is an essential component of life. It can be found in the structure of key biochemicals like nucleotides and proteins. Despite the fact that there is a substantial amount of N_2 in the air in the form of gas, the plant cannot use it. Biological nitrogen fixation is the primary process by which nitrogen-fixing bacteria convert N_2 into ammonia, which plants may utilize as a nitrogen source. Because plants can only access a limited amount of fixed nitrogen. Farmers must consequently supplement their agriculture with nitrogen-containing fertilizers. Pesticides are incredibly costly for farmers and have harmful environmental consequences. These deficiencies can be addressed by using PGPR and having the BNF provide the necessary N. Farmers may find this to be a viable alternative to enhancing agricultural output. In addition to the PGPR developing symbiotic nodules with legumes, non-symbiotic free-living N-fixing bacteria such as *Azotobacter, Azospirillum, Azoarcus, Bacillus polymyxa, Gluconoacetobacter, and Herbaspirillum* can create biologically fixed N (Dobereiner *et al*., 1971).

Phytostimulator: Photostimulation is a synthetic substance manufactured outside of the plant that stimulates plant growth while also enhancing crop production. Phytohormones are organic compounds produced by microorganisms that alter the quantities of IAA, cytokinin, and gibberellic acid. Low levels of phytohormones are sufficient to modify the physiological, morphological, and biochemical activities of plants.

Auxin: Auxin is a basic chemical that both indirectly and directly regulates the most vital metabolic processes in plants. Although not all rhizospheric bacteria can produce auxin, a large portion of the bacterial flora can, accounting for more than 80% of the bacterial flora in the rhizosphere. The production of IAA by certain PGPR promotes root growth and length. A modest auxin level is enough to promote main root growth, but a high IAA level lowers root length, root hair production, and lateral root growth. As a result, the proper auxin concentration increases the surface area of the root, which aids in nutrient absorption.

Gibberellic acid (GA): GA is a man-made substance that promotes seed germination, stem lengthening, floral induction, and fruit set. The primary physiological activity of GA is elongation. Tomato plant infected with the LK11 strain of gibberellin-producing *Sphingomonas sp*., which is essential for plant growth. However, only two species, *Bacillus licheniformis, and Bacillus pumilus*, have been characterized as producing gibberellins via PGPR. (Jha and Saraf, 2015).

Cytokinins: Cytokinines are an important molecule that plays an important function in root and shoot initiation, cell growth, cell division, and root hair proliferation, which significantly increases root surface area. Oriental Thuja seedlings infected with cytokinin-producing Bacillus subtilis strains were more drought-tolerant, according to Liu *et al*. (2013). Rhizobacteria that may produce cytokinins include *Rhizobium spp., Bacillus subtilis, Rhodospirillium rubrum, Paenibacillus rubrum, Pantoea agglomerans*, and *Pseudomonas fluorescens.*

Biofertilizer: Biofertilizers are commonly utilized to augment the use of synthetic chemical fertilizers in sustainable agriculture and organic farming across the world. Biofertilizer is a product that comprises dormant cells or active strains of beneficial bacteria that may be applied to soil, plant surfaces, and seed and colonizes the rhizosphere's root region, stimulating root growth by increasing primary nutrient availability. Rhizobacteria found in the rhizospheres of non-leguminous plants such as maize, rice, sugarcane, and wheat are capable of fixing nitrogen and solubilizing phosphorous (Dobereiner *et al.,* 1997). In sustainable agriculture, biofertilizer has been utilized as an alternative to inorganic fertilizers to boost plant output and development.

Nutrient Mobilization in the Rhizosphere

Phosphate solubilisation: Phosphorus (P) is the second most essential macronutrient for plants since it is involved in all main physiological and biochemical activities such as cell division, photosynthesis, respiration, root system development, and macromolecule creation. It also improves stem strength, crop maturity and yield, and quality in a wide range of fruits, vegetables, and cereal crops. P is a necessary component of nucleic acid and phospholipids. The most important function of phosphorus at the cellular level is energy storage and transfer *via* ATP. It helps crops survive harsh winter conditions and improves production quality (fruits, vegetables, grains). Phosphorus deficiency results in slowed plant growth, chlorosis, and decreased yield. Stunting, purpling, or browning of leaves are symptoms of severe cases and are especially visible during fast growth periods, i.e., in young plants. It is also required for the biological nitrogen-fixing of legumes. Although P is abundant in both organic and inorganic forms in the soil, only a small amount (0.1%) exists in the soluble (plant-available) form (HPO_4^{-2} or H_2PO_4). Organic phosphorus contributes approximately 20-80% of the phosphorus pool and remains as soil humus, primarily storing immobilized P. The majority of organic P is accessible in the form of sugar phosphates, inositol phosphate (10–50%), phospholipids (1–5%), nucleotides (0.2–2.5%), phosphonates, and phosphoproteins. Weathering of rock results in the formation of inorganic phosphate, which is sequestered in soil by adsorption on soil mineral surfaces or precipitation. P is fixed by free oxides and hydroxides of iron and aluminium in acidic soils, whereas calcium fixes P in alkaline soils. Due to a lack of available phosphorus in cultivable regions, considerable amounts of artificial phosphate fertilizer are applied to the soil to promote crop development. However, only a small percentage of the applied fertilizer is absorbed by the plant, with the balance being converted into an insoluble form that the plant cannot use. This excessive accumulation causes eutrophication, which is dangerous to both aquatic life and humans. Mineralization turns insoluble organic P to a soluble form, whereas P solubilization hydrolyzes inaccessible inorganic P. Actinomycetes, fungi, and bacteria are all important components of the natural P cycle and play a part in phosphate transformation in soil. Only 1-50% of bacteria and 0.1-0.5% of fungi in the soil's total microbial population can solubilize P.

They convert insoluble inorganic phosphate to plant-available phosphate via H+ excretion and organic acid production. Acetate, citrate, lactate, ketogluconate, gluconate, succinate, malate, oxalate, and other organic acids are generated, which can form complexes with phosphate-linked cations and convert the P into a soluble form. Keto gluconic acid and gluconic acid are the major acids involved in P-solubilization. Bacteria with this ability are known as P-solubilizing bacteria (PSB). Organic acids may chelate with cations on the soil's mineral surface, reducing phosphate adsorption sites on soil particles and increasing phosphate availability. Because of the PSB's generation and release of organic acids and protons, the pH of the rhizospheric soil decreases. PSBs from the genera *Arthrobacter, Bacillus, Delftia, Enterobacter, Gordonia, Klebsiella, Pseudomonas, Serratia,* and *Xanthomonas* solubilize P by proton excretion and organic acid production.PSB also generates chelating agents and inorganic acids including nitric, carbonic, and sulfuric acids, which contribute to the solubilization of inorganic P. These molecules, however, have been demonstrated to be less effective in releasing P in the soil when compared to organic acids. These PSB were shown to enhance soil-accessible P; for example, inoculation with *Pseudomonas* resulted in a 16% increase in soil P availability in the rhizosphere of wheat. Similarly, as compared to the control (non-inoculated) (2.33 mg/kg), *Pseudomonas* and *Acinetobacter* strains raised soil-accessible P to roughly 3.11 and 3.9 mg/kg, respectively. The process of turning organic P into a soluble form is known as P-mineralization. Several soil microbes are capable of mineralizing P. This procedure involves the release of several enzymes including as

1. Phosphatases, which are engaged in the dephosphorylation of organic molecules' phosphor-ester or phospho anhydride bonds, and
2. Phytases, which liberate the P contained in plant components as phytate. Phosphatases produced by bacteria can be acidic or alkaline. These nonspecific phosphatases have a higher affinity for organic P molecules and convert them to a soluble form.

Several bacteria from the genera *Aneurinibacillus, Bacillus, Burkholderia, Flavobacterium, Lysinibacillus, Pseudomonas,* and *Serratia* have phosphatase activity and help wheat and maize develop. *Bacillus sp., Citrobacter braakii, Escherichia coli, Pseudomonas sp., Raoultella sp., Enterobacter,* and anaerobic rumen bacteria, including *Megasphaera elsdenii, Mitsuokella spp., Prevotella sp.,* and *Selenomonas ruminantium,* have all been found to have *phytolases. Tetrathiobacter* and *Bacillus* strains that produce phytase increased shoot and root dry weight, which boosted plant development and P content in *Brassica juncea*.

Zn-mobilization: Zinc is a micronutrient that crops require in tiny amounts to complete a range of critical actions throughout their life cycle. It participates in a range of physiological and biochemical processes in plants (Kumar *et al*., 2019) and, due to its presence in DNA-binding proteins, plays a key role in DNA transcription. Zn-finger proteins have a role in several developmental processes as well as responses to environmental stimuli. Zn is the only element found in all six enzyme categories (hydrolases, isomerases, ligases, lyases, oxidoreductases, and transferases) and is necessary for enzyme activity. PGPR can enhance Zn availability to plants and thereby alleviate Zn deficiency in plants by solubilizing complicated Zn compounds. By increasing zinc availability, zinc biofertilizers containing effective zinc solubilizing bacterial strains (ZSB) promote plant growth and development. Bacillus sp. and Pseudomonas fluorescens were shown to be capable of solubilizing ZnO, ZnS, and $ZnCO_3$ in garden and paddy soil. Later, other effective zinc-solubilizing PGPR strains were identified, including *Acinetobacter, Bacillus thuringiensis, Burkholderia cenocepacia, Gluconacetobacter diazotrophicus, Pseudomonas aeruginosa, P. striata, Serratia liquefaciens,* and *S. marcescens.* The mechanism of Zn-solubilization is similar to that of P-solubilization in that solubilization occurs through acidity or chelation. ZSB produces organic acids such as acetic acid, formic acid, gluconic acid, citric acid, 2- keto gluconic acid, lactic acid, malic acid, and oxalic acids in the rhizosphere, which acidify the surrounding environment. Because these organic acids chelate with the cations linked to the zinc molecule, zinc solubility increases.

Fe-sequestering: Iron (Fe), a key micronutrient, is essential for managing the cellular processes necessary for plant growth and development. It functions as an enzyme cofactor and is involved in photosynthesis, respiration regulation, DNA synthesis and protection, and metal homeostasis. Iron is the fourth most abundant metal in the world, although its availability to plants is limited, particularly in calcareous soils. At neutral and alkaline pH, it exists in oxidized ferric (Fe^{3+}) form, which is extremely insoluble and inaccessible to plants. Plants with inadequate Fe absorption from iron-deficient soil have decreased photosynthesis, chlorosis, yield, and crop quality. Furthermore, iron deficiency affects around 30% of the world's population, resulting in anemia, a nutritional disorder in humans. Plants use a number of methods to obtain this essential trace element from their environment. One of the most important techniques is microbe-mediated iron uptake in plants. Siderophores are PGPR-produced low molecular weight, high-affinity ferric iron chelators that allow iron acquisition via specific absorption pathways. The hydroxamates, catecholates, and carboxylates are the three primary groups of siderophores depending on the functional group used to form complexes with the ferric. The ligands securely attach the siderophores to the insoluble ferric ion (Fe^{3+}) in the soil, resulting in a soluble complex. The cell membrane siderophore receptors in plant roots identify the Fe-siderophore combination and transfer it to the cell (Singh, 2020). In addition to insoluble hydroxide, siderophores may absorb iron via ferric phosphate, ferric citrate, and ferric transferring iron linked to plant flavones, pigments, glycosides, and sugar (Ghosh *et al*., 2020). Several bacteria such as *Agrobacterium tumefaciens, Azospirillum, Azotobacter, Bacillus, E. coli, Enterobacter, Mycobacterium, Neisseria gonorrhoeae, Paracoccus denitrificans, P. fluorescens, Rhizobium meliloti, Serratia,* and *Streptomyces,* etc. have been reported to synthesize siderophores (Singh, 2020). By boosting Fe availability, the use of siderophore-producing bacteria has boosted the growth and productivity of several agricultural plants, including rice, wheat, maize, and chickpea. Siderophores increased chlorophyll content and plant biomass while decreased iron concentration under water stress conditions inoculated with *Pseudomonas sp., Enterobacter spp.,* and *Bacillus sporothernodurans* (Pourbabaee *et al*., 2018). Furthermore, the PGPR strains *Alcaligenes sp., Agrobacterium sp., Bacillus sp., Staphylococcus sp.,* and *Pantoea sp.* improved the organic acids in the leaf, as well as the Fe contents in the leaf, root, and soil, and the activity of the ferric chelate-reductase (FC-R) enzyme in calcareous soil grown pear.

Indirect mechanisms

Siderophore: Iron is abundant in the soil ecosystem, largely in the oxidized ferric form, but it is unimportant to plants since plants cannot absorb iron in the ferric form. To overcome this problem, certain PGPR displays peculiar characteristics such as secreting a Siderophore, a tiny molecular weight molecule that serves as a chelator and has a high affinity for iron. The siderophore possesses specific iron binding sites on the bacterial cell membrane to create the siderophore complex, where ferric is converted to a ferrous form and released by the siderophore under iron-limited circumstances for plant absorption. Flores-Felix *et al*. (2015) revealed that the *Phyllobacterium* strain is a rhizobacterium that produces siderophores and boosts strawberry growth and quality.

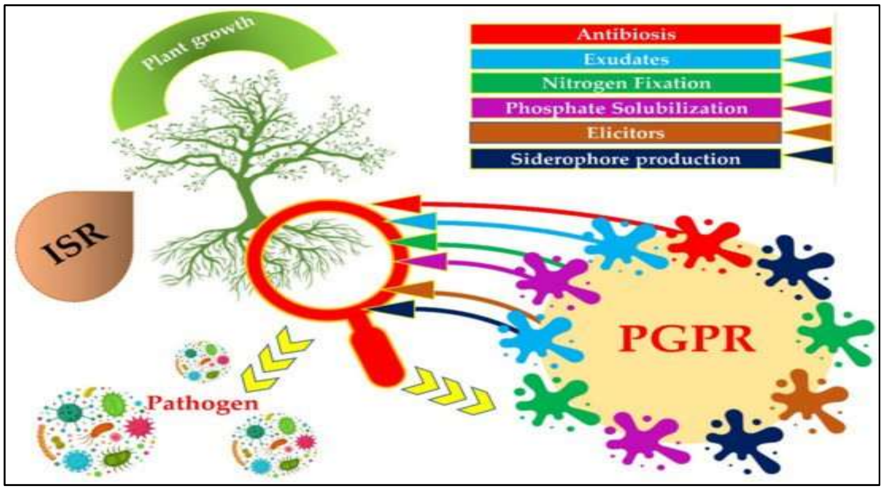

Fig. 2: Different strategies of Plant Growth Promoting Rhizobacteria (PGPRs) to enhance plant growth

Biocontrol: Biocontrol is the most visible indirect method used by PGPR to produce various antibiotics for the control of phytopathogen growth. Only 1-35% of PGPR bacterial isolates exhibited antagonistic properties that inhibited the development of harmful microorganisms in vitro. According to scientists, *Bacillus* and *Pseudomonas*are two excellent biocontrol agents of PGPR because they can live in a broad range of environments while also permitting effective biofertilizer formulation. According to Bhattacharyya and Jha (2012), most rhizobacteria generate antifungal metabolites such as HCN, pyoluteorin, tensin, 2,4-diacetyl phloroglucinol, phenazines, nicotinamide, and pyrrolnitrin. Other pathogen suppressive mechanisms demonstrated by PGPR include inducing systemic resistance (ISR), siderophore, enzymatic secretion, and others. The phenomenon of ISR occurs when the systemic response is activated without direct contact with resistance-inducing PGPR with the plant pathogen. This is caused by non-pathogenic bacteria and begins in the root and spreads to the shoot. Because it is a tiny molecular protein with a high affinity for the iron present in the rhizospheric zone, siderophore is one of the effective ways for restricting the proliferation of plant diseases. As a result, iron becomes unavailable for bacterial and pathogen growth in the rhizosphere area.Several enzymes, including chitinase, lipase, proteinase, and -1,3-glucanase, are generated by different PGPR, which hydrolyzes the pathogen's chitin, cellulose, hemicelluloses, and protein. A high density of PGPR in the vicinity of the rhizosphere is good for plant development and enhances the biological conversion of primary nutrients (N, P, and K), and also governs plant pathogen proliferation.

Induced Systemic Resistance: PGPB can cause ISR (induced systemic resistance) in plants, which is phenotypically similar to systemic acquired resistance (SAR), which happens when plants activate their defensive systems in response to pathogenic agent infection. ISR-positive plants are considered to be "primed," meaning that they respond to pathogen assaults faster and more powerfully by triggering defensive systems. ISR does not specifically target pathogens. Rather, it might be useful in managing illnesses caused by several infections (Rehman *et al*., 2020). Within the plant, ISR involves jasmonate and ethylene signaling, and these hormones increase the host plant's defensive responses against a variety of diseases. ISR does not require any direct contact between the pathogen and the resistance-inducing PGPB. Other bacterial molecules, in addition to ethylene and jasmonate, have been reported to act as signals for the induction of systemic resistance, including the O-antigenic side chain of the bacterial outer membranesalicylic acidprotein lipopolysaccharide, cyclic lipopeptide surfactants, flagellar proteins, chitin, -glucans, and pyoverdine.

Nutrients: PGPM has been investigated as a biofertilizer with the potential to increase macro and micronutrient supply, stimulate plant development, and minimize the requirement for chemical fertilization. Plants require nutrients such as nitrogen, phosphorus, and iron. As a result, siderophore generation, nitrogen fixation, and phosphate solubilizationcapability are commonly studied in PGPM selection tests.

Nitrogen is a macronutrient that is required for the synthesis of nucleic acidsand proteins. *Azospirillum, Bradyrhizobium, Achromobacter, Beijerinckia, Azotobacter, Klebsiella, Rhizobium, Frankia, Anabaena, Nostoc,* and *Clostridium*are biological nitrogen fixers that convert nitrogen gas (N_2) to ammonia (NH_3) (Bhat *et al*., 2019).

Phosphorus is a macronutrient that is required for the formation of phospholipids, adenosine triphosphate (ATP), and enhanced photosynthesis. Nonetheless, a considerable amount of the P in the soil is in insoluble forms, rendering it inaccessible to plants. PGPM raises the pH of the soil in order to dissolve inorganic phosphates. PGPM decreases pH in alkaline soils by excreting organic acids such as gluconate, citrate, lactate, and succinate, which solubilize $Ca_3(PO_4)_2$. In acid soils, PGPM raises the pH by producing protons during ammonium (NH^{+4}) assimilation, thereby solubilizing $AlPO_4$ and $FePO_4$. *Achromobacter, Bacillus, Rhizobium, Burkholderia, Pseudomonas, Micrococcus, Agrobacterium, Erwinia sp., Penicillium sp.,* and *Aspergillus sp.* can solubilize inorganic phosphorus and convert it into forms that plants can absorb, such as monobasic (H_2PO_4) or dibasic phosphate (HPO_4^{-2}).

Iron is an essential micronutrient for chlorophyll production, photosynthesis, and respiration. Siderophores are produced by *Burkholderia, Enterobacter, Grimontella, and Pseudomonas*. Siderophores are chelators with high selectivity for binding iron, which is followed by Fe^{3+} transit and deposition within bacterial cells. As a result of iron sequestration from the environment, siderophores excretion increases plant nutrition and suppresses phytopathogens.

Sulphur is a macronutrient that is contained in cysteine and methionine. These amino acids are necessary for the maintenance of enzymes and protein synthesis. Cysteine is required for cell division, while methionine is a precursor of ethylene, which is required for fruit ripening. Bacillus produces volatile chemicals like dimethyl disulfide, which gives sulphur to plants.

Phytohormones: Phytohormones are chemical molecules that regulate plant growth. There are PGPMs that can modulate phytohormones. Microbial inoculants reduce the effects of stress on plants by producing auxin, cytokinin, gibberellin, ACC deaminase, abscisic acid, jasmonates, brassinosteroids, and strigolactones. In most PGPM selection assays, auxin and ACC-deaminase are studied. This is due to the fact that auxin generated by bacteria increases auxin in the plant and promotes plant development by increasing nutrient and water absorption. Microbial auxins are also useful in the control of cell division, shoot development, vascular tissue differentiation, adventitious and lateral root elongation, and root surface area. Microorganism-produced ACC-deaminase is a helpful enzyme for lowering ethylene levels and decreasing stress in plants. Leaf chlorosis, necrosis, senescence,photosynthesis, root growth, leaf expansion, and fruit production lossare all caused by high ethylene levels. Plant growth is aided by *Pseudomonas sp.* and Bacillus, which enhance auxin and ACC-deaminase.

Exopolysaccharides: Exopolysaccharides are known to be produced by microbes, which create a protective biofilm on the root surface. This technique improves soil particle water retention and keeps soil moisture in the root zone. It protects root cells from osmotic and ionic stress by controlling osmotic balance under changing pH, saline stress, drought, and temperature extremes. Exopolysaccharides are produced by PGPM to alleviate stress. This process maintains soil ionic equilibrium by immobilizing Na^+ under salt stress. Bacillus produces exopolysaccharides to improve its antibacterial activity in the soil.

Antioxidants: PGPM inoculants improve plant growth and tolerance to abiotic stresses by increasing antioxidant levels and lowering reactive oxidative stress and oxygen species (ROS). pH, temperature, heavy metals, water availability, and UV-B radiation all have an effect on cellular homeostasis, causing an increase in reactive oxygen species such as superoxide anion, hydroxyl radical, hydrogen peroxide, and singlet oxygen. Abiotic stress produces high quantities of ROS, which are extremely destructive and cause oxidative stress in cells. ROS also causes oxidative damage to lipids, proteins, and nucleic acids, as well as enzyme inhibition and the activation of programmed cell death in chloroplasts, mitochondria, and peroxisomes. Microbial inoculants protect cells, membranes, and biomolecules against ROS by increasing the production of antioxidants such as superoxide dismutase (SOD), catalase (CAT), glutathione (GSH), ascorbate peroxidase (AsA), phenolics, tocopherols, and carotenoids. The environment reduces CAT activity while raising hydrogen peroxide (H_2O_2).

Catalase is also produced by microbes. Although determining whether microbes produce catalase is relatively simple, it is rarely done on screening tests. Microorganisms must synthesize catalase in screening tests, mostly to boost plant tolerance to abiotic stresses. This enzyme is effective in degrading H_2O_2, lowering ROS and oxidative stress, and thereby increasing plant tolerance to abiotic stress. This is a fundamental PGPM analysis that should be done on a frequent basis in selection testing.

Osmoregulants: Under stress conditions, microbial inoculants increase the synthesis of osmoregulants such as lipids, proteins, amino acids, proline, trehalose, glycine betaine, and carbohydrates. Thus, osmoregulation keeps homeostasis in check by preventing membrane plasmolysis, increasing HSP synthesis, and modulating biological enzymatic activities. Under salinity, osmoregulators control turgor pressure, maintain osmotic equilibrium across the membrane and allow for correct protein folding. By changing glucose metabolism, *Burkholderia sp*. increases plant resilience to low temperatures. *Pseudomonas fluorescens* enhances plant tolerance under water stress by increasing catalase and peroxidase activity, as well as proline accumulation. Beneficial bacteria increase plant tolerance by boosting osmolyte accumulation in the cytoplasm of plant cells. This maintains cell turgor and increases plant stress tolerance. Plants rely on the osmoregulation system to survive and improve tolerance under adverse conditions by reducing cellular damage caused by abiotic stress.

CONCLUSION

Plant growth-promoting rhizobacteria have a variety of functions aimed at promoting plant growth as well as bio-remediation potentials by detoxifying pollutants such as pesticides and heavy metals and controlling a variety of phytopathogens as bio-pesticides and have produced incredible results in a number of crop studies. Crop production is influenced by a wide range of environmental problems brought on by complex environmental settings. To combat environmental (or abiotic) stress, environmentally friendly measures must be used. Using this helpful group of bacteria is one way to produce environmentally friendly, sustainable agriculture. In a variety of methods, PGPR enhances soil and crop health. More research and understanding of the processes of PGPR-mediated phytostimulation would pave the way for the development of more competent rhizobacterial strains that might work in a variety of agroecological conditions.

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Chapter - 13

Azolla: Nature's Tiny Powerhouse Shaping Ecological System

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This chapter focuses on the multifaceted potential of Azolla, an aquatic fern, in the realms of sustainable agriculture and environmental conservation. Azolla has garnered increasing attention in recent years due to its unique characteristics and versatile applications. The chapter provides an in-depth analysis of the various aspects of Azolla, including its biology, cultivation, nitrogen-fixing capability, biomass production, nutrient composition, and environmental benefits.

Keywords: *Biofertilizers, bioremediation, fern, green manure, nitrogen-fixation*

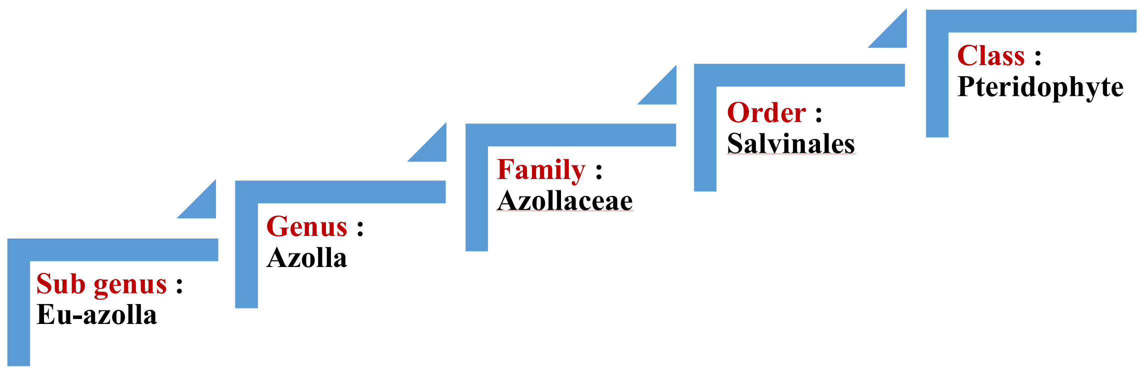
INTRODUCTION

A. Definition and characteristics of Azolla: Azolla is a genus of small, floating aquatic ferns (Sadeghi *et al.*, 2013) that belong to the family *Salviniaceae*. These unique plants are often referred to as "mosquito ferns" due to their ability to form dense mats on the surface of still or slow-moving water bodies. Azolla species are characterized by their tiny size, with individual plants typically measuring just a few millimeters in length.

Fig. 1: Azolla

B. Historical background and discovery: The discovery of Azolla dates back thousands of years. Fossil records indicate that Azolla existed as early as the Eocene epoch, which began around 56 million years ago. The ancient use of Azolla as a fertilizer has been documented in Chinese agriculture, where it was cultivated alongside rice as early as 1,000 BC.

Taxonomic classification



C. Distribution and habitats: Azolla is found in various parts of the world, particularly in tropical and temperate regions. It thrives in freshwater environments such as ponds, lakes, slow-flowing rivers, and rice fields. Azolla species are well adapted to survive in diverse climatic conditions, including both humid and arid regions.

Azolla's unique characteristics and ecological significance make it a fascinating subject of study. In the following chapters, we will explore the role of Azolla in shaping ecological systems, its impact on biodiversity, its agricultural applications, its potential for mitigating climate change, and more.

Azolla's Ecological Significance

A. Azolla's role in nitrogen fixation: One of the key ecological contributions of Azolla is its ability to fix atmospheric nitrogen. Azolla forms a symbiotic relationship with a nitrogen-fixing cyanobacterium called Anabaena azollae in its dorsal leaves, which resides within specialized structures called "hairs" on the fern's leaves and is known as potent N_2 fixer (Bhuvaneshwari *et al.*, 2015). This partnership allows Azolla to convert atmospheric nitrogen into forms that are usable by plants, enriching the surrounding ecosystem with nitrogen and enhancing soil fertility.

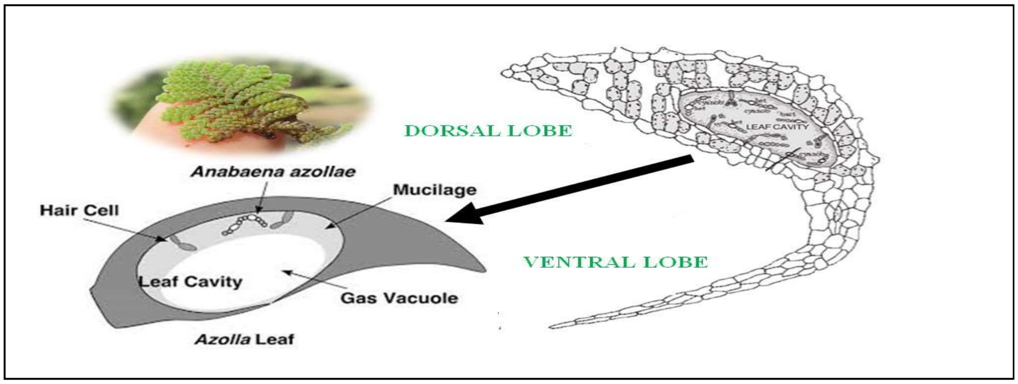


Fig. 2: Azolla-Anabaena symbiosis

B. Azolla's impact on water quality: The dense mats of Azolla floating on the water's surface provide several benefits to the aquatic environment. The fern's rapid growth and coverage help to shade the water, reducing sunlight penetration and thereby suppressing the growth of algae and other aquatic plants. This shading effect prevents excessive algal blooms and helps maintain water quality by reducing nutrient levels and oxygen depletion.

C. Azolla as a biofertilizer: Azolla's nitrogen-fixing capabilities make it a valuable biofertilizer. When Azolla biomass is incorporated into agricultural systems, it releases fixed nitrogen into the soil, providing a natural and sustainable source of nutrients for crops. Its use as a biofertilizer can reduce the dependence on synthetic fertilizers, which often have detrimental environmental impacts.

D. Azolla's contribution to carbon sequestration: Azolla plays a role in carbon sequestration, the process by which atmospheric carbon dioxide is captured and stored in plants and soils. As Azolla grows and accumulates biomass, it absorbs carbon dioxide from the atmosphere through photosynthesis. When Azolla biomass is incorporated into soils or sediment, the captured carbon becomes sequestered, helping to mitigate climate change by reducing greenhouse gas concentrations.

Azolla's ecological significance extends beyond these points, as it provides habitat and food for various organisms, promotes biodiversity, and has the potential for applications in wastewater treatment, bioenergy production, and phytoremediation. In the following chapters, we will delve deeper into these aspects and explore the multifaceted role of Azolla in shaping ecological systems.

Azolla and Biodiversity

A. Azolla as a habitat and food source for aquatic organisms: The dense mats of Azolla floating on the water's surface create a unique habitat for a wide range of organisms. Many species of insects, crustaceans, and other small invertebrates find shelter and food within the Azolla mats. These organisms, in turn, attract predators such as fish, birds, and amphibians, creating a diverse and interconnected food web.

B. Interactions with other plant and animal species: Azolla interacts with other plant and animal species in various ways. In some cases, Azolla acts as a pioneer species, colonizing disturbed habitats and providing a favorable environment for other plants to establish and grow. Azolla also forms symbiotic relationships with certain species of cyanobacteria, such as Anabaena azollae (Akhtar *et al*., 2021), which contribute to its nitrogen-fixing capabilities. These interactions play a vital role in supporting the overall biodiversity of the ecosystem.

C. Azolla's role in promoting biodiversity: The presence of Azolla in aquatic ecosystems can increase overall biodiversity. The dense mats create a complex microhabitat with different zones, providing niches for various organisms. The shelter, food, and spawning grounds provided by Azolla contribute to the survival and proliferation of many species, thereby enhancing biodiversity at both the local and ecosystem levels.

The interactions and ecological relationships that Azolla establishes with other organisms contribute to the intricate web of life in aquatic ecosystems. By providing habitat, food, and contributing to nutrient cycling, Azolla plays a significant role in promoting biodiversity and maintaining the ecological balance.

Azolla in Agriculture

A. Azolla's use as a green manure crop: Azolla has long been recognized for its potential as a green manure crop in agriculture especially in paddy field. Its ability to fix atmospheric nitrogen allows it to enrich the soil with nutrients, particularly nitrogen, which is essential for plant growth (Raja *et al*., 2012). Farmers can incorporate Azolla biomass into their fields as a natural fertilizer, reducing the need for synthetic nitrogen fertilizers and improving soil fertility. This practice can enhance crop yields and promote sustainable agriculture.

Table 1: Proximate comparison of Azolla with other protenious feed

Parameter	Azolla	Berseem	Cowpea	Mustard cake
Proximate composition				
DM	88.72	87.26	88.69	92.33
OM	75.79	87.96	90.89	91.68
CP	25.63	18.51	17.68	36.11
EE	4.12	2.24	3.29	7.76
Total Ash	20.21	12.04	9.11	8.32
NFE	33.57	39.21	47.27	40.35
Cell wall constituents				
NDF	46.89	59.15	53.14	16.65
ADF	33.81	37.18	29.66	15.17
Cellulose	16.02	30.04	24.39	10.30
Hemicellulose	13.08	21.97	23.48	1.48
ADL	10.11	6.67	4.95	3.26

(Source: Sharma *et al.*, 2015)

B. Azolla's potential as animal feed: Azolla can also be used as a nutritious feed source for livestock, particularly poultry and pigs. Azolla fed to broiler resulted in growth and body weight values similar to those resulting from the use of mustard oil cake (Ashraf *et al.*, 2015). The fern is rich in proteins, essential amino acids, vitamins, and minerals, making it a valuable supplement to animal diets. By incorporating Azolla into animal feed, farmers can reduce their reliance on conventional feed sources, such as soybean meal, and potentially lower production costs while maintaining animal health and productivity.

Fig. 1: Chicken fed with Azolla

C. Azolla cultivation techniques and benefits for farmers: Azolla cultivation is relatively simple and can be done in small-scale systems such as ponds or containers. The fern grows rapidly, doubling its biomass in just a few days under favorable conditions. This fast growth rate allows for frequent harvests and continuous availability of Azolla biomass for use as a fertilizer or animal feed (Kollah *et al.*, 2016). Additionally, Azolla cultivation can contribute to water management by acting as a natural filter, reducing nutrient runoff from agricultural fields.

Agronomic significance of Azolla

Fig. 2: Agronomic significance of Azolla

By integrating Azolla into agricultural systems, farmers can benefit from its nitrogen-fixing properties, reduce input costs, improve soil fertility, and enhance the sustainability of their operations. The use of Azolla in agriculture presents a promising avenue for promoting environmentally friendly and economically viable farming practices.

Azolla and Climate Change

A. Azolla's ability to mitigate greenhouse gas emissions: Azolla has the potential to contribute to climate change mitigation by sequestering carbon dioxide (CO_2) from the atmosphere. As Azolla grows, it photosynthesizes and absorbs CO_2, incorporating it into its biomass. When Azolla biomass is incorporated into soils or sediment, the captured carbon becomes stored, preventing its release back into the atmosphere as a greenhouse gas (Kollah *et al.*, 2016). This carbon sequestration process helps to offset CO_2 emissions and mitigate the effects of climate change.

B. Azolla's role in adapting to and mitigating climate change: Azolla is well adapted to various climatic conditions, including high temperatures and low water availability. Its ability to thrive in these challenging environments makes it a potential tool for agricultural adaptation to climate change. As a fast-growing crop with nitrogen-fixing capabilities, Azolla can help farmers maintain productivity and soil fertility under changing climatic conditions. Additionally, Azolla cultivation can contribute to water conservation and reduce the need for synthetic fertilizers, which are energy-intensive to produce.

C. Azolla as a sustainable solution for a changing climate: The sustainable cultivation of Azolla can provide multiple benefits in the context of a changing climate. By reducing the reliance on synthetic fertilizers, which contribute to greenhouse gas emissions, Azolla can help mitigate the carbon footprint of agriculture. Its nitrogen-fixing abilities also reduce the need for nitrogen-based fertilizers, which can be a source of nitrous oxide (N_2O), a potent greenhouse gas (Gunawardana, 2019). Moreover, the use of Azolla as animal feed can reduce the environmental impacts associated with conventional feed production, such as deforestation for soybean cultivation.

Azolla's potential contributions to climate change mitigation and adaptation make it a valuable resource in the context of a warming planet. By harnessing its carbon sequestration capabilities, incorporating it into agricultural systems, and utilizing it as a sustainable feed source, Azolla offers promising solutions to address the challenges posed by climate change.

Azolla's Potential Applications

A. Azolla in wastewater treatment: Azolla has shown promise in the field of wastewater treatment. Its ability to absorb and accumulate nutrients, such as nitrogen and phosphorus, makes it an effective natural filter for polluted water (Kollah *et al.*, 2016). By cultivating Azolla in constructed wetlands or wastewater treatment ponds, it can help remove excess nutrients and pollutants, improving water quality and reducing the environmental impact of wastewater discharge.

B. Azolla as a source of bioenergy: Azolla has the potential to be utilized as a source of bioenergy. Its fast growth rate and high biomass production make it an attractive feedstock for biofuel production, such as biogas or bioethanol. The fermentation of Azolla biomass can generate renewable energy while also providing a sustainable alternative to fossil fuels.

C. Azolla's potential in phytoremediation: Phytoremediation refers to the use of plants to clean up contaminated environments. Azolla has shown promise in phytoremediation due to its ability to accumulate heavy metals and other pollutants from water and soil (Akhtar *et al.*, 2021). The fern's efficient nutrient uptake and growth provide an opportunity for its use in cleaning up polluted sites, such as mining areas or industrial sites.

Exploring the various applications of Azolla, from wastewater treatment to bioenergy production and phytoremediation, highlights its versatility and potential to address environmental challenges. Continued research and development in these areas may unlock further opportunities for harnessing the power of Azolla to create sustainable solutions for a range of environmental and societal needs.

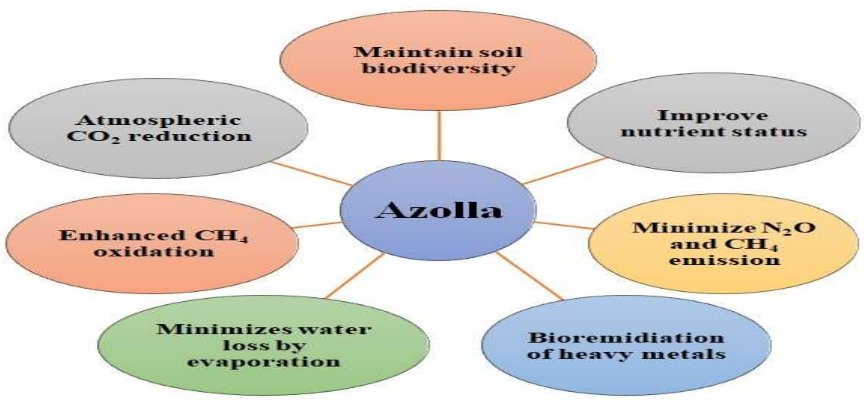


Fig. 3. Applications of Azolla in Agriculture

Conservation and Management of Azolla

A. Threats to Azolla populations: Despite its ecological significance, Azolla populations face various threats that can impact their abundance and distribution. Habitat destruction, pollution, invasive species, and climate change are among the factors that can negatively affect Azolla. Human activities such as drainage of wetlands, water pollution from agricultural runoff or industrial activities, and the introduction of non-native species can disrupt Azolla habitats and reduce their populations.

B. Conservation strategies and initiatives: Recognizing the importance of Azolla, conservation efforts are underway to protect and manage its populations. These initiatives involve the preservation and restoration of suitable habitats, including wetlands and water bodies, where Azolla can thrive. Conservation organizations and research institutions work towards raising awareness about the ecological value of Azolla and implementing conservation measures to safeguard its populations.

C. The importance of sustainable management practices: Sustainable management practices are crucial for the long-term conservation of Azolla. This includes adopting responsible cultivation techniques that maintain the health and genetic diversity of Azolla populations. Implementing measures to prevent the spread of invasive species and reducing pollution in water bodies can also contribute to the preservation of Azolla habitats. Sustainable management practices ensure that Azolla can continue to play its vital role in shaping ecological systems.

Efforts to conserve and manage Azolla populations not only protect the fern itself but also safeguard the ecosystems and biodiversity that depend on it. By implementing sustainable practices and raising awareness about the importance of Azolla, we can contribute to its long-term survival and ensure its continued contribution to ecological systems.

Future Research and Outlook

A. Current gaps in knowledge and research on Azolla Despite the extensive research conducted on Azolla, there are still several gaps in our understanding of its biology, ecology, and potential applications. Further studies are needed to explore the genetic diversity and evolutionary history of Azolla species, as well as the mechanisms underlying its nitrogen fixation capabilities. Additionally, more research is required to investigate the interactions between Azolla and other organisms, the impacts of Azolla on water ecosystems, and the potential risks and benefits associated with large-scale cultivation.

B. Promising areas for future research and exploration: Future research on Azolla could focus on optimizing its cultivation techniques and exploring its potential applications in various fields. Investigations into the best management practices for sustainable Azolla cultivation, including nutrient optimization and disease control, can contribute to its efficient and widespread use as a biofertilizer and animal feed. Additionally, exploring novel applications such as Azolla-based bioplastics, pharmaceutical compounds, and novel biotechnological advancements can unlock new possibilities for Azolla utilization.

C. The potential impact of Azolla on future ecological systems: As we continue to face challenges such as climate change, pollution, and declining soil fertility, Azolla holds promise as a nature-based solution for sustainable agriculture and environmental management. Further research can help us understand the full potential of Azolla in mitigating climate change, improving water quality, and promoting biodiversity. By incorporating Azolla into ecological restoration efforts and sustainable farming systems, we can shape future ecological systems to be more resilient, productive, and environmentally friendly.

The future outlook for Azolla research is promising, as it offers opportunities for sustainable agriculture, climate change mitigation, and ecosystem restoration. Continued research and exploration into the diverse aspects of Azolla will deepen our understanding of its capabilities and expand its practical applications. By harnessing the power of Azolla, we can pave the way for a more sustainable and resilient future.

CONCLUSION

Azolla, the tiny powerhouse of nature, plays animportant role in shaping ecological systems. Its ecological significance is evident through its ability to fix atmospheric nitrogen, improving soil fertility and promoting plant growth. The dense mats of Azolla on water bodies provide habitat, food, and spawning grounds for a wide range of organisms, contributing to biodiversity. Azolla's impact on water quality, carbon sequestration, and its potential applications in agriculture, wastewater treatment, and bioenergy production further highlight its importance. By harnessing Azolla's potential, we can address environmental challenges such as climate change, water pollution, and soil degradation. Its nitrogen-fixing capabilities reduce the dependence on synthetic fertilizers, mitigating their negative environmental impacts. Azolla's ability to sequester carbon dioxide helps mitigate greenhouse gas emissions, while its role in wastewater treatment and phytoremediation aids in improving water quality and cleaning up polluted sites. Conservation and sustainable management of Azolla are crucial for its long-term survival and continued contributions to ecological systems. Through research and awareness, we can protect Azolla populations from threats and implement responsible cultivation techniques. Future research and exploration hold immense potential for unlocking further applications and understanding the complexities of Azolla's biology, ecology, and its interactions with other organisms.

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Chapter - 14

Internet of Things (IoT): Its Application and Implications in Smart Agriculture

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Currently agriculture is facing a lot of issues with climate change, declined soil fertility, malnutrition, food security at stake. In contrary the rising population has imposed more pressure on the global food security. So, with the all these issues a new method or technology should be employed to dealt with the situation of the available technologies, Internet of Things (IoT) has shown some promising results. IoT is a technology is internetworking of physical devices. This system has ability to transfer data over a network. Mostly without requiring human intervention. The IoT devices are installed in field, connected to the internet-based monitoring and commanding platform. With the help of the devices farming can remotely access to the field conditions, monitor and also can do the required work with the help of the sensor-based devices. These IoT devices can monitor some parameters temperature, rainfall, humidity, pest, insect and disease infestations, nutrient deficiencies, irrigation etc. Through this we can automate the farm and can control the field operations remotely. If implemented in effectively way this technology has capability to change the face of the nation's economy.

Keywords: *Agriculture, smart farming, technology, internet, IoT and sensors*

INTRODUCTION

As per the UN, the global population by 2050 is going to reach 9.7 billion and 69 % of rise in the world-wide agricultural production from 2010 these situations have engrossed the attention of the farming fraternity as this creates the pressure on global biodiversity and also the food production (Parul Saxena, 2021). The estimated food production requirement is high and rapidly increasing of population with the years passing is posing a challenge (United Nations, 2009). Global agriculture due to the peak of climate change because of the famines, droughts, raise in temperatures and salinity; in coming days the agriculture stress arises and increase the hunger and water scarcity etc., (IPCC, 2007). Particularly in developing countries possible improvement economic status of the population in coming decades when compared to now, can rise the food demand. Countries must be cautious with quality of food, with diet shift from wheat to legumes and further meat and dairy products which by estimates double of food production (Zhang and Davidson, 2018; United Nations, 2009). Agriculture sector being the biggest bestower for Indian economy, with 57% population from rural localities and 18% of GDP. Despite the increase in the agri output, there has been a clear decline in the cultivators 45% in 2011 from 72% in 1951 (Reddy, 2018). The projections of The Economic Survey, 2018 by GoI made prediction that percent of agricultural workers in whole workforce will crash to 26% by 2050. Deplorably, because of the constraints like climate, temperature, soil quality, topography and non-homogenous arable land make not every region apposite for agriculture on earth surface (FAO, 2002). The current arable land is disjointed for monetary, radical attributes and hasty urbanization trend unswervingly creating the stress on accessibility of arable land (Roser *et al.,* 2013). To accomplish the needs annual production of cereals nearly three billion tons are year in contrary with present two billion, whereas 470 m tons is required with increase of 200 m. tons to the present scenario (FAO, 2019; Tripathi *et al.,* 2019).

The demand of the resources is not just confined to the consumption purpose it is correspondingly vital for the industries, some cash crops like plant-based gum, rubber and fibre crops like cotton are contributing one to the global economies. With the industrialization the food-crop-based market of bioenergy production has seen a boom. During past decade, for ethanol production coarse grains of 110 m. tons i.e., 10% of the world production of coarse grains (Elder and Hayashi, 2018; Tripathi *et al.,* 2019). Food security is at stake with intensified usage of food crops for production of bioenergy, biofuel and industrial purpose has been creating more stress on the current inadequate agricultural resources. Zhang *et al.* 2018 studies reveals that total cultivable land for production of food was 19.5 sq. miles *i.e*., 39.47% of the land area of world, however there has been a steep fall to 18.6 sq. miles in 2013 *i.e*., 37.73% of land area of world. This contradicting tendency of the supply versus demand for food is distressing with the time pass.

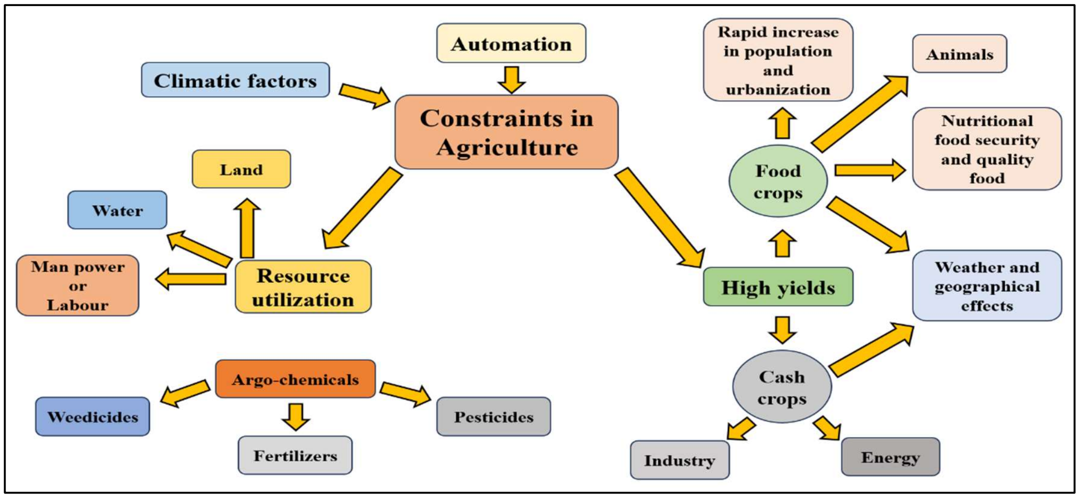

Fig. 1: Constraints of technology in the agriculture sector

Sustainable agriculture is ecologically sound way of food grain production with perseverance and subsistence (Srisruthi *et al.,* 2016). Sustainable agriculture take part a vital role in conserving the resources by thumbling the losses to biodiversity and putting check to Green House Gas (GHG) emissions (Obaisi *et al.,* 2022). The approach of sustainable agriculture encourages the agricultural practices that will reassure the resources and endure farmers in an economically viable way. It upholds the soil quality, preserves water resources, safeguard the environment in sustainable way by ameliorating the biodiversity (Brodt *et al.*, 2011).

Sustainable agriculture is farming practice in which farming is done in a conservative way without putting future cohorts at stake for present needs, whilst enlightening the farming practices. The practices like crop rotation control of nutrient deficiencies, pests and diseases in crops, water harvesting, recycling in benign ways for better environment. With the contamination caused due to the emission of wastes, GHG, excessive use of fertilizers, plant protection chemicals and degradation dead plants etc will the affect the soil microbiota, humans, animals and environ hence forth sustainable agriculture helps environment as well as living beings (Latake *et al.,* 2015). Due to which new technologies in agriculture is a much-needed aspect to deal with it in the future.

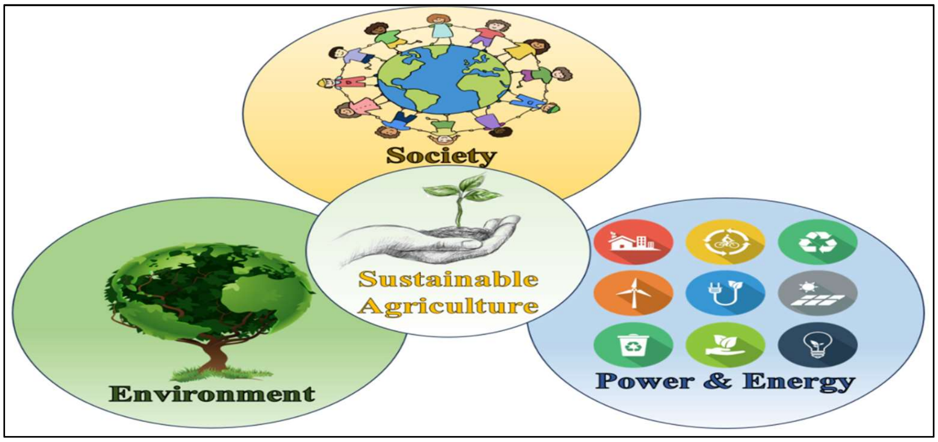

Fig. 2: Factors that affect sustainable agriculture

1. Smart farming

Modern technology-based ways are required to harvest more yield from minimal land. In conventional agricultural practices, normally a farmer makes a field visit for the inspection of crop in a routine for a comprehension of crops conditions (Navulur *et al*., 2017). The contemporary technologies proffer an accurate interpretation of the field conditions which farmers have the ability to monitor agricultural activity without physically being in the field. Utilization of the wireless sensors has higher precision that perceive the problems at the initial growth stages with effective use of tools from the land preparation to harvest of the crops (Ayaz *et al.,* 2018).

With the effective use of sensors and accurate monitoring makes the farming very smart and also cost effectual. Numerous sovereign harvesters, unmanned vehicles i.e., drones and robotic weeders comprises of specific sensors that keeps on accumulate the data over a short period of time. These sensor technologies give information on the needs of crops at the right time without any human intervention and capable of acting remotely (Lin *et al.,* 2017). Due to immense scale of agriculture creates a stress on modern technology in sustainable way with minimal impact on ecology. Such one of the smart farming technologies is IoT (Internet of Things) with employment has shown the light rays of hopes from the dark clouds for farming society which is facing drastic situations due to climate change, soil fertility losses etc.

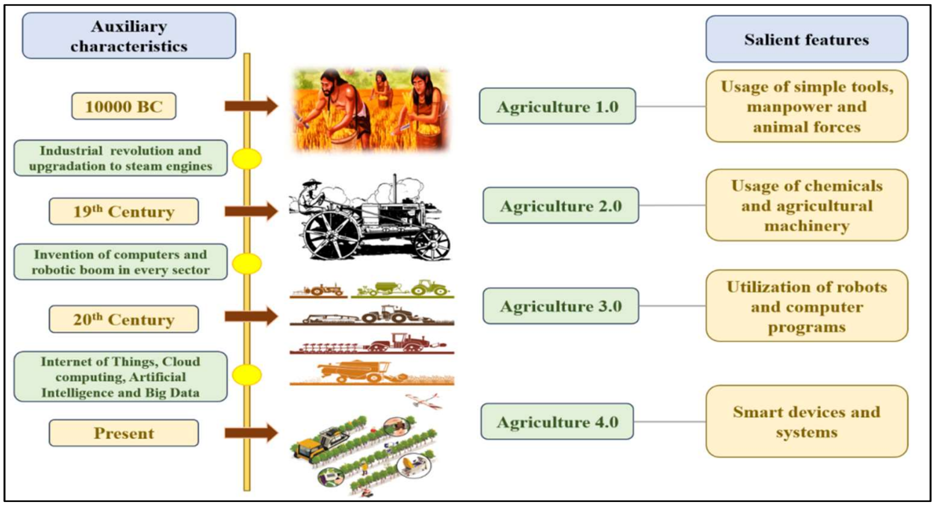

Fig. 3: Agricultural decision support system framework

2. Internet of Things (IoT) in Agriculture

Internet of Things (IoT) is a latest technology which smart farming goals can be achieved by remotely accessing the devices through internet (Patil and Kale, 2016). This IoT has impacted a wide range of sectors like health, trade, industries, communication, agriculture and energy production, to augment the productivity across the sectors (Sisinni *et al*., 2018; Shi *et al*., 2019 and Elijah *et al*., 2018). IoT is an amalgamation of numerous technologies like web technologies, wireless communications, network, embedded systems, sensors and actuators, etc. IoT technology monitors crops and livestock without any human intervention in the field and retrieves the data to mobile phones and computer devices. The sensors and equipment of IoT helps farmer in predicting the weather and also the expected production and yield of the crops remotely. In case of irrigation for the crops the IoT technology helps farmers in monitoring and regulate the flow, water harvesting, evaluating the crop water demand, time to supply and thus water saving, as mentioned above these sensors and cloud support through the internet the farmer can remotely from home can observe the situation of water supply based on the plant and soil sensor data (Yong *et al*., 2018 and Mekala *et al.,* 2017). IoT also monitor the crop with the help of sensor in ways that every plant can be individual monitored for the any kind of nutrient deficiencies or incidence of pest and diseases which is impossible task farmer physically inclusion of this technology has reached breakthrough in the agriculture (Mittal *et al*., 2007).

Over past years' investigators in IoT have introduced various methods, designs and instruments to monitor and retrieve the data of the crop at various growth stages and type of field etc. Various companies offer multiple sensors, drones, machineries, communication devices and robots to data collection and the Governmental as well as the Food-Agro organizations develops the policies and strategies to regulate the technology usage for the conservation of food and environ (Bonneau and Copigneaux, 2017 and King *et al*., 2017).

The introduction of IoT in the agriculture sector has fetched enormous benefits like optimization of farm inputs, water use efficiency and energy and environment conservation etc with its real-time monitoring capacity. Sensors and the internet connectivity with IoT in agriculture has hoarded the farmers time and also abridged excessive use of resource slike electricity, fuel and water. It monitors climatic factors like humidity, temperature, soil, automation in irrigation etc and gives the vibrant simultaneous observations. This is extremely competent than the conventional ways. With continuous development of platforms that interconnect and sense the accurate field environment information to augment the farm productivity. The technologies of IoT include the drones, energy harvesting, transmitter, microcontrollers Led lights etc. (Jagadish, 2022).

With the installation of the IoT system, farmers can effortlessly monitor a diverse environmental parameter and make the recommendation if needed in the field and implemented effectively then farmers can easily benefit and face encounters in farming with the high-quality perceptions from the sensors and more precision in the fertilizers and plant protection chemicals with the good returns in terms of yield and also monetary advantage for farmers (Jagadish, 2022).

2.1. Basis of IoT technology in Agriculture

The IoT technology should be cost effective, comprehensible and interactive user interface platform on various conventional agricultural practices, techniques, implements, past and future predictive information of crop diseases and pest incidence for sustainable agriculture. Interactive user interface platform enables farmer for the easy accessibility of the information via various devices like mobiles, tablets and computers (Chandhini, 2016).

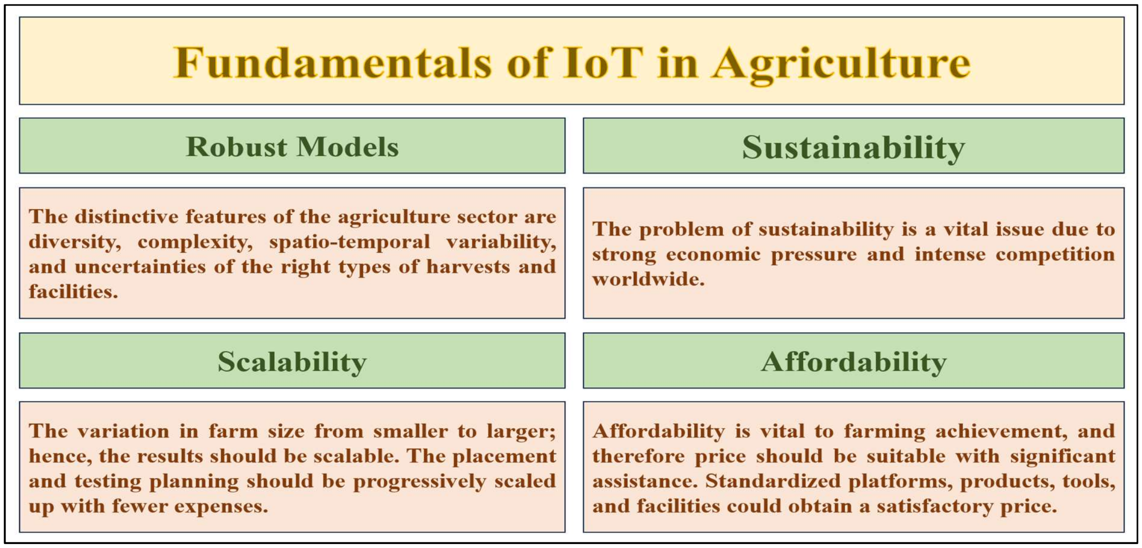

Fig. 4: Fundamentals of IoT in Agriculture

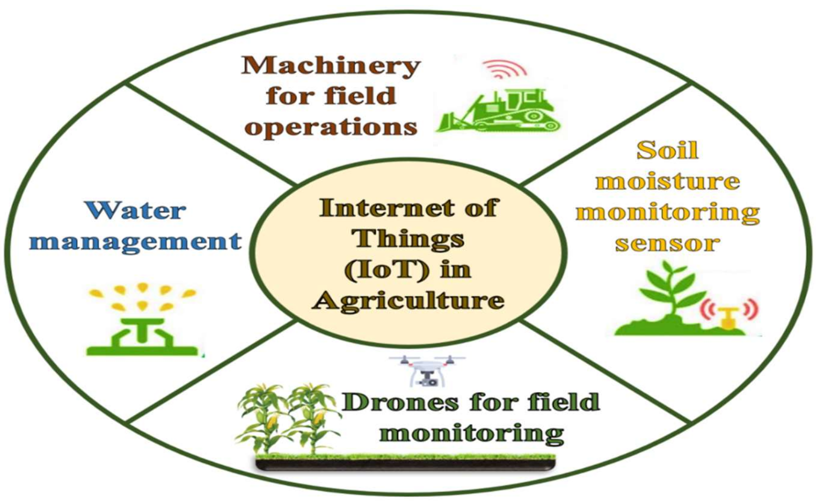

Fig. 5: Overview of IoT in agriculture

3. Applications of IoT in agriculture

Every feature of conventional farming techniques can be maintained through the implementation of the most recent sensor and Internet of Things (IoT) technologies in agriculture. Many of the challenges that conventional agriculture encounters, notably land suitability, drought monitoring, irrigation, pest management, and yield maximization, are tackled via the adoption of wireless sensors and IoT in smart farming. The following applications demonstrate how using cutting-edge technology at various phases optimizes efficiency and revolutionizes agriculture. The applications of IoT in Agriculture as follows (Arthav Meshram, 2022):

3.1. **Monitoring of climate conditions:** The weather stations that integrate several smart farming sensors are probably the most appreciated smart technology for agriculture. Located across the field, they acquire diverse environment data and transmit it to the cloud for storage.

3.2. **Crop management:** They should be installed in the field, similar to weather stations, to collect data pertaining to crop farming, like temperature and precipitation as well as leaf water potential and overall crop health. To effectively stop diseases or pests that could potentially diminish your crop's output, you can keep on monitoring your crop's growth and any erratic behaviours.

3.3. **Cattle monitoring and management:** There are IoT agricultural sensors that can be equipped for the animals on a farm to monitor their health and monitor performance, just like crop monitoring. Data on the overall health, location, and well-being of livestock can be obtained through the application for livestock tracking and monitoring. For instance, these kinds of sensors may identify ill animals, enabling farmers to pull them from the herd in order to avoid infection.

3.4. **Greenhouse automation:** They can acquire precise real-time data on greenhouse variables like lighting, temperature, quality of soil, and humidity through the incorporation of IoT sensors. Weather stations might autonomously adjust their conditions in accordance with the specified criteria along with sourcing data on the environment. Particularly, automation systems for greenhouses work on a similar theory.

3.5. **Precision farming:** Precision farming, also referred to as precision agriculture, is all about productivity and making precise data-driven decisions. It's also one of the most prevalent and effective IoT applications in agriculture. Farmers can acquire an array of metrics on every component of the field ecosystem and microclimate via IoT sensors, including lighting, temperature, quality of soil, humidity, CO_2 levels, and infestations of insects. With the application of this data, farmers are able to accurately forecast the water, fertilizer, and pesticide requirement of their crops, reduce expenses, and produce better, healthier crop harvests.

3.6. **Agricultural drones:** The use of agricultural drones in smart agriculture is undoubtedly one of the most intriguing advances in agritech. Drones, at times, referred to as unmanned aerial vehicles or UAVs, are more efficient at acquiring agricultural data than satellites and aircraft.

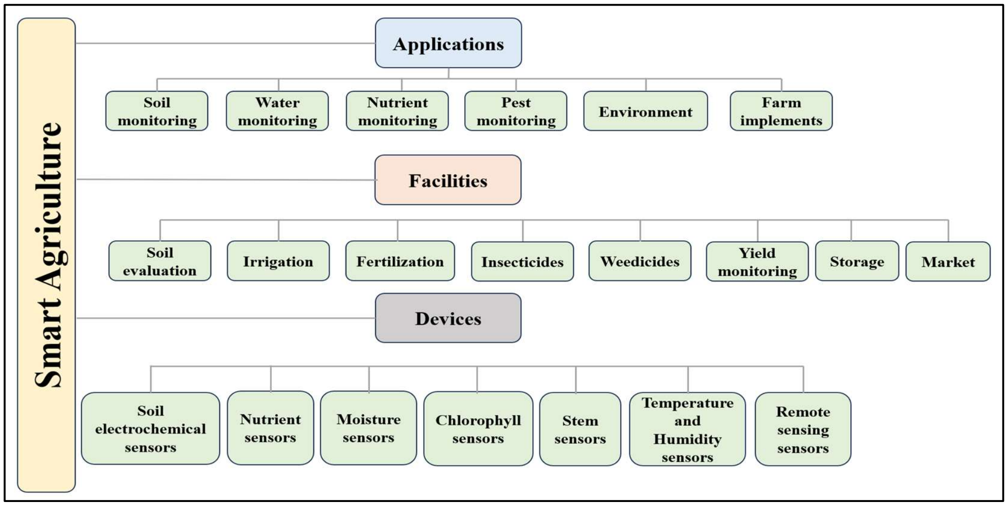

Fig. 6: Hierarchy of probable applications, facilities and devices for smart agriculture

4. Challenges in implementation smart farming technologies

Implementation of technology in farming will provide precise, efficient and alleviated time boundness with increased productivity of crops despite the all the positives there are some of the negative aspects that are challenging in the employment of these technologies (Foster, 2010). Challenges with descriptions as follows (Dhanaraju *et al.,* 2022).

4.1. Cost of the installation of the technologies:

The workforce is minimized with current technologies, which also function very quickly and precisely. Therefore, it is presumed that machines will probably replace the human workforce eventually. It is, however, impossible since poverty has arisen in numerous countries wherever labor was the primary source for the agricultural sector. When exploring beyond conventional tools, farmers have challenges with regard to affordability since installing modern technology and devices costs a substantial amount of money (Dhanaraju*et al.,* 2022).

4.2. Lack of farmers literacy:

One of the most significant barriers hindering the deployment of modern technologies in developing nations is the level of expertise among farmers. The abilities that are essential for operating the tools involve combined technical and academic expertise. The ability of a farmer to comprehend information and make decisions employing smart technology for agriculture increases with comprehension (Feder *et al.,* 1985), enabling the use of computers among farmers quicker (Alvarez *et al*., 2006). Due to a lack of expertise and awareness of cutting-edge technologies, most farmers in underdeveloped countries are unaware and unskilled (Kimiti *et al*., 2009). As a consequence, it is a contributing reason certain farmers prefer conventional agriculture over smart farming (Khan *et al*., 2007).

4.3. Management of data:

Farmers are experiencing difficulties organizing and altering the data which the sensors have gathered. The weather stations are producing data, but farmers are ignorant about how to use data or transform it in a more comprehensible way. Its sophisticated mechanisms, coupled with concerns with acknowledgment and usability, result in erroneous computation. The accessibility of information and data in productive systems must be strengthened for farmers, consultants, and other stakeholders in the production process (Dhanaraju *et al.,* 2022).

4.4. Lack of Financial Resources:

If farmers did not receive their projected production, perhaps as a consequence of unanticipated disasters like drought, flood, pests, and diseases damaging the crops, financial supporters might provide adequate loans to farmers (Dhanaraju *et al.,* 2022).

4.5. Infrastructure of telecommunications:

Arable land is better for farming than polluted land in most rural locations. Data transmission is, however, unreliable owing to inadequate telecom infrastructure, especially when utilizing mobile phones and tablets. In order to use information, smart farming is required to be linked to the internet in real time. In order to produce outcomes, multiple operation control systems, among them those for fertilizers, pesticides, and seed quantity, necessitate a high-quality internet connection. Rural producers have access to mobile internet because of the growth of mobile phones; however, signal strength and input speed are hampered (Dhanaraju *et al.,* 2022).

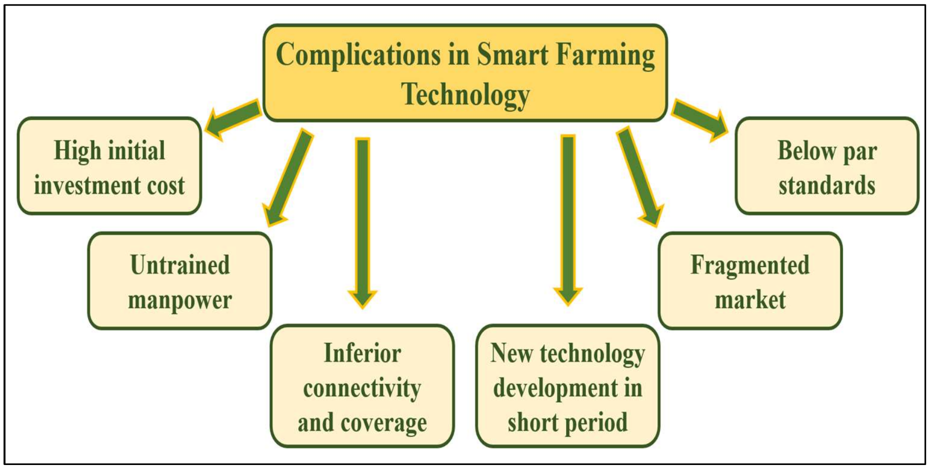

Fig-7: Complications in smart farming technology

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Chapter - 15

Role of Organic Amendments in Horticultural Crops

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The deterioration of soil health as a result of extensive use of chemical fertilizers is a matter of great concern for future. Organic amendments in horticultural crop cultivation provide a sustainable alternative to conventional cultivation practices in order to enhance soil fertility, promote plant growth while not causing any adverse effect on the environment. In this chapter we delve into the different types of organic amendments used in horticulture as well as the crucial role they play in the sustainable cultivation of horticultural crops.

Keywords: *Organic amendments, sustainable, soil health, horticultural production*

INTRODUCTION

Horticultural crops encompass a diverse range of fruits, vegetables, flowers, herbs, and ornamental plants which hold significant importance in various aspects such as food security, economic development and biodiversity conservation. Vegetables and fruits are known to provide essential nutrients, vitamins, and phytochemicals necessary for human health. Horticulture plays a vital role in stimulating economic growth by providing employment opportunities, income generation, and market value for farmers, traders, and related industries. India produces 320.48 million tons of horticulture produce from an area of 25.66 million hectare making a significant contribution of about 33% to the agriculture Gross Value Added (GVA) (Ministry of Agriculture). Additionally, horticultural crops help in habitat diversification, preserving and enhancing biodiversity.

Conventional cultivation practices are heavily reliant on synthetic inputs which pose significant challenges in terms of environmental sustainability and long-term soil health. Soil health is defined as the capacity of soil to function as a vital living system, to sustain plant and animal health and productivity, and maintain or improve water and air quality. Inappropriate use of mineral fertilizers can pose a threat to soil health as it can lead to changes in soil pH, acidification, increased pest attacks, decreased soil organic carbon and reduced plant growth and yield (Krasilnikov *et al*., 2022). Conservation of ecosystem while obtaining desired crop yield is a major challenge in agriculture. In this context, organic farming practices have gained considerable attention due to their potential to mitigate these challenges by emphasizing the use of organic amendments.

Organic amendments

Soil amendments are all inorganic and organic substances mixed into the soil to enhance soil health and in return increase plant productivity. Soil properties such as water holding capacity, nutrient availability and aeration are enhanced by the incorporation of soil amendments. Organic amendments refer to those which are derived from living sources such as plants and animals. Peat, animal manure, municipal bio-solids, green manure, compost, bone meal, bat guano, earthworm castings are some examples of organic amendments used in organic cultivation practices.

Types of organic amendments

Animal manure: Animal manures such as pig, cattle, sheep, chicken manure are used as an economic nutrient source for horticultural crops. Their use helps in increasing nutrient cycling, stimulating microbial activity and reducing costs of applying synthetic inputs. Manure amendments also improve soil structure and water-use efficiency. Cattle manure as for example contains 68.2% moisture, 1.85 N, 0.81% P, 1.69% K,1.54% Ca, 0.62% Mg and 0.29% S (Howeler, 2017).

Compost: Compost is on the most used soil amendment; it is a product of the controlled decomposition of organic matter. Compost not only supplies nutrients like N, P, K, and Mg but also enhance soil structure, water-holding capacity, an increase in organic C content and microbial activity. The application of compost promotes the formation of stable soil aggregates, increasing porosity and facilitating root development. Compost also helps in recycling green waste (Ganesh *et al.,* 2017).

Peat: Peat helps in soil moisture retention, aeration of clay rich soils and provides better structure to fine soils. It is highly acidic in nature (pH 3 - 4.5) and aids in lowering the pH of highly alkaline soils along with controlling the loss of added nutrients in soil. It is derived from decomposed *Sphagnum* moss and contains less than 1 % N, with P and K below 0.1 % (Stewart, 2023).

Biochar: Biochar is a bio-based compound obtained through pyrolysis of biomass and is a carbon-rich substance. Biochar exhibits unique properties as an organic amendment as it mitigates climate changes through carbon (C) sequestration and reduction in emission of greenhouse gases. It enhances soil fertility and plant productivity by improving soil physical, chemical, and biological properties. Biochar amendments increase soil water-holding capacity, nutrient retention and cation exchange capacity, leading to improved nutrient availability for horticultural crops. It also promotes the immobilization of heavy metals, organic pollutants and pesticides in the soil, thus restoring degraded soils (Rivelli & Libutti, 2022).

Vermicompost (Earthworm castings): Vermicomposting is the process of composting of organic wastes through earthworm activity to modify physical and chemical status of such waste by reducing its C: N ratio, exposing it to micro-organisms and further decomposition. A finely divided peat-like material with high porosity is the end product obtained. Worm castings are known to have N: P: K ratio of about 3.2:1.1:1.5. Unlike animal manure and synthetic fertilizers, the nutrients in earthworm castings are readily available for the plants to use. Some other minerals found in these castings are magnesium, calcium, manganese, copper, zinc, cobalt, borax, iron and carbon (Ganesh *et al.,* 2017).

Cover crops and Green manure: Cover crops are planted before the next crop to protect the soil from erosion. They also aid in enhanced soil structural stability, increased microbial activity and providing essential nutrients such as atmospheric N fixed by leguminous cover crops. Green manure crops such as dhaincha are grown when a field is not in use and are then plowed under and incorporated into the soil before the succeeding crop is established. They are used primarily for the addition of nutrients and organic matter to the soil (Ganesh *et al.,* 2017).

Municipal bio-solids: Bio-solids are a by-product of municipal wastewater treatment which are rich in both organic matter and essential plant nutrients. They are generally used to meet the N requirements of a crop. The total Nitrogen percentage in municipal bio-solids range from 1 to 7%. Recent studies have indicated that use of bio-solids may reduce the soil erosion and increase soil C. Application of different bio-solid soil blends have also been indicative of exceptional growth and plant quality (Brown *et al.,* 2020).

Tank silt: Tank silt is a mixture of sand and clay particles accumulated in the water tanks or lakes. Soil aeration, moisture retention, porosity and nutrient contents are some of the factors for which tank silt is used as an amendment. Studies have found tank silt to help in releasing nutrients such as total nitrogen. Organic carbon, microbial biomass carbon and residual pesticides are also found in the tank silt (Singh *et al.,* 2022).

Bone meal: Grounded animal bones and slaughterhouse waste mixture is termed as bone meal. Meat and bone meal (MBM) contains about 8% of total nitrogen, 5% phosphorus and 10% calcium. Bone meal which is finely ground tends to provide nutrients faster than the coarse bone meal (Jeng *et al.,* 2007; Ganesh *et al.,* 2017).

Bat guano: Bat guano is a lesser known and used amendment used in organic farming practices. It is the waste material of bats containing C, N, vital minerals and beneficial microbes. It is said to act as a fertilizer, soil cleanser, fungicide, nematocide and compost activator (Ganesh *et al.,* 2017).

Importance of organic soil amendments

Soil is a primary requisite for crop production and needs to be conserved for the future generations. Hence maintaining good soil health encompassing its physical, chemical and biological properties is of great importance. The rise in use of chemical fertilizers is associated with a range of adverse effects on soil health. The major concern being depletion of organic matter in the soil which leads to deteriorated fertility as well as reduced microbial activity over time. Additionally, the excessive use of chemical fertilizers can also lead to salinization, making it less permeable and reducing water-holding capacity. This continuous use of chemical fertilizers without proper soil management practices will only degrade soil health, reducing its long-term productivity and sustainability. However, with the increasing world population and limited land for cultivation, the preservation and reclamation of soil health is a necessity as the crop production needs to be increased.

Organic amendments are thus an alternative to chemical fertilizers in order to conserve the soil health and fertility in long-term. The utilization of organic amendments in horticultural crops offers numerous advantages from both agronomic and environmental perspectives.

Benefits of using organic amendments

Organic amendments offer a range of benefits that contribute to improved soil fertility, enhanced plant growth, and overall sustainable horticultural production, some of the major benefits are listed as follows:

- They provide macro and micro nutrients required for plant growth
- Reduce dependence on synthetic fertilizers, mitigating the risk of environmental pollution.
- Application of organic amendments can lead to improved soil carbon level
- Increased soil microbial activity enhances nutrient cycling, disease suppression, and overall plant health
- Improved soil aggregation
- Reduced soil bulk density and compactness
- Improved soil permeability and water holding capacity
- Prevention of water and wind erosion
- Restores and maintains the soil organic matter content, which greatly contributes to physical, chemical, and biological aspects of long-term soil fertility
- Organic amendments affect crop growth and yield either by directly supplying essential nutrients or indirectly by altering the physical properties of the soil such as aggregate stability, porosity and available water volume.

Studies on effects of organic amendments in different horticultural crops

- Bell pepper-French bean- Garden pea: In an experiment conducted by Gopinath *et al.* 2011 to study the effects of organic amendments on productivity and profitability of Bell Pepper–French Bean–Garden Pea system, six treatments were established:

composted farmyard manure (FYMC, T_1); vermicompost (VC, T_2); poultry manure (PM, T_3) along with bio fertilizers (BF) [Rhizobium/Azotobacter + phosphorus solubilizing bacteria (Pseudomonas striata)]; mix of three amendments (FYMC + PM + VC + BF, T_4); integrated nutrient management (FYMC + NPK, T_5); and unamended control (T_6). They reported that T_4 and T_1produced greater yields of both bell pepper (27.96 Mg ha–1) and french bean (3.87 Mg ha^{-1}) compared with other treatments. In garden peaT_4 gave the greatest pod yield (7.27 Mg ha–1). It was concluded that T_1 and T_4 were more suitable for enhancing the productivity of bell pepper–french bean–garden pea system, through improved soil properties, during transition to organic production.

- Tomato: The effects of organic amendments, synthetic fertilizers and compost extracts on crop health, productivity and storability of tomato was studied in an experiment in which the treatments included different fertilizers of cattle, sheep and poultry manures, green-waste and household composts and chemical fertilizers of urea and superphosphate; and five aqueous extracts from cattle manure, poultry manures, green-waste, and household composts plus water as control. The study concluded that poultry manure showed lower disease incidence as well as highest marketable yield of 16 t/ha, 6 weeks after storage compared to other treatments and thus can be a sustainable alternative to chemical fertilizers (Ghorbani *et al.,* 2008).

- Strawberry: A study was conducted on strawberry using six different organic amendments. The results of this experiment suggested that farm yard manure(FYM) and vermicompost based organic amendments enhanced vegetative growth of the plants and of strawberry fruits was also improved (Khalid *et al.,* 2013).

- Banana: An experiment with 12 different treatment combinations of Farmyard manure, Vermicompost, Neem cake, Wood ash and green manures along with and without microbial inoculants (Arbuscular mycorrhizae, Azospirllium, Phosphate solubilising bacteria and Trichoderma harzianum) comparison with inorganic sources alone on quality attributes and shelf life of banana cv. Grand Naine was conducted. It was reported that the maximum quality attributes such as TSS – 23.23%, acidity – 0.82%, ascorbic acid – 12.92 mg/ 100 g, non-reducing and total sugars - 6.06 and 14.92%) and shelf life of banana (14.03 days) was enhanced by the treatment T_{10} (Farmyard manure @ 10 kg + Neem cake @ 1.25 kg + Vermicompost @ 5 kg and Wood ash @ 1.75 kg /plant + Triple green manuring with sunhemp + Double intercropping of Cow pea + biofertilizers viz., Vesicular Arbuscular Mycorrhizae @ 25 g, Azospirillum @ 50 g, Phosphate solubilizing bacteria @ 50 g and Trichoderma harzianum @ 50 g/plant) (Vanilarasu & Balakrishnamurthy, 2014).

- Gladiolus: An investigation was undertaken to study the effect of organic and inorganic fertilizers on growth and flower quality of gladiolus cv. H.B.PITT. The treatments used were T_1 (100% RDF), T_2 (75% RDF + 25% FYM), T_3 (50% RDF +50% FYM), T_4 (25% RDF + 75% FYM), T_5 (75% RDF+ 25% vermicompost), T_6(50% RDF + 50% vermicompost), T_7(25% RDF + 75% vermicompost), T_8(75% RDF + 25% biomeal), T_9 (50% RDF +50% biomeal) and T_{10}(25% RDF +75% biomeal). This study concluded that nutrition in the form of 50 % RDF + 50 % vermicompost per hectare was the best for obtainingbetter plant growth and flower quality (Ghisewad *et al.,* 2016).

- Marigold: An investigation was conducted by Himaja *et al.,* 2021 in African marigold to study the effect of organic manures on growth, flowering, yield and quality of the flower. They concluded that the treatment T_6 (poultry manure) showed significant effect on all the quality parameters as well as maximum cost benefit ratio (4.5) was recorded in this treatment under Allahabad agro climatic conditions.

CONCLUSION

The utilization of organic amendments plays a crucial role in the sustainable cultivation of horticultural crops as it enhances soil fertility, promotes plant growth, and supports environmental sustainability. Incorporating organic amendments allows horticulturists to contribute to the production of high-quality and nutritious crops while minimizing the negative impacts on the environment. However, in order to fully harness the potential benefits of organic amendments in horticultural crop production, more research is needed. It is essential to develop a comprehensive guide that outlines the optimal application rates, timing, and combinations of various organic amendments for specific horticultural crops and soil conditions. Additionally, investigating the long-term effects of organic amendments on soil health, crop productivity, and environmental sustainability is crucial to encourage their widespread adoption.

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Chapter - 16

Post-Harvest Storage and Processing Technology of Horticultural Crops

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Post-harvest storage and processing plays an important role in maintaining the quality and nutritional value of fruits and vegetables. Post-harvest techniques are mainly used to reduce the losses after harvesting of fruits. It also extends the shelf life and increase the market value of the product. The right method of harvesting, handling and storage can reduce the losses caused by mechanical damage when harvesting, physiological deterioration and microbial spoilage of the horticultural crops. It is important to know the right method of harvesting, handling methods, storing and packaging to preserve the product value for the market. Value addition of fruits and vegetables increases marketability and shelf life. Post-harvest technology therefore reduces food wastage and ensures food security, it provides a better economy to the farmers and youth.

Keywords*: Post harvest, storage, horticultural crops, food processing*

INTRODUCTION

Post-harvest management is the processes that take place after the harvesting of crops. It is the major factor responsible in marketability of the harvest minimizing losses and makes sure food products reach the consumers in good condition by maintaining its nutritional content and enhancing product value. India is the second largest producer of fruits and vegetables in the world, after China. As per National Horticulture Board, in the year 2021 to 2022, production of fruits and vegetables in India is 107.24 M metric tonnes and 204.84 M metric tonnes respectively. Every year there are reports of loss of 5 to 15% of fruits and vegetables.

Post-harvest management can be referred to the various methods to reduce harvest loss and maintenance of quality which starts from the field itself viz. proper harvesting methods, preservation and processing, storage and packaging techniques, transportation until it reaches the consumers. Reducing losses after harvest also depends on the use of cultivars which have a longer shelf life and proper agronomic practices (Kader, 2013). Consumers not only demands for quality like appearance and flavour but also in nutritional content and less usage of chemicals and synthetic products during processing (Wu, 2010). It ensures utilization of the certain commodity, whether it may be consumed raw, cooked or dried.

Proper harvesting techniques which include harvesting at proper maturity, selective and careful picking, proper handling is important to ensure the crop is free from damage and deterioration, free from pests and pathogens. A small contamination with pests and/or pathogens to a new place of trade will cause quarantining and certain restrictions (Neven, 2010).

Another major factor in post-harvest management is regulation of temperature and humidity. The commodities which are to be stored should be kept in an environment which makes sure it can be stored for a longer period, slowing down its physiological processes. Commodities are stored according to its type and rate of deterioration. Cold storage facilities, dark room with natural or forced ventilation are some common types of storage facilities for keeping fruits and vegetables.

Value addition of horticultural commodities enhances the marketability as well as elongates the shelf life reducing risks of physical damage and contamination, making it more convenient to consumers. Value addition meant the processing as well as packaging methods. Processing methods such as drying, canning, etc., are done according to the type of commodity. Packaging provides protection from damage and moisture losses reduce respiration rate and attracts consumers. After value addition comes transportation, it is responsible to make sure the commodity reaches the consumers on time, retaining its quality and without any damage. Goods are transported to the markets and stores in containers according to its type and perishability. Fruits and vegetables are transported in CFBs (corrugated fibre boxes), wooden crates, plastic crates, jute bags, gunny sacks, plastic boxes, etc., to preserve its shape and form and its freshness.

Post-harvest management can help in improving the economy of the farmer by reducing the risk of crop wastage and by learning the skills of value addition of the products which can be sold in a relatively higher price compared to the commodity he is growing, for example, dried mushrooms, dried fruits costs almost 10 times more than fresh mushrooms and fresh fruits; similarly processed products can be made from vegetables, like ginger candy, dried vegetables for instant cooking, petha, a local sweet made from ash gourd, potato chips and many more. Most importantly we need to understand the basic steps of post-harvest management which will be discussed below.

Harvesting, Harvesting maturity and Maturity indices

Every crop should be harvested in its ideal maturity, according to the type of market and how it would be consumed. Selective picking of fruits and vegetables are recommended while harvesting, healthy and attractive ones are picked for sale in the market while unattractive ones are taken to make value added/processed products. For example, tomatoes are harvested in its breaker or turning stage for distant markets but for local markets it can be harvested in pink or light red stage and for preparation of sauces or puree it is harvested in mature red stage. Picked apples are sold in the market while fallen apples were used to produce cider and drinks.

Harvesting should be done in a proper manner with the use of proper implements to minimize damage and contamination. Harvested commodities should be cleaned to remove dirt and debris and reduce the possibility of pests and pathogens. A small damage in the fruit skin caused during harvesting or by a pest may cause excessive production of ethylene causing faster ripening and deterioration. Farmers have a good knowledge of harvesting fruits and vegetables but need the proper and accurate timing when to harvest according to the market type and the type of commodity it would be sold as, *i.e.*, fresh or processed.

Maturity means when the edible part of our crop is fully developed, and it is ready to be harvested. Some common determination methods of maturity indices include:

1. Colour: It is a common factor of determining maturity. Fruits tend to change colour from green to yellow or different shades of yellow/red from light to deep colour. Some common crops which are determined by colour are apple, mango, plum, tomatoes, chilli, etc.
2. Shape and Size: The shape and size of a fruit determines its maturity in several crops, for example the head of a cabbage grows as it is ready to be harvested, the pod of beans grow longer.
3. Firmness: As crops mature, they become firmer and have a rigid shape.
4. Calculated days: A simple and easy way to harvest crop properly is by recording the days of transplanting, days of planting, days of anthesis or flowering and days of first fruit formation.
5. TSS: It can be determined by taking a small sample and using a refractometer.

Table 1: Some fruits and vegetables and their maturity indices

Crop	Maturity indices
Mango, apple, strawberry, papaya	Colour
Chilli, Tomato, Brinjal	Colour
Watermelon, Gourds, Cabbage	Desirable size
Cauliflower and Broccoli	Firm and compact head
Beans	Shape of pods and colour
Okra	Size and snapping
Onion and potato	Drying of foliar portion, neck fall
Radish and Carrot	Days after planting

Storage methods, regulation of temperature and humidity: An important factor

Fruits and vegetables, to retain their nutritional content and marketability must be stored provided with proper storage techniques. The main aim of storage is to extend the shelf life of our commodities by regulating the temperature and the humidity which directly affects the respiration rate and/or ethylene production that causes quick ripening and faster deterioration and reduce losses caused due to pest and pathogens infestation. The shelf life can be extended by following various techniques in storage which will be discussed as follows,

1. **Cooling and refrigeration**: Temperature is one of the most important factors affecting shelf life of horticultural crops. Physiological processes like respiration and enzymatic activity are mainly influenced by temperature, which directly affects the quality of the products. Fruits and vegetables can be stored for a longer extended period when they are stored in a cool environment. To make sure the quality of the commodity is maintained, it is important to cool starting right after harvesting before storage and transportation, this is called as precooling.

Precooling is an important stage as it reduces the respiration rate and enzyme activity as well as production of ethylene. There are seven principal methods of cooling fresh produce:

a. **Room cooling**: In this method cold air is supplied to the storage room either from active or passive cooling methods. In this method the products are kept in plastic or wooden boxes/crates and are meant for produce which generally does not deteriorate quickly as it is a slow method. It is suitable for tuber and root crops like potato, onion, yams and tapioca and fruits like banana.
b. **Forced air cooling**: It is a modified system of room cooling where the air is supplied with higher pressure. It also depends on the pattern of placement of the commodity to ensure a better pathway for airflow.
c. **Hydrocooling**: Here the products are cooled by immersing in cold water before packing and transportation. Hydrocooling cools the produce faster than air cooling methods and reduces moisture losses. It is used to cool products like cherries, melons, and vegetables like peas and beans, leafy vegetables where respiration is faster and dries up quick. It is recommended for roots and tuber types which will cause unwanted sprouting.
d. **Ice cooling**: Ice is being provided by crushing the ice and mixed with water filling up the container holding our products. It is used for vegetables like peas and beans but not recommended for leafy greens and capsicum which are susceptible to cold damage. Berries are suitable for ice cooling.
e. **Vacuum cooling**: It works on the principle of evaporation of moisture. Uniform cooling of products can be achieved through vacuum cooling.

f. **Cryogenic cooling**: It applies the use of liquid nitrogen at -196 ^{o} C. It is used for cooling of berry type of fruits where it is passed in a tunnel where the liquid nitrogen is kept, we have to take care that the produce is not frozen and spoiled. It is a costly method.

g. **Evaporative cooling**: In this method air is let to flow through a moist padding or a fine shower of water then to the products kept. It is suitable for crops like tomatoes, chilli, capsicum, brinjal which requires an ambient moderately cool temperature but would deteriorate quickly in room cooling methods.

Refrigeration of products needs to be regulated as per the products being stored. Certain fruits and vegetables have a requirement for its storage temperature. Chilling and frost injury are a major problem in storing of crops like capsicum, leafy greens, banana, etc.

Table 2: Some horticultural crops and the methods used in cooling

Crop	Types of cooling
Apples	R, F, H
Beans	R, F, H
Broccoli	I, F, H
Cabbage	R, F
Cauliflower	H, V
Cucumbers	F, H
Brinjal	R, F
Grapes	F
Garlic	N
Onion	N
Peaches	F, H
Peas	F, H, I
Potatoes	R, F
Pumpkin	N
Strawberries	R, F
Tomatoes	R, F
Watermelon	N

(Source: eagri.org)

Where R is room cooling, F is forced air cooling, N is none, V is vacuum, I is ice cooling and H is hydrocooling.

2. **Cleaning**: Fruits and vegetables are cleaned by washing in water treated with chlorine, fungicides, etc., or by wiping with a damp cloth to remove dust and debris, insects, etc. Trimming is another important method to ensure removal of vegetative parts like excessive leaves which may increase respiration rate or may be a host for insects.

3. **Sorting and grading**: Commodities which are either damaged or unattractive for market are removed, this step is called sorting. The crops are then being separated by grading based on either colour or shape or size. Potatoes with injuries and green patches are sorted out and then further graded according to their size.

4. **Waxing and coating**: Applying a thin layer of a substance, mainly esters and fatty acids on the surface of fruits and vegetables to reduce spoiling caused by physiological processes like respiration and sprouting and damage caused by microbes. It enhances its appearance and retains its moisture thus maintaining its structure from wilting or shrinking. It can be an easy way to incorporate anti-fungal components and growth regulators. Common types of coatings used are paraffin wax, carnauba wax and bee wax.

5. **Packaging**: Packaging helps in maintaining the quality as it reduces the physical damages during transit, moisture losses, contamination with dirt and debris and pest and pathogen attacks. Packaging comes in many types for various type of commodities like wooden boxes for fresh fruits and for vegetables which are intended to be sold in local market, sacks and gunny bags for potatoes and onion, CFB for fruits, plastic wraps for cabbages, sliced watermelon, etc. Canning and bottling are done for processed products which are pickled, fermented or made into juice.

Types of storage: Fruits and vegetables are stored in rooms/storage facilities during precooling stage and/or after transportation to its target market. Types of storage ranges from low-cost structures to hi-tech structures.

a. **Ambient storage**: It is storing of the products in the normal room temperature. It can be used for crops like potatoes and other tubers. Temperature generally ranges from 15^{o} to around 30^{o} C.
b. **Air cooled storage**: Storage facilities which are cooled using either air cooling or forced air cooling are considered under this category.
c. **Zero energy storage**: It is a type of low-cost storage system where energy consumption is minimized. It utilizes the method of evaporative cooling, developed in India as Pusa Zero Energy Cool Chambers. It can reduce 10^{o} to 15^{o} C from the outer temperature.

d. Controlled atmospheric storage: This technique is used for storing fruits and vegetables in an environment with regulated temperature and humidity beyond normal levels (Neven, 2010). To avoid spoilage caused by respiration, levels of oxygen can be reduced and increase the levels of carbon dioxide. Using the principle of CAS, modified atmospheric packaging is a type of packaging where products are packed in packets filled with CO_2 or with complete removal of O_2.
e. Hypobaric storage: In this method the products are stored in a reduced atmosphere. Reduced atmospheric pressure can help in reducing the levels of oxygen decreasing rate of respiration, and supressing ethylene production.

Processing and value addition of fruits and vegetables

Value addition is the processing of fruits and vegetables into a multiple type of products including jams and marmalades, jellies, juices, dried or dehydrated fruits, purees and sauces, pickles, minimally processed and ready to eat vegetables and many more. It gives the consumers a variety of products according to their choice and convenience. This also reduces the losses caused due to damage, overmature or products which are not sold out in time, allowing the farmers/producers a second chance of selling their products.

The shelf life, vitamin and mineral content of perishable fruits and vegetables can be maintained through canning, freezing and drying. It also ensures easy storage and transportability after processed and packed in bottles or cans.

According to consumers' choice of eating and convenience, value added products offer a wide range of scope. Minimally processed products, ready to eat meals, processed foods help to save time in preparation giving a good choice for students and people with a busy schedule.

Value addition can give a livelihood to several people, encouraging small industries and self-help groups giving them opportunities expanding their market in industries of supplying raw materials as well as in processingunits (Devi, 2023). Value added products have a higher profit as compared to raw andfresh products.

Types of value-added products:

1. Juices and beverages: Many types of fruits are processed to prepare juices, shakes, alcoholic drinks and carbonated drinks. Vegetable smoothies are also in a current trend being a good source of vitamin and dietary fibre.
2. Jams, jellies and marmalades: Fruits are being processed into jams, jellies and marmalades, giving full and proper utilization to its pulp as well as peels, reducing wastes which would otherwise be disposed of.
3. Candies and confectionaries: Ginger candy and petha is a common example in candied vegetables. Fruits like watermelon, mango and strawberries are also used in making of ice lollies. Bottle gourd is used for making of tutti-fruity and mango is used to prepare aampapad.
4. Sauces and purees: Tomato sauce and puree is a very common value-added product. Purees can be made from fruits like apple, pear, melon, etc.
5. Pickles and fermented products: Pickling is an easy method of enhancing taste and shelf life of many vegetables and fruits, it is either done in brine or oil. Sauerkraut and kimchi are fermented products which are made from vegetables. Sauerkraut is made from cabbage and kimchi is made from napa cabbage. They are rich in probiotics and vitamin C.
6. Dry and dehydrated products: A numbers of fruits are preserved by drying, gooseberries, oranges, pineapples. Raisins are the most common dried fruit product in the market. Vegetables are dehydrated to be consumed as ready to eat items like soup medium and in cup noodles. Potato is powdered to be a thickening mediumin soups.

CONCLUSION

Post-harvest management is important for reducing food wastage, ensuring food security and better economy, thereby can be considered as a practice of sustainable agriculture. It is necessary to maintain and preserve the quality from spoilage caused by mechanical damages, pests, environmental and physiological effects.

Proper methods of preservation and storage increases marketability, helps to extend the shelf life, ease in transportation as well as availability of food products in off season. Value addition of horticultural crops reduces crop wastage and provides a source of income for farmers and entrepreneurs. It improves the economy and provides a livelihood to people in rural areas. Following conventional methods of post-harvest handling without skipping any stage required for the crop, namely, sorting and grading, cooling, packaging and storage can maintain the quality of the commodity and increase its sales in the market without much loss.

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Chapter - 17

Genetically Modified Crops: Its Impact and Limitation in Agricultural Food Products

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Since 1973 by development of many biotechnological tools like DNA recombination technology, advancements in modern agriculture science and technology have brought about the current Genetically Modified (GM) crop revolution. GM crops becomes a promising tools to mitigate current and future problems in modern agriculture. Genetically modified crop has become an argumentative subject as its benefits for both food producers and consumers are companied by potential biomedical risks and environmental side effects. The production of GM crops is increased day by day for their numerous benefits. The genetic modification in crops express many qualitative traits, such as, increasing yield, higher vitamin and micronutrient content, resistance to insect, diseases and pests, longer shelf-life for and so on. The principal Genetically Modified crops grown commercially in field are herbicide and insecticide resistant soybeans, maize, cotton and canola. Like all new technologies, they pose some risks, both known and unknown. Independent scientists, environmentalists, farmers and consumers who warn that genetically modified crop may introduce new risks to food security, the environment and human health such as loss of biodiversity, the emergence of superweeds, the increase of antibiotic resistance, food allergies and other unintended

effects. This book chapter gives major viewpoints which are currently debated on benefits and risks of GM crops for human health, ecosystems and biodiversity. In this context, some regulations and precautions exist, which should be strictly applied for the safety of GM crops consumption.

Keywords: *Genetic Modification Crops, DNA recombination, Transgene, Regulation, Food security, Limitation*

INTRODUCTION

Genetic modification (GM) is the alteration of a living organism's genetic code to give it the ability to carry out specific functions (Raman, 2017). The World Health Organisation (WHO) has the following definition of a genetically modified organism: "Organisms" (*i.e.*, plants, animals, or microbes) in which the genetic material (DNA) has been transformed in a way that does not occur normally via mating and/or natural recombination" (WHO, 2016). Genes from one organism can be transferred into another, typically unrelated, organism using DNA recombinant technology. In 1946, when scientists first learned that genetic material could be transferred between various species, breakthroughs took place that would eventually lead to modern genetic manipulation.

Following this, Watson and Crick discovered the DNA double helix structure and developed the fundamental theory that DNA gets transformed into RNA, which is then translated into proteins. As a result, Boyer and Cohen's ground breaking studies from 1973 involved "cutting and pasting" DNA between several species using restriction endonucleases and DNA ligase - "molecular scissors and glue" - and were a major step towards creating the first genetically modified organism. The first genetically modified (GM) plants in agriculture, such as the antibiotic-resistant tobacco and petunia, were successfully developed in 1983 by three different research teams. China was the first nation to commercialise genetically modified tobacco for viral resistance in 1990.

In 1994, the Flavr Savr tomato (Calgene, USA) was the first ever Food and Drug Administration (FDA) approved GM plant for human consumption. This GMO tomato was genetically modified by antisense technology to interfere with polygalacturonase enzyme production, consequently causing delayed ripening and resistance to rot. Since then, several transgenic crops has approved for large scale human production in 1995 and

1996. Initial FDA - approved plants such as maize, cotton, potatoes, canola and soybeans (Bawa and Anilakumar, 2013). Currently, the GM crop pipeline has expanded to cover many horticultural and agricultural crops such as fruits, vegetables and cereals such as lettuce, strawberries, eggplant, sugarcane, rice, wheat, carrots etc. with planned uses to increase vaccine bioproduction, nutrients in animal feed as well as confer salinity and drought resistant traits for plant growth in unfavourable climates and environment (Raman, 2017). Throughout history, people's main concern was producing enough food. Civilization advanced as we developed agriculture. For 10,000 years scientists bred wild plants to produce more food with less work. Agriculture got a boost in the 1950s with new chemicals that control insects, weeds, and disease. At the same time, plant breeders developed more productive varieties of wheat, corn, and rice. Together, new farm chemicals and improved crops led to much higher yields (amounts produced). This increase in production was known as the "Green Revolution". Worse, many of the world's poor have never benefited from the Green Revolution because it did not solve the underlying problem: poverty. Many farmers can't afford the chemicals and improved seeds. Many scientists think a new "Gene Revolution" can help both hungry humanity and the sensitive environment. The Gene Revolution uses biotechnology to create new genetically modified or "GM" crops. These crops can potentially produce more food with fewer chemicals and higher nutritional value than traditional crops. Scientists think they can improve even more crops than the Green Revolution did not only grains, but also the legumes, vegetables, roots, and fruits that people need for a balanced, nutritious diet (Jones, 2021). Since their commercialisation, the global food crop yield (1996–2013) has increased by 370 million tonnes over a relatively small acreage area (Zhang *et al.*, 2016). Furthermore, GM crops have been recorded to reduce environmental and ecological impacts, leading to increases in species diversity. Genetically modified (GM) crops had considerable potential to improve food security and the effectiveness of the agricultural sector in developing countries. Moreover, they reduce costs for food production, reduce need for pesticides, and enhance nutrient composition and food quality and resistance to pests and disease (Phillips, 2008). Nevertheless, advancements in GM crops have raised significant questions of their safety and efficacy. The GM seed industry has been plagued with problems related to human health and insect resistance which have seriously undermined their beneficial effects. Moreover, poor science communication by seed companies, a significant lack of safety studies and current mistrust regarding GMOs have only compounded problems. These have led many countries, particularly the European Union and Middle East to implement partial or full restrictions on GM crops (Raman, 2017). So, this study is done to know the promise, benefits and problems, besides precaution and regulation of GM crops.

Genetically Modified Crops

Genetic modification is a biological process that modifies the genetic code of all types of living organisms. DNA is inserted into an organism's genome by means of the GM technology. New DNA is introduced into plant cells to create a GM plant. The cells are typically cultured in tissue culture after which they transform into plants. The modified DNA will be passed along to the seeds that these plants generate.

History and Development of Genetically Modified Crops

Genetic material can be transferred throughout various species, which led researchers to discover DNA modification technology in 1946 (McCarty and Avery). The field of molecular biology as we know it today was founded on a number of fundamental studies. The double helix structure of DNA was discovered by Watson and Crick in 1954, and the "central dogma" that DNA is translated into messenger RNA and then into proteins was established. By 1963, the genetic code had been cracked by Nobel Laureate Marshall Nirenberg (Nirenberg *et al*., 1963) and others. The invention of DNA recombination technology by Cohen *et al*. in 1973 demonstrated the interspecies transferability of genetically modified DNA molecules. Three separate research teams created the first genetically altered plants in 1983, including petunias and tobacco that were resistant to antibiotics. The Food and Drug Administration (FDA) approved the first tomato species with the trait of delayed ripening in 1994, bringing it to market in the US. Since then, the FDA has approved a number of transgenic crops (Bawa and Anilakumar, 2013).

Creation of GM plants Researchers must insert the gene(s) encoding for certain features into a plant cell in order to produce GM crops, and they must then regenerate a plant through tissue culture. The plan to maximise the property of the result is typically included into how and where the transplanted gene is expressed (Zhang et al., 2016). DNA must be transferred into a plant cell as the initial step in creating a GM plant. The necessary DNA segment is applied to the surface of tiny metal particles, which are then blasted into the plant cells as one way to transfer DNA. Utilising a virus or bacterium is another approach. Numerous bacteria and viruses routinely insert their DNA into host cells as a necessary step in their life cycle. The most popular bacteria for GM plants is known as Agrobacterium tumefaciens. The desired gene is introduced into the bacterium, and the bacterial cells later introduce the new DNA to the plant cells' genome. The successfully incorporated plant cells are then cultivated to produce a new plant. Due to the fact that individual plant cells have an impressive capacity to generate entire plants.

The Need for GM Crops

Before starting discussing the merits and demerits of GM crops, it is important to set forth why there is such great effort to develop them. There are three major challenges we are facing that motivate our resort to the new technology for help.

A. **Expansion of population:** There are about 7.35 billion people on the planet right now. Despite a recent slowdown (1.18% per year compared to 1.24% per year ten years ago), the global population is still growing. In 2030, there will be 8.5 billion people on the planet, and 9.7 billion in 2050. The U.N. Food and Agricultural Organisation (FAO) claimed in 2016 that 795 million people worldwide, including 780 million people in developing nations, were undernourished. Therefore, eliminating hunger should be a top goal in developing policies. Increasing crop yields on already cultivated land is perhaps the most practical way to meet the rising worldwide demand for food. In order to meet the demands of population growth, higher nutritional standards, and declining arability, agricultural yields must increase at a pace more than 1.7% each year (Ray *et al.*, 2013). This is a challenging undertaking that looks only to be accomplishable through crop genetic optimisation in conjunction with quantitative advancements in agricultural system management.

B. **Decrease in arable land**: According to the FAO's estimate (Alexandratos and Bruinsma, 2012), the quantity of scarce arable land available for food production per person will drop from the present 0.242 ha to 0.18 ha by 2050. The issues of population expansion and starvation are complicated by this issue. The other option is to increase production per acre, which requires more fertiliser, water, insect and weed control, and/or genetic advancement in agriculture.

   This scenario is compounded by several complicating factors:

   (1) The increased demand for biofuel and feedstock production;

(2) Accelerated urbanization;

(3) Land desertification, salinization, and degradation;

(4) Altered land use from staple foods to pasture, driven by socioeconomic considerations;

(5) Climate change;

(6) Water resource limitation

C. **Bottleneck of conventional and modern breeding:** In traditional breeding, the goal is to express a desired trait (such disease resistance) by sexually crossing one paternal line with another. Breeders pick the best progeny and back-cross it to one of its parents (plant or animal) in order to select for the desired characteristic and to minimise extraneous or undesirable features. According to Oliver (2014), the procedure often takes several years (depending on generational time, for example, 10-15 years for wheat). Considering these facts, the development of GM crops and the introduction of biological technology promise to drastically shorten the time it takes to produce new strains and give us additional options for achieving long-term global food security.

D. **Popular traits:** Currently, 30 characteristics are bred into plants for commercial purposes, including improved vitamin absorption and resistance to pesticides, diseases, insects, and herbicides. The ones that provide herbicide tolerance and insect resistance are the most common.

E. **Herbicide Resistance**: An herbicide-specific transgene confers resistance. This trait enables the cultivar to use a herbicide that kills a variety of weeds while without harming the GM crop. According to Thomas *et al*. (2003), herbicide tolerance is currently the most widely utilised GM trait in the world. Examples include soybean, maize, cotton, and oil seed rape. They accounted for 83% of the world's total GM crop area, or little under 8% of the arable land. The majority of genetically modified (GM) crops that are herbicide resistant have been bred to be glyphosate tolerant; in the USA, 93% of the GM soybeans and most of the GM maize (Green, 2014).

F. **Insect/pest resistance:** A transgene develops toxins for particular crop-feeding insects. The use of herbicides and insecticides has already been significantly reduced as a result of the widespread use of such genes (Thomas *et al*., 2003). The majority of currently accessible genes used to create insect resistance originate from the bacteria Bacillus thuringiensis. Several species of coleopteran (beetles) and lepidopteran (moths) are the targets of insect resistant crops (Fleischer *et al.*, 2014). Both industrialised and developing nations cultivate insect-resistant cotton, maize, and potato cultivars. Resistance to bacteria, fungi, and viruses In this case, a transgene renders crops resistant to biotic stressors like plant diseases, which frequently significantly diminish yields. In crops that are resistant to viruses, the transgenic stops the virus from successfully reproducing in the host plant. In Hawaii, commercially cultivated VR papaya varietals were first released in 1998. In the late 1990s, VR squash production started in the US. In 1998, China authorised the commercial cultivation of VR sweet pepper (*Capsicum annuum*). (National Academies of Sciences, Engineering, and Medicine, 2016).

G. **Abiotic stress resistance**: The ability of some plants to survive in harsh climatic or soil conditions such as drought, heat, frost and acidic or salty soils is sometimes associated with specific groups of genes. These genes can be isolated and introduced into crops. Research on crops such as cotton, coffee, rice, wheat, potato, Brassica, tomato and barley varieties is currently in different stages of completion.

H. **Enrichment in micronutrients**: The provision of vitamins or minerals by GM crops may be crucial in the effort to prevent malnutrition. Through eating of their principal crop, GM crops may contribute to the provision of people with vital micronutrients. Currently, research is being done in this field on millet, potato, rice, and cassava. (Thomas *et al.*, 2003). Additional altered attributes some crops have been bred for different characteristics. For instance, attempts have been made to raise the oxidative stability of soybean oil in order to prevent the production of trans fats as a result of the hydrogenation process and to increase the oil's omega-3 fatty acid content for usage in both food and feed. GE characteristics for drought resistance and enhanced alpha-amylase content have been developed in maize. In 2015, nonbrowning varieties of apple and potato were sold commercially (National Academies of Sciences, Engineering, and Medicine, 2016). GM Crops Production The total area of GM crops amounted to 175 million hectares by at the end of 2013.

The main growers of GM crops are the US, Brazil, and Argentina, while India, Canada and China also are important producers (Atici, 2014). GM crops are predominantly found in these six countries (92 per cent of GM crops).

Currently just four crops – soybean (50%), maize (31%), cotton (14%) and canola (5%) account for 99% of global genetically modified crops (Pispini *et al.*, 2014).

I. **GM Crops in Asia**: In comparison to North and South America, Asia produces significantly fewer GM crops. The ISAAA research states that 19.1 million hectares of GM crops were cultivated throughout five nations, with India, China, Pakistan, the Philippines, and Myanmar accounting for 10.9% of the world's production of GM crops. The predominant qualities are the resistance against insects. Insect-resistant (Bt) cotton is the only GM crop grown in China, India, Pakistan, and Myanmar. It is also the most widely grown GM crop worldwide. Only the Philippines cultivates GM maize, which makes up around 28% of the country's total maize acreage. With 10.8 million acres, or 93% of the world's cotton land, India is the front-runner in terms of GM cotton. (Pispini *et al.*, 2014).

GM crops' acceptance over the past two decades, the growth in the number of approved GM crops has been largely consistent since the first GM crop was certified in 1994. Various GM characteristics in different crops, including potato, canola, maize, cotton, and soybean, have received approval on a global scale. The approval status of many GM crops differs from nation to country in addition to the enormous number of GM features.

Benefits of Genetically Modified Crops

1. **Reduction in Herbicide Use:** It is estimated that 2.3 million kg less active ingredient was administered to these crops than would have been the case if a traditional crop had been planted due to a little net decrease in the amount of herbicide active ingredient utilised (0.1%) in GM soybean. Herbicide usage in GM maize was reduced by just over 21.8 million kg of active ingredient (9.8%) in 2013. Over the years 1996 to 2013, the adoption of GM cotton resulted in a net decrease of around 21.3 million kg in the use of herbicide active ingredients. Usage has decreased by 7.2% as a result. Herbicide active ingredient use was reduced by 2.9 million kg (or 5.6%) in 2013 as a result of the deployment of GM cotton technology. In 2013, the use of GM HT canola resulted in a 2.1 million kg reduction in the amount of herbicide active ingredient use (−17.1%).
2. **Reduction in Insecticide and Pesticide Use:** The reduction in pesticide levels utilised by cultivars is the main benefit of Bt crops. Given that overuse of pesticides can have negative effects on the ecosystem, this can have significant ecological benefits. Additionally, there may be financial advantages. According to James (2002), 20% of

all pesticides used globally in 2001 were sprayed to cotton, costing a total of US$1.7 billion. For farm workers who use pesticides or insecticides, or who work in fields where they have been used, significant reductions can also have positive health effects. Compared to farmers that plant non-Bt cotton, it was suggested that such occurrences would be 60% less common. Insecticide application rates for maize decreased by 75% from 0.2 kg/ha in 1998 to roughly 0.05 kg/ha in 2011. The statistics show that seed treatments accounted for over 50% of the weight of pesticides sprayed. Data from the USDA on pesticide use in cotton and maize from 1996 through 2007 were examined for the 2010 National Research Council report on the effects of GE crops in the United States. The report observed a definite shape of drop in both crops in terms of pounds of active insecticidal ingredient (a.i.) sprayed per acre.

3. **Increase Crop Yield:** According to a report by Graham Brookes and Peter Barfoot, biotechnology is thought to have contributed to an increase in global production of 138 million tonnes of soybeans, 274 million tonnes of corn, 21.7 million tonnes of cotton lint, and 8 million tonnes of canola between 1996 and 2013 (Zhang *et al*., 2016). Crop yields have grown by 21% thanks to GM technology. According to Qaim and Zilberman (2003), these yield increases are not the result of increased genetic yield potential but rather of more efficient pest control that results in less crop damage. GM crops have simultaneously reduced pesticide expense by 39% and quantity by 37%. The impact on production costs is negligible. Although GM seeds are more expensive than non-GM seeds, there are savings in chemical and mechanical pest management that make up for the higher seed cost. The typical profit increase for farmers that use GM crops is 69%.
4. **Improvement in Nutritional Quality:** Due to its altered genetic characteristics, golden rice expresses large levels of beta-carotene (a precursor to vitamin A) (Oliver, 2014). To create a breed of rice that is ß-carotene enriched, two daffodil genes and one bacterial gene were inserted into a different type of rice. The primary objective of the researchers was to aid in the prevention of vitamin A deficiency (VAD), a problem that is frequently encountered in underdeveloped nations. Three million of the 14 million children under five who had clinical VAD in 1995 also had xerophthalmia, the main cause of juvenile blindness. There were 250 million kids who were subclinically deficient. The daily requirements of the children might be fully met by golden rice

varieties with a little -carotene content (orange), which require very low dietary consumption of vitamin A from other sources (green). In rice-based civilizations, Golden Rice lines with 4 g/g -carotene might be able to supply sufficient quantities of provitamin A, especially when accounting for a moderate contribution of provitamin A from other meals. Over time, appropriate amounts of vitamin A can be maintained in the blood with a stable supply of 50% RNI (red line).

5. Increase in Predator: More recently, researchers discovered that the widespread use of Bt cotton in China was associated with a significant rise in generalist predators (ladybirds, lacewings, and spiders). This rise in generalist predators spread to non-Bt crops (such as soybean, peanut, and maize) and improved biological control of aphid pests. (Gilbert, 2013).
6. Protection of the Environment: Less frequent spraying of GM IR (insect resistance) crops like maize, cotton, and HT (herbicide tolerance) crops has saved fuel, which has led to long-term reductions in carbon dioxide emissions. This resulted in a 785 million litre reduction in fuel use in 2013, which resulted in a saving of approximately 2,096 million kg of carbon dioxide. These savings would remove 0.93 million vehicles from the road for a year.
7. Resistance against Abiotic Stresses: In GM rice, resistance to environmental challenges like cold, moisture stress, and high soil salt levels can be achieved. Researchers at Cornell University studied a type of GM rice that maintained yields under abiotic challenges like cold, dryness, and salty soil successfully in a greenhouse setting in 2002. Given that drought affects 1.3 billion hectares of the world's arable land, such research is essential. According to estimates, the improved variety may be able to uphold yields under difficult circumstances by as much as 20%. (Thomas *et al*., 2003).
8. Resistance against Insects and Pests: It was found decades ago that a soil bacterium known as Bacillus thuringiensis (Bt) infects and kills the caterpillars that eat their crops. Millions of litres of pesticides have already been removed thanks to Bt crops, particularly in cotton. In 2013, Bangladesh became the first country to market insect-resistant Bt brinjal (egg plant). Currently, four different types of the crop are being grown by roughly 6,000 farmers. Farmers who plant the crop have reduced their use of insecticides by 80%–90% as a result of adoption. The deadly Fruit and Shoot Borer (FSB), which causes losses of up to 70% in commercial plantings, cannot harm

brinjal, making it the nation's first genetically engineered crop. The four varieties popularly known as Bt Uttara, Bt Kazla, Bt Nayantara and Bt ISD-006 approved for commercial cultivation in four major brinjal growing regions in Bangladesh.

9. **Resistance against Diseases:** Since 1991 the Kenya Agricultural Research Institute (KARI), in cooperation with Monsanto and universities in the US, has developed GM sweet potato strains that are resistant to the feathery mottle virus. It is expected that yields will increase by approximately 18-25%. It has been predicted that the increased income will be between 28-39% (Thomas *et al*., 2003).
10. **Resistance against Herbicides:** As of 2015, soybean, maize, cotton, canola, sugar beetroot and alfalfa all included GM herbicide resistance. With major effects in Brazil, Australia, Argentina, and Paraguay, glyphosate-resistant weeds have now been discovered in 18 nations globally (Gilbert, 2013). For instance, the planting area (hectares) of GM canola increased to 14% in 2014 from just 4% in 2009, nearly tripling that amount and adding to Australia's expanding biotech crop acreage. (Zhang *et al*., 2016).
11. **Economic Benefit:** Genetically modified organisms (GMOs) have been a subject of debate, and their economic benefits have been a topic of discussion. Here are some potential economic benefits associated with GMO crop cultivation. GMOs can be engineered to possess traits that enhance productivity, such as resistance to pests, diseases, and environmental conditions. This can lead to increased crop yields and improved food production, which can help meet the growing demand for food globally. GMO crops can be developed to be more resistant to pests, reducing the need for expensive pesticides and herbicides. This can result in lower production costs for farmers, making agriculture more economically viable. GMOs can be designed to have improved nutritional profiles, extended shelf life, and enhanced taste and texture. These qualities can increase the market value of the crops and provide economic benefits to farmers. Genetic modifications can confer drought and stress tolerance traits to crops, enabling them to thrive in challenging environmental conditions. This can be particularly valuable in regions prone to drought or extreme weather events, allowing farmers to continue cultivation despite unfavorable conditions. GMOs can be engineered to have increased resistance to spoilage, pests, and diseases, leading to reduced post-harvest losses. This helps preserve the quality and quantity of harvested crops, leading to higher profits for farmers. GMOs can contribute to

sustainable agriculture by reducing the need for chemical inputs, minimizing soil erosion, and conserving water resources. These factors can contribute to long-term economic benefits by promoting environmental stewardship and reducing resource consumption. The decreased costs of production (e.g. from reduced pesticide and herbicide usage) contributed the remaining 58% (Zhang *et al.*, 2016). In a study, the production of GM crops indicates the gross farm income and it is cost saving

12. **Ensuring Food Security -** According to a study, there is no discernible difference between Bt adopters and non-adopters in terms of the average farm household's land ownership of 5 ha. The average yearly per-person consumption costs lie between US$300 and US$500. In comparison to non-adopting homes, Bt adopting households consume considerably more calories and have a lower rate of food insecurity. The findings show that households that grow cotton may have experienced improved food security as a result of adopting Bt.
13. **Improvement in Food Processing:** Food processing can also be facilitated by using GM technology. The development of "Flavr Savr" tomatoes is noteworthy. The genetic modification entails the introduction of an antisense gene, which inhibits the polygalacturonase enzyme. As a result, tomatoes ripen more slowly, extending their shelf life. The transgenic fruit has ethylene levels that are 85% lower than controls.
14. **Products for therapeutic purposes**: The edible part of plant cells can express viral or bacterial antigens thanks to genetic engineering techniques. As possible carriers of edible vaccinations against many illnesses, such as Escherichia coli toxins, rabies virus, Helicobacter pylori bacteria, and type B viral hepatitis, a range of crops (such as rice, maize, soybean, and potatoes) are being studied. (Zhang *et al.*, 2016).
15. **Increase nitrogen use efficiency**: It is necessary to manipulate many genes related to nitrogen absorption, translocation, and remobilization, carbon metabolism, signalling targets, and regulatory elements in order to increase the efficiency with which plants utilise nitrogen. It has been determined that several genes from various sources regulate these activities, and it has been examined whether modifying these genes will improve plants' utilisation of nitrogen. (Pathak *et al.*, 2011)

Problems of Genetically Modified crops

1. **Food Safety:** People worry that eating GM foods could lead to undiscovered food sensitivities. Companies must label a food if the added gene comes from a known

allergy, such as nuts or wheat, and they must test the new gene for allergic qualities. Foods contaminated with mould and fungus pose health hazards, and organic crops are more likely to include them. The cancer-causing chemical aflatoxin is produced by a mould that thrives on maize and peanuts, and it can lead to the rejection of a whole crop. Employees who used Bt sprays also reported irritation to their eyes, noses, throats, and lungs.

2. **Health Risks:** GM crops are an "imperfect technology" with significant potential health dangers due to their toxicity, allergenicity, and genetic hazards. According to Bawa and Anilakumar (2013), these could be brought on by inserted gene products and their possible pleiotropic effects, the GMO's natural gene disruption, or a combination of the two. The cultivar Starlink maize, which expresses Cry9c and confers gluphosinate tolerance, is the most known example of this. Due of its potential to interact with the human immune system, Cry9c Starlink was categorised as "potentially 26 allergenic" by the USDA's Scientific Advisory Panel (SAP) in the middle of the 1990s. Starlink remnants were found in food supplies in 2000 not just in the US but also in the EU, Japan, and South Korea, where it was outright prohibited (Raman, 2017). In a study, rats fed GM potatoes displayed increased cell development in their stomach lining, a condition that may cause cancer. Rats also had compromised immune systems and organs.
3. **Decrease in Biodiversity:** The number of Monarch butterflies (Danaus plexippus), according to the Centre for Biological Diversity, has decreased by 90% in the previous 20 years. Monarch butterflies move to Mexico's Oyamel fir forests every winter from the corn-belt region of the Midwest. This graph from the conservation organisation Monarch Watch depicts the sharp population change in terms of the overall area inhabited by monarchs during the winter in Mexico. Recently, a portion of that habitat was lost, and pesticide spraying along the monarchs' migration route severely decreased their population. To determine the impact of Bt maize on monarch butterflies, several researchers devised a straightforward laboratory experiment. They raised a "control" variety of maize and a Bt variety of maize. Then they sprinkled the maize pollen on the milkweed plants. Monarch caterpillars, which ate the pollen, were placed in petri dishes with these leaves by scientists. While the other larvae survived, the Bt pollen-eating larvae perished within days. (Delude and Mirvis, 2000).

A meta-analysis of 25 studies on the effects of the Bt toxin on honey bee larvae and adults was carried out by Duan *et al.* (2008). They came to the conclusion that the honey bee was not suffering any negative effects. Johnson (2015) came to the conclusion in a recent assessment of honey bee toxicology that evidence from numerous researches suggests that Bt pollen and nectar are not dangerous to honey bees. Since the introduction of GE maize and soybean, there is minimal indication of a significant movement towards continuous cropping of maize, soybean, and wheat (3 or more consecutive years of a single crop) at the individual farm level in the United States (Claassen, 2018).

4. Increase in Secondary Pests: It is occasionally possible to boost the populations of "secondary" insect species by using Bt toxins to suppress the populations of targeted species. Due to their lack of resistance to or diminished vulnerability to the specific Bt trait in the crop, the secondary insect pest populations grow. Before the Bt crop was introduced, broad-spectrum insecticides would have been used to control the insects. Bt cotton in China is one of the greatest instances of a secondary pest epidemic. Populations of a mirid beetle (Heteroptera: Miridae), which is unaffected by the Bt toxin in the cotton, continuously rose during the course of a ten-year research from 1997 (when Bt cotton was introduced) through 2008. (National Academies of Sciences, Engineering, and Medicine, 2016).
5. Rising of Superweed: It is crucial to determine whether crops that are herbicide-resistant will produce "superweeds." Could the crops pollinate the weeds, making them resistant to herbicides? Would these hardy weeds proliferate like the southern states' invasive kudzu vine? When conventional crossbreeding was producing crops that were herbicide-tolerant, researchers started looking at this potential. Only a closely related weed can be pollinated by a herbicide-resistant crop. Since soybeans have no wild relatives in the Western Hemisphere, herbicide-resistant weeds don't seem likely under this situation. The soybean does have weedy ancestors in the Eastern Hemisphere that could acquire the herbicide-resistant gene. Farmers must use additional pesticides in soybean fields to eradicate weeds since glyphosate is the only one that will kill them. To ensure that any herbicide-resistant weeds are eliminated as soon as they appear, U.S. regulatory officials are regularly monitoring fields (Jones, 2021)

6. Rising Costs: The rising costs of seeds and inputs are a reflection of the biotech corporations' close to monopoly position and a sign of the expanding market concentration in the broader agricultural input sector. 89% of the soybean seed market in the US is under Monsanto's control, as is 79% of the market for maize seeds. For small farmers, many of whom already struggle with debt, the high cost of seeds is perceived as a particular challenge. According to a Burkina Faso study, the costs were quite high and the hazards of producing GM cotton grew disproportionately high. The six global corporations Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF sold a total of $34,495 million worth of seeds worldwide in 2011 (Benbrook, 2012).
7. Suicide: There was an increase in farmer suicides in India following the 2002 introduction of Bt cotton, which was genetically modified. Regulation and Safety The majority of individuals concur that the seriousness of the effects of gene flow should take precedence in any evaluation of the environmental safety of GM crops. Some people, however, believe that GM crops shouldn't even be created because there's a very slim chance that they'll have some unexpectedly negative, severe effects. The so-called precautionary approach is commonly used in discussions about this issue. No new technology should ever be implemented without an assurance that no risk will materialise, regardless of potential benefits (Thomas *et al.*, 2003). GM crops have always been subject to regulation, which was enhanced in 2000. The Environmental Protection Agency (EPA) is investigating the possible issue of superweeds and superbugs and requires permits and testing for pest- and herbicide-resistant crops. Before releasing a new GM food, companies must provide the Food and Drug Administration (FDA) with comprehensive safety information. Field trials of GM crops are supervised by the U.S. Department of Agriculture (USDA). Strict regulatory measures have been proposed to prevent cross-contamination of split-approved GM crops that are prohibited from being consumed by humans in order to reduce the issues with GM technologies. These include establishing buffer zones and enforcing them to prevent crop contamination, improving laboratory testing to confirm cases of adverse allergic reactions, and generally involving stakeholders and representatives in policymaking and communication. (Raman, 2017).

CONCLUSION

In traditional farming practises, plant genes are altered to produce desired features. DNA recombination, on the other hand, results in the highly focused transfer of genes from nearly any organism to make the genetically engineered crops. Crops that have been genetically modified (GM) can help modern agriculture overcome a number of existing problems. GM crops are essential for meeting the demands of population increase, improved nutritional standards, and declining arable land. In contrast to Bangladesh, which produces only Bt brinjal on 700 hectares of land, the production of GM crops covers 175 million hectares globally. Soybean, maize, cotton, and canola account for 99% of the GM crop production. Current market trends predict that GM crops will become one of the most inventive and rapidly expanding global sectors, benefiting not only consumers but also major national economies and farms. In addition to helping to protect and preserve the environment by increasing yield and decreasing reliance on synthetic pesticides and herbicides, GM crops also enable plants to grow under biotic and abiotic stresses, thereby achieving sustainable global food security. Despite their many advantages, GM crops have a number of health and biodiversity-related issues. Stricter regulation, monitoring, and implementation by government agriculture organisations, an improved global risk mitigation strategy, and communication with growers can all be used to address flaws and significant GM technology, ensuring wider acceptability. Before being introduced, the dangers should have been investigated and eliminated. It is important to make a significant effort to comprehend how people feel about this gene technology. GM crops are anticipated to increase productivity and profitability in current agriculture for more seamless advancement in the future. These advancements include major innovations in precision gene-integration technologies and rising research in biofortification and stress tolerance.

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Chapter - 18

Integrated Organic Farming System: Enhancing Livelihood and Nutritional Security for the Resource Poor and Marginal Farmers

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A promising strategy for reducing the environmental costs associated with input-intensive agricultural practises is organic farming. The main issue with organic farming is the lack of readily available large quantities of organic inputs needed for crop nutrition and maintaining soil health. This issue can be solved by effectively recycling the on- and off-farm resources that are currently available and integrating the components according to the specific locations. Integrated organic farming system (IOFS) model is an on-farm resource management strategy which aims to create sustainable and profitable agricultural output in order to satisfy the varied needs of farm households while protecting the resource base and sustaining high environmental quality. Components of farming system when carefully chosen and executed depending upon the suitability of the farm fulfils the input demand internally and mostly avoids purchase of any external inputs. Rather than these there are many advantages of adopting the model and IOF model has been applied in several states of India, employing various animals, vegetables, fruits, and crops.

Keywords: Integrated organic farming system, sustainability, livelihood, nutritional security

INTRODUCTION

Organic farming has grown significantly as more people become aware of the need of protecting our planet and its resources. The introduction of nutrient-responsive, high-yielding crop varieties, increased exploitation of irrigation potentials, and other green revolution technologies that encourage use of synthetic agrochemicals have improved production output in most situations. However, improper selection and ongoing use of these high energy inputs is causing a loss in crop output and factor productivity as well as deterioration in the environment and health of the soil. As a result, adopting an alternative farming system, such as organic farming, is necessary to maintain a healthy ecosystem. The main problem with organic farming is the lack of large quantities of organic inputs needed for crop nutrition and maintaining soil health. This problem can be effectively solved by recycling the available on- and off-farm resources and integrating the components according to the specific locations.

The current agricultural production system has a tremendous challenge in providing food security for a rapidly expanding worldwide population that is expected to reach 9.1 billion in 2050 and over 10 billion by the end of the twenty-first century (UNPFA, 2011). Organic agriculture is one of the potential production techniques for reducing the environmental costs associated with input-intensive agricultural practises and producing nutritious food (Das *et al*., 2017). It promotes the farming practices which are sustainable from the environmental, production and socio-economic point of view and to produce enough food and nutritional security to over growing nation's populations (Saikia *et al*., 2023). By composting and reusing the entire residue, the soil's fertility is preserved, minimising the time between nutrient supply and loss from the soil. The farmers incorporate agricultural production, cattle, poultry, fisheries, beekeeping, and other activities on their farms in order to sustain and meet as many of their requirements as possible. By incorporating additional and complementary businesses, it is possible to efficiently use all the resources available on and off the farm, ensuring the sustainability of organic agriculture.

The emergence of Integrated Organic Farming System (IOFS) has enabled us to develop a framework for an alternative development model to improve the feasibility of small sized farming operations in relation to larger ones. Integrated organic Farming emphasizes the interconnection of all life. Integrated organic farmers employ natural methods to grow crops and maintain healthy soil. It entails to a sustainable approach through the development of interdependent agri-ecosystems comprising different modules of cereals, pulses, oilseeds, vegetables crops, fruits, dairy unit, fodder crops, water harvesting and nutrient recycling components on a certain field or piece of land (Fig. 1). To fulfil the varied needs of the farm home while protecting the resource base and keeping good environmental quality, it is important to achieve economic and sustainable agricultural output. The components of IOFS are wholly reliant on the suitability of the farms, internal fulfilment of input requirements, and complete avoidance of external inputs. By recycling organic waste, this not only lowers the cost of manufacturing but also improves the quality and quantity of the output as well as the environment (Das *et al.*, 2018).

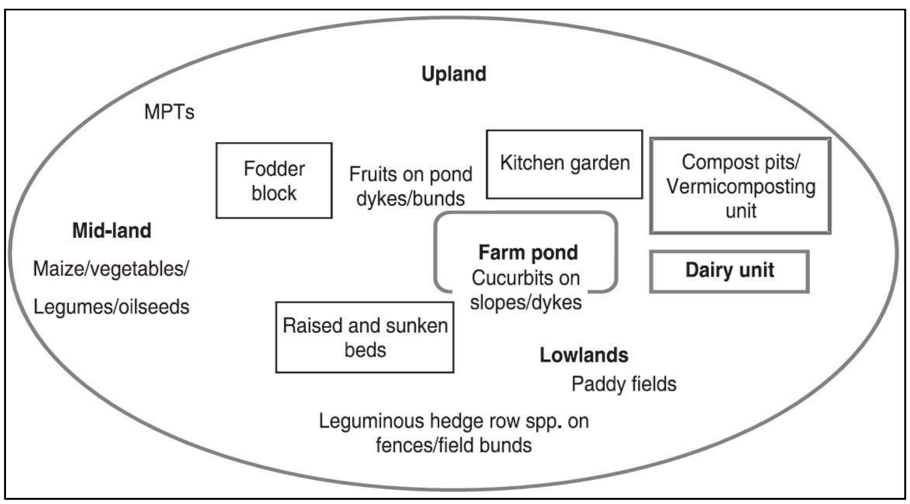

Fig. 1: Schematic diagram of IOFS model (Source: Das et *al.*, 2019)

Integrated organic farming system is often and liberally used to describe a more integrated approach to farming than monoculture alternatives. This method makes use of a network of interconnected businesses so that the "waste" from one component may be used as an input for another, lowering costs and increasing output and revenue. It functions as a system of systems to make sure that leftovers from one type of agriculture are used as resources for another. Since wastes are used as resources, we not only reduce wastes but also guarantee an overall boost in production for the entire agricultural systems.

Need for Integrated Organic Farming System (IOFS)

Productivity improvement may be a critical option for ensuring food and nutrition security for a huge population. This entails implementing scientific agronomic practises and technology that promise to increase the productivity of conventional agricultural systems. Agronomic techniques like the liberal application of inorganic pesticides and fertilisers during the 20th century greatly increased productivity, but unfavourable environmental degradation and rising operating costs in agriculture raised questions about the viability and sustainability of the practise (IAASTD, 2009; FAO, 2010). Unsustainable farming leads to environmental pollution and threatens the livelihood of millions of small farm holders. Strengthening agricultural production systems for greater sustainability and higher economic returns is a vital process for increasing income and food and nutrition security in developing countries (Ravallion, 2007).

A sustainable method that increases productivity and strengthens the soil is organic farming. Making the switch to organic farming practices can improve crop fertility, provide farmers with a boost in crop prices, and potentially bring in up to 200% more money on the international market (Agrifarming, 2021). The adoption of organic agriculture in an integrated farming system approach, *viz*., an integrated organic farming system (IOFS), will not promote only organic farming system but also reduce dependence on external resources. This technique will raise soil fertility, resulting in more fertile land for farming and a larger output of organic goods. Additionally, natural plant extracts and minerals are employed for biological control measures rather of pesticides, offering a sustainable and eco-friendly form of farming. Thus, the focus should be on integrating complementary and supplementary enterprises, such as crops, fruits, vegetables, livestock, poultry, fish, multipurpose tree species, and mushrooms, along with adequate nutrient recycling strategies (Ravisankar *et al*., 2021). Through the IOFS, the Indian government offers states the chance to adopt organic farming.

Natural methods used in Integrated Organic Farming System

Farmers in IOFS cultivate their crops using natural methods to support healthy soil. Among these include companion planting, crop rotation, the use of natural fertilisers, and pest control techniques. Crop rotation increases soil fertility while decreasing the burden from insects and diseases. Companion planting is the practise of growing different plants together that has a beneficial connection, such as planting beans and maize together to supply nitrogen to the maize.

Compost and manure, two organic fertilisers, increase soil fertility. In addition, eco-friendly pest management strategies including biopesticides and traps are employed to keep pests at bay. All living things in an ecosystem are connected, according to integrated organic farming. Everything, including the environment, plants, and animals, is interconnected and dependent upon one another. The agricultural system aims to promote natural equilibrium since it benefits both the farm and the surrounding ecology (Fig. 2). Farmers may create a sustainable ecosystem that sustains a variety of plants and animals, including beneficial insects and birds, by boosting biodiversity. It helps maintain a natural equilibrium that is advantageous to the farm and the area's environment. While placing a strong emphasis on the use of local resources and traditional knowledge, IOFS supports biodiversity.

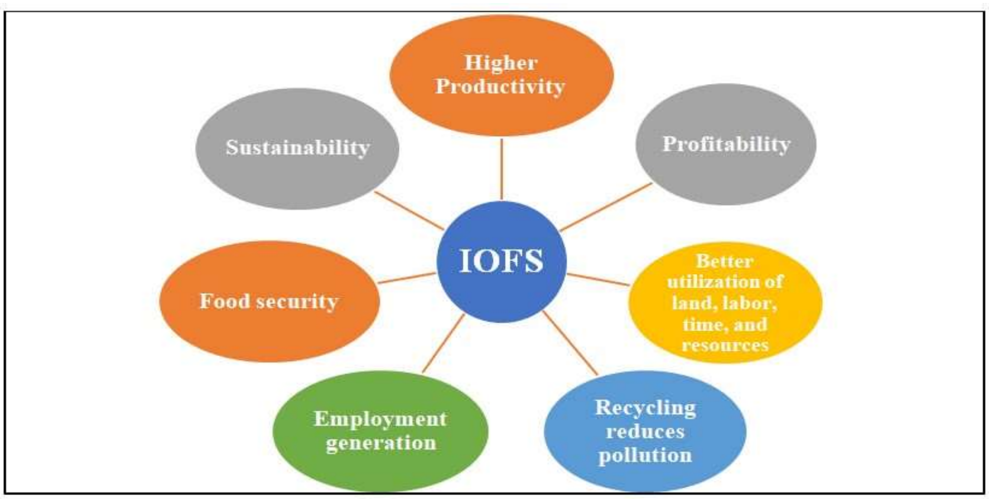

Fig. 2: Benefits of Integrated Organic Farming

It comprises using agricultural and animal varieties that have been suited to the local environment as well as utilising time-honoured farming methods. Farmers can create a farming system that is suited to their environment and culture by using traditional knowledge. In IOFS farmers are urged to employ waste management, energy efficiency, and sustainable water management practises. It aids in reducing agriculture's negative environmental effects and preserving resources for future generations.

Integrated Organic Farming Systems adopted in different regions of India

In India, Integrated Organic Farming Systems (IOFS) are being used to promote ecologically friendly and sustainable farming techniques. Sikkim is becoming the first organic state in India thanks to the government's implementation of a comprehensive policy to support organic Farming. The state has established a certification and accreditation system for organic food. It offers technical and financial aid to farmers to convert to organic Farming.

Integrated Organic Farming in Sikkim: Rice, peas, potatoes, toria, maize, soybeans, coriander, radish, broccoli, fenugreek, cauliflower, beetroot, spinach, and buckwheat are just a few of the crops grown in Sikkim using integrated organic farming (IOF) on a 1.25-acre plot of land. Fifty chickens and two cows are also part of the IOF model. The IOF model seeks to provide a yearly net income of Rs. 137,000 (Mishra *et al.*, 2022).

Integrated Organic Farming in Meghalaya: An integrated organic farming system model which was developed at ICAR Research Complex for NEH Region, Umiam, Meghalaya, that comprised of different enterprises such cereals (rice and maize), pulses (lentil, pea), oilseeds (soybean, rapeseed), vegetable crops (French bean, tomato, carrot, okra, brinjal, cabbage, potato, broccoli, cauliflower, chili, coriander, etc.), fruits (Assam lemon, papaya, peach), dairy unit (a milch cow + calf), fodder crops, central farm pond, farmyard manure pits and vermicomposting unit. The total cost of cultivation incurred was recorded at 55,839/- per year under the IOFS model with an area of 0.43 ha. Under the model, the total net return of Rs. 62,531/- per year (Rs. 5211/month) a net income of Rs. $100/- per month was achieved, which was much higher than the regional farmer's income through common practices of farming or cropping systems (Layek *et al.*, 2020).

Integrated Organic farming in Tamil Nadu: One acre integrated organic farming system model for irrigated upland ecosystem of Tamil Nadu was developed to cater the needs of marginal farmers of Tamil Nadu, and was evaluated continuously for 6 years from 2013-2019. The system consists of crops, livestock, fodder, agroforestry, pest repellent, composting and beekeeping. The system productivity on expand was Rs. 3034 kg/ha/year. *Kharif* crops shares 45% of the net returns compared to the winter season (*rabi*) crops. Total 34 tonnes crop were recycled through which revenue of Rs.11782 was realized. About 29 tonnes of green fodder was produced per annum, which met the fodder requirement of the livestock for 342 days. Annually Rs. 1742 litres milk was produced to assure an annual income of Rs. 37426. Annually 11.8 tonnes cowdung and Rs. 9217 litres cow urine were obtained with the nutritional value of Rs. 5586. On averages, 2004 kg compost was produced through which Rs. 3007 was realized, Net income of Rs. 75544 was realized through boundary plantations. From the IOFS model, a total mean annual net income realized was Rs. 72006. Through recycling of residues and manures 12% of the total cost of the model was saved. The relative share of different components in the order of merit was livestock (47%), crops (29%), fodder (20%), boundary horticultural crops (6%) and compost (2%). The benefit cost ratio of the IOFS model was 2.24, with an annual employment generation of 571 man-days (Somasundaram *et al*., 2021).

Integrated Organic Farming in Karnataka: One-hectare area for integrated organic farming system model was developed at Organic Farming Research Institute Farm, UAS, Karnataka for six successive years of 2014-21 to explore the productivity and profitability. The system constitutes Crop and Cropping sequence (9000 m^2), Livestock (300 m^2), Farm pond (300 m^2), Composting unit, storage (250 m^2) and Farmhouse (150 m^2). Under the model, net returns (Rs. 79,923) and benefit cost ratio (3.30) with net monthly income (Rs. 6,660) were recorded. The productivity and profitability under the practice of integrated organic farming system records higher net, gross return with lesser cost of cultivation (Rao *et al*., 2022).

Integrated Organic Farming in Kerala: Turmeric, coconut, yam, vegetable cowpea, fodder, bananas, and tapioca are the crops used in Kerala's Integrated Organic Farming System (IOFS) concept. Additionally, it covers Calicut's cattle (two cows). The model's objective is to provide a net revenue of Rs. 1,23,000 per acre and pay for 89% of the planting seeds, other planting supplies, and nutrients the plants and soil needs (Agrifarming, 2021).

Integrated Organic Farming Systems Approach

The shortcomings of the reductionist, command-and-control approach to agricultural research became increasingly evident, especially as it was understood that the farmer's production environment was much more heterogeneous than had been thought. In actuality, farmers in less advantageous regions fought these developments and did not embrace the technical packages. This made people more conscious of the need to evaluate technical advancements on more than just their short-term effectiveness. Additionally, they had to be adaptable and take into consideration how the farmers perceived security and unpredictability, as well as their long-term outlooks and farming objectives. As a result, it was acknowledged that many geographical and temporal dimensions needed to be considered, and that the study strategy needed to be more integrative, systematic, and thorough (Kalyani, 2019). A science-based recommendation's limitations were also highlighted, along with the requirement to adopt an actor-oriented strategy to assure compatibility with the socioeconomic environment. This gave rise to a new developmental paradigm that contrasts the previous technology blueprint approach to learning with a learning process that is centred on humans. This strategy made room for a number of advancements.

Developing organic farming system: Organic management is an integrated strategy, thus changing or adopting only one or a couple of the phases may not provide noticeable improvements. All necessary elements must be developed in a methodical way to maximise output. These actions consist of (i) habitat development, (ii) infrastructure for input production on farms, (iii) growing crops appropriate to the location, soil, and climate, (iv) cropping sequence and combination planning and (v) three to four-year rotation planning.

Development of farm facilities and habitat:

Infrastructure: Reserve 3–5% of the farm's space for utilities, including room for livestock, vermicompost beds, compost tanks, vermiwash/compost tea units, etc. Trees should be planted on this area, as all utility infrastructure needs shade. This utility area may also include infrastructure for water pumps, irrigation wells, and other things. Percolation tanks for rainwater conservation (1 pit per hectare) at suitable locations depending on slope and water flow should be created. Create a farm pond if you can, ideally one that is 20 by 10 metres in size. Keep a few 200 lt tanks (1 per acre) for preparing liquid manure and a few containers for plants.

Habitat and biodiversity: An integral part of an organic farming system is the management of an environment that is suitable for the sustenance of many life forms. This may be accomplished by keeping a broad range of trees and plants that are suitable for the climate and by guaranteeing agricultural diversity. These shrubs and trees will not only assure the transportation of nutrients from the deep soil layers to the top layer of the soil, but they will also draw birds, predators, and beneficial insects, as well as serve as food and shelter.

Conversion to organic system: While turning towards organic system it is essential that the basic requirements of the system and the area are properly understood and long term strategies are addressed first. In most parts of the country poor soil health due to loss of organic matter and soil microbial load is a major problem. Reducing water availability and increasing temperature is further adding to the problems. Too much dependence on market for supply of inputs and energy has made the agriculture a cost intensive high input enterprise with diminishing returns. It is widely known fact that some biological processes of plants involved in acquiring nutrients such as nitrogen e.g. N_2 fixation are generally inhibited by adding Nitrogenous fertilizer. Soil scientists generally caution against non-judicious fertilizer use and encourage use of organic compost otherwise it may lead to deficiency of micronutrients. Therefore, in organic farming systems there is no place for chemicals. We need to address all these concerns and develop a system, which is not only productive and low cost but also resource conserving and sustainable for centuries to come. To start with, following parameters need to be address (Table 1).

Table 1: Important parameters for achieving sustainable organic system

Parameters	Management
Banning of chemicals	Avoid use of any synthetic fertilizers, pesticides, herbicides, or any other chemicals
Enrichment of soil	Use crop residue as mulch, use organic derived manure, adopt crop rotation and multiple cropping, avoid excessive tilling and keep soil covered with green cover or biological mulch

Conservation of rain water	Dig percolation tanks, maintain contour bunds, farm ponds in sloppy lands and adopt contour row cultivation, maintain low height plantation on bunds
Use of biofertilizers and liquid organic manure	Organic biological fertilizers, microbial inoculants, panchagavya, jeevamruth, beejamruth etc.
Self-reliance in inputs	On-farm production of compost, vermicompost, vermiwash, liquid manures and botanical extracts.
Maintenance of natural cycles and life forms	Develop habitat for sustenance of life forms, never use pesticides, create enough diversity
Maximum reliance on renewable energy sources, such as solar power and animal power	Use solar energy, bio-gas and bullock driven pumps, generator and other machine

Optimizing the Total System

The "Farmer first and last model" is an alternative to the "transfer-of-technology" paradigm that is based on the farmer's priorities and perceptions rather than the scientist's professional preferences, criteria, and goals (Devi *et al*, 2023). The starting point is to have a scientific understanding of the resources, demands, and issues faced by farmers with limited access to resources, and to recognise the role that research stations and labs serve as consultative and referral sources. The employment of technology as a means of assessment, research and development conducted on farms and in collaboration with farmers, and the use of informal survey methods are characteristics of this paradigm. For the best possible use of locally "available alternative" resources, the agricultural system must be properly integrated.

Empowerment of women through integrated organic farming

Women play a very important role in household management including agricultural operations. This is especially true for hilly and tribal areas. For tribal and hilly places in particular, this is true. By strategically deploying family labour, adopting creative strategies, and assuring multiple uses of different home resources, there is a significant opportunity to increase household profitability. Women's empowerment through site-specific trainings and crucial need-based assistance makes this feasible. The role of women in agricultural and family resource management will become more significant as education levels rise in the coming years. Women have achieved great strides in agripreneurship thanks to innovation and assistance; as a result, feminization of agriculture and the development of women-centric agricultural system models are therefore envisaged in the long run (MoA& FW, 2021).

CONCLUSION

In recent years, organic farming has gained popularity as a sustainable method of managing soil and crops, particularly for resource poor and marginal farms. In addition to several ecological services including climate change mitigation, it supports soil health. Through effective recycling of on-farm biomass and other resources, an integrated organic farming system will not only support the production of organic food but also lessen reliance on outside resources. When on-farm resources are effectively recycled, the use of organic liquid manure, biofertilizer, and natural fertilisers can satisfy the IOFS farm's nutritional needs. India requires location-specific IOFS models to scale up human welfare, socioeconomic advancement, and environmental health. Therefore, IOFS may be a good choice for the development of sustainable agriculture and the production of organic food.

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Chapter - 19

Integrated Farming System (IFS): Potential for Sustainable Livelihoods and Food Security of the Rural Poor

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The population's wellbeing and nutritional health are greatly influenced by food, which is a basic necessity of existence. Indian agriculture has been in responsibility of providing food and nutrition to the country's crowding millions of citizens. Agriculture is primarily the source of income for people living in rural areas. To ensure that small and marginal farmers, in particular, can support their livelihoods and receive better nutritional support, it is essential to develop agricultural practises and technologies that generate sufficient income and job opportunities. Through the synergistic interactions between the parts of farming systems, IFS can increase the production of farms by using integrated agricultural system models based on different scenarios. With limited resources available to the small and marginal farming community, the Integrated Farming System (IFS) appears to be the primary answer to the growing demand for farm sustainability, stability, food production, and nutrition improvement. The IFS systems can partially or totally satisfy the dietary needs of farm families from a small piece of land in the case of marginal and disadvantaged farmers. Additionally, the ongoing need for labour to maintain a system of various crops and livestock keeps farm families actively engaged in farming activities, providing a chance to create more jobs.

Keywords: Farming system, sustainable, livelihood and food security

INTRODUCTION

India being the highest populated country in recent times stresses a lot on the production of the food sector and agriculture to feed it billions. With the increase in the population, the demand for food increases and with it comes the scarcity of quality food intake in the population. Food being a basic necessity of life decides the nutritional health and the wellbeing of the population to a great extent. The availability of quality nutrients among the people will be determined by the exposure to the variety of quality food products of major food groups such as cereals, pulses, legumes, tubers, meat/ fish, milk and milk products. The livelihood of the rural population is majorly agriculture based. Indian agriculture has been in charge of giving its thronging millions of people food and nutrition. The sustainability of agricultural systems and the nation's food security objectives are in danger due to the widespread incidence of negative consequences of green revolution technologies in states with intense agriculture, such as Punjab and Haryana (Kumar *et al.*, 2022). The viability and profitability of farming are seriously threatened by the trend of gradually shrinking landholdings. Between 1970 and 1971, the average size of a landholding was 2.28 hectares; between 2010 and 2011, it was 1.16 ha. The average Indian holding size would decrease even further by 2030, to 0.32 hectares, if this trend were to continue (Kumar *et al.*, 2022). Thus, especially for small and marginal farmers, it is crucial to provide agricultural methods and technologies that offer adequate income and opportunities for employment so that they can sustain their livelihood and get better nutritional support.

Environmental contamination from unsustainable farming threatens the livelihood of millions of small farmers. A crucial step towards raising income and ensuring improved food and nutrition security in developing nations is the development of sustainable agricultural production systems that are more economically viable and environmentally responsible (Ravallion, 2007). Sustainable agriculture provides a much-needed substitute for conventional input-intensive farming, which has negative long-term effects on biodiversity, groundwater levels, and topsoil degradation. In a world where climate change is a concern, sustainable farming approaches are essential to guarantee India's food security (Gupta *et al.*, 2021). Farming system research plays an integral role in development of such environment friendly, economically viable and sustainable practices (Devi *et al.*, 2023). Farming system research is an innovative form of agricultural research and development that views the entire farm as a system and concentrates on 1) the interdependencies between the components that are under the control of the household and 2) how these elements interact with one another in relation to the biological, physical, and socioeconomic factors that do not come under the control of the household (Shaner *et al.*, 1982).

The development of Integrated Farming Systems (IFS) has made it possible to think about an alternative development model to increase the viability of small-scale farming operations relative to more extensive ones. Compared to monoculture techniques, integrated farming systems use a more integrated approach to farming. It is frequently referred to as a "integrated biosystem" and refers to agricultural systems that integrate fish and cattle or livestock and crop production (Soni *et al.*, 2014).

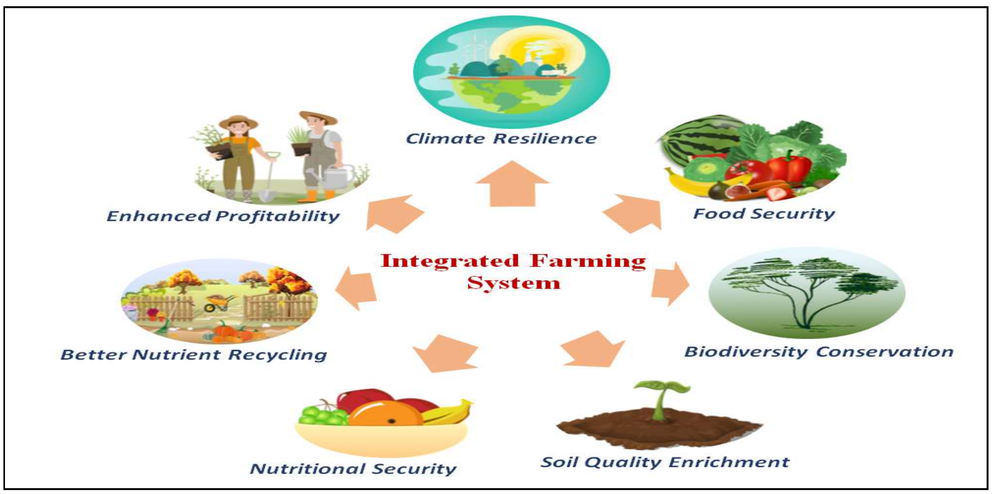

Fig. 1: Ecosystem services offered by IFS (Source: Soni *et al.*, 2014)

IFS help to increase resource usage efficiency and farm by-product recycling, via synergistic interactions between the components of farming systems. IFS gives room for more crops, animals, trees, honeybees, etc., which provides better carbon sink that is more resilient to climatic fluctuations and could be an intriguing approach for combating climate change. The benefits provided by the IFS can be well understood from Figure1 (Soni *et al.*, 2014).

Sustainable livelihood

A livelihood consists of the skills, possessions, and pursuits necessary for a means of subsistence. It is considered sustainable when it can withstand stresses and shocks, recover from them, and maintain or improve its capacities, assets, and activities both now and in the future without compromising the natural resource base (Serrat, 2017). Understanding the varying capacities of rural communities to deal with crises like droughts, floods, food insecurity, or plant and animal pests and diseases constitutes the root of sustainable livelihood. According to the Development Alternatives (DA) organisation, sustainable livelihoods include all current development strategies that attempt to economically support disadvantaged or marginalised groups so they can live honourably and sustainably in their communities (Valdes-Rodriguez & Pérez-Vázquez, 2011).

To improve the livelihood sustainability of the rural poor, it is important that we understand the various components that underlines the livelihood. In this context the sustainable livelihoods approach enhances better understanding of the livelihood scenario of the rural poor (Saikia *et al.*, 2023). It groups the variables that limit or improve living opportunities and demonstrates how they are related. It can aid in the planning of development initiatives and the evaluation of the contribution that already-conducted initiatives have made to maintaining livelihoods. It focuses on developing ideas regarding the way the poor and vulnerable carry out their lives and the significance of institutions and policies (Serrat, 2017). This can be better understood from the Sustainable Livelihood Framework developed by Department for International Development (DFID) in Figure 2).

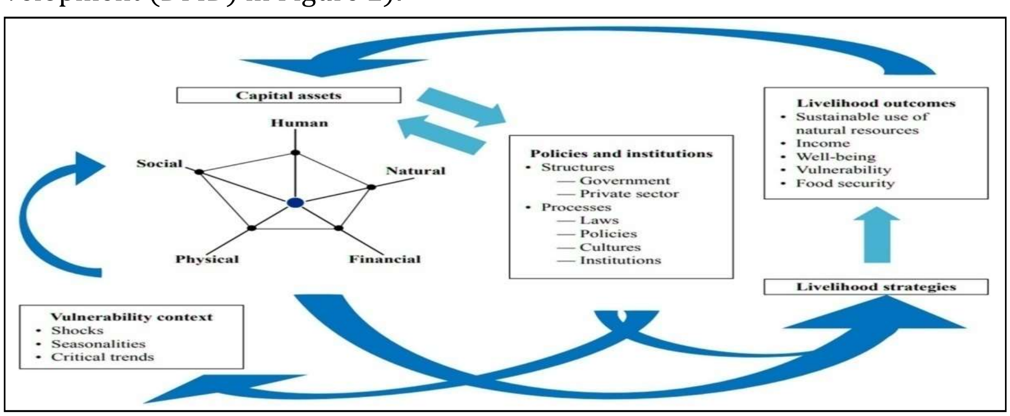

Fig. 2: Sustainable Livelihood Framework

According to the framework, stakeholders operate in an environment of vulnerability where they have access to specific resources. The current social, institutional, and organisational environment (policies, institutions, and procedures) gives assets weight and worth. The livelihood options available to people in pursuit of their self-defined favourable livelihood outcomes are significantly shaped by this setting.

Food Security

When every person, at all times, has physical and financial access to enough safe and nourishing food that satisfies their dietary needs and food preferences for an active and healthy life, it is defined as food security as. The four primary aspects of food security are (FAO, 2023):

1. Physical accessibility to food
2. Having financial and physical access to food
3. Food usage
4. The stability of the other three dimensions over time

To achieve food security objectives, all four dimensions must be achieved at the same time. Both food intake and disease are factors in determining whether a person's nutritional demands are met; the latter increases nutritional requirements and has an impact on how nutrients are metabolised and utilised by the body. The consistency of the food supply is another crucial aspect of food security. Food security can be studied at varying levels such as individual, household, community, region, district, etc. Different aspects, dimensions, and indicators can be used, depending on the level of emphasis (De Pee, 2013). Food security and household livelihood security are closely related, with the latter being defined as a household's capacity to provide for the necessities of its members.

Integrated Farming System

Integrated Farming System refers to agricultural systems that integrate crop production and livestock or fishery and livestock or in other terms integrate bio systems in agriculture. This is inter-related system includes the use of wastes from one component as part in another component of the system, which reduces the cost of cultivation and improves production as well as income. The appearance of Integrated Farming Systems (IFS) has facilitated to develop an outline for an alternative development model to advance the feasibility of small and marginal sized farming operations. In other terms IFS acts as a system of systems, it ensures that waste of one system becomes a resource for another system or form of agriculture. Since IFS makes use of wastes as resources, it not only reduces wastes but also increases the whole productivity in agricultural systems (CARDI, 2010).

Goals of IFS

Manjunatha *et al*. (2014) mentioned four primary goals of IFS which are as follows:

1. Maximisation of yield across all components to ensure consistent and reliable income.
2. Achieving agro-ecological equilibrium and improving the system's productivity.
3. Manage weed, disease, and insect populations naturally through cropping systems, and keep them at control.
4. Providing healthy foods to the society and ensuring clean environment by reducing the use of chemicals such as pesticides and fertilisers.

Advantages of IFS

1. Increased productivity by improved economic yield per unit area per time by virtue of intensification of crops and allied systems.
2. Through recycling of wastes of one system as energy input for other systems it boosts profitability.
3. By integration of diverse bio systems IFS generates greater sustainability in production on farm.
4. It reduces the dependency on external inputs by recycling of wastes (in built of system) thus conserves natural resources and reduces scarcity of resources.
5. It creates the opportunities to resolve malnutrition problems by producing varieties of food products in system.
6. Avoids piling of wastes and its consequent pollution in environment by recycling of wastes.

7. The system generates money flow throughout the year to the farmer by the way of bio systems integration (poultry, dairy, apiculture, sericulture, mushroom culture, etc.)
8. Usage of recycled organic wastes restricts the requirement of chemical fertilizers and controls the pest diseases by improving the quality of farm.
9. Inclusion of agro forestry component reduces pressure on forests and provides fuel and timber.
10. Diverse integration of components raises input use efficacy and improve the standard of living by creating scope in farming round the year.

Components of IFS	Elements of IFS
1. Agriculture	1. Watershed
2. Horticulture	2. Farm ponds
3. Agro forestry and bio fencing	3. Bio-fertilizers
4. Fish farming (fishery)	4. Bio-pesticides
5. Dairy	5. Bio-gas
6. Mushroom cultivation	6. Solar energy
7. Apiculture (Bee keeping)	7. Compost making and green manure
8. Sericulture	8. Rain water harvesting
9. Poultry	
10. Sheep and goat rearing	
11. Piggery	
12. Rabbit rearing	
13. Azolla farming and fodder production	
14. Vermiculture	
15. Duck and pigeon rearing	
16. Nursery and seed production	
17. Kitchen gardening	
18. Value addition	

A pathway to sustainable environment

Overusing natural resources during the past few years has frequently led to short-term gains, but ultimately deteriorated soil fertility and production, as well as created ecological disparities. Serious issues with salinity, soil erosion, water logging, multitude of complicated pests and illnesses, threat and degradation of the environment, including air and water pollution, has been triggered by it.

Therefore, an efficient integrated farming system is needed in order to sustainably retain the land's productivity even after harvesting higher crop yields and to raise the land's productivity year after year. The long-term goals of such an integrated farming system need to be generating enough to satisfy the real demands and needs of society, be profitable on the part of the farmer, protect the natural resource base, and maintain a safe and healthy environment. Alternative integrated farming methods can be used respective to the variances in soils, local climatic conditions, and farmers' economic and social circumstances (Nadagouda, 2000). For the majority of farmers with small and marginal holdings, maintaining household food supplies has been a top priority. Due to their financial hardship and risky environments at work, farmers who fall into one of these groups are prime candidates for developing technology for interdisciplinary projects like farming system research. It proposes the creation of technologies through the integration of related components with already-existing crop components in order to maximise the productivity and profitability of each business while taking into account the priorities, socioeconomic circumstances, and resource availability of the farmer. Thus, a farming system is the proper combination of farm activities, such as crops, livestock, fishing, poultry, mushroom farming, and beekeeping. The resources available to the farms also serve as important manures for systemic recycling.

By recycling organic sources of nutrients from the respective components used, integrated farming system models for various situations can increase farm output, increase farmer income, and maintain soil productivity which preserves the environment in addition to generating viable income for the farmer (Dar *et al.*, 2018).

Nutrient cycling in farm

In IFS, replenishment of soil fertility status through substantial improvement in the post harvest available NPK nutrients could be achieved even with higher removal of nutrients through crop uptake by the application of recycled or composted pigeon and poultry manure combined with inorganic fertilizer. Application of 50% nitrogen through fertilizer and 50% through goat manure enhances the soil fertility status and provided better opportunity for recycling of manure to the crops. Continuous dairy based- farming system increases organic carbon and available status of nutrients (Dar *et al*., 2018). Integrated fish farming system utilizes the waste of agriculture, livestock and poultry by-products for fishery. The pond sludge becomes rich in nutrient by ongoing fish culture which can be further utilized as fertiliser for crops.

IFS's main goal is to recycle waste in order to save expense on fertiliser and manures and to create an environmentally friendly farming system. In order to meet household demand for the 4Fs (food, fodder, feed, and fuel), as well as recycling waste to meet the nutrient requirements of various components, the IFSs have been designed scientifically at various locations through All India Coordinated Research Project (AICRP). These modules include plantation crops, orchards, dairy, goat, sheep, poultry, fish, pigs, apiaries, and boundary plantations. In order to produce as many nutrients inside the farm as possible, recycling was primarily carried out through the creation of vermicompost (VC) at all places. Additional components like Azolla and biogas were also added (Panwar *et al.*, 2021).

In agriculture, mixed crop and livestock production system is one of the predominant forms of IFS. In the developing world population crop and livestock integrated system produces about one-half of the world's food (Hererro et al. 2009). They are characterized by a strong complimentarily in use of recourses, with outputs from one component being supplied to other components in system (Devendra and Thamas, 2002)

IFS and sustainable livelihood

The majority of the Indian economy is rural and agricultural in nature and marginal and small-scale farmers make up 76.2% of the farming population. Farmers can combine agricultural activities like dairy, poultry, pigeon, fisheries, sericulture, apiculture, etc., suitable to their agro-climatic and socio-economic conditions. The problem is made more difficult in India by the declining average farm size and financial restrictions on further investment in agriculture because 80% of farm households fall within the small and marginal farmer groups. Improved productivity may be a critical option for ensuring nutrition and food security for a large population. (Gupta *et al.*, 2020). IFS as a mixed farming system that consists of at least two separate but logically interdependent parts such as a crop and livestock enterprises. An aquaculture system can be integrated with animals in which fresh animal waste can be used to feed fish which can complement both the component and boost production. IFS takes into account the concepts of increasing production, minimizing risk and profits whilst improving the utilization of organic wastes and crop residues of the field

Role of IFS in Economic Upliftment

Integrated farming systems widen the scope of production through the mixed usage of the multiple components that are being used in the area. For the long term improvement of farmers' livelihoods, IFS may be a practical choice for boosting production and maintaining income flow. Livestock-fish-crop, or pig-fish-vegetable farming, is an environmentally viable integrated farming technique that is appropriate for small and marginal farmers from tribal communities in Assam, especially in the BTAD region (Brahma *et al.*, 2020). It is a low-cost technique that enables recycling of organic wastes and the best possible utilisation of the biological resources that are now available. Pig excrement is recycled in fish ponds, while extra livestock waste and nutrient-rich pond water are utilised to fertilise horticulture crops. The cost of producing fish is lowered by 60-70 percent when external feed and manure are not used, and the cost of producing horticulture crops is decreased by about 60 percent when organic wastes are used as manure. The use of poultry waste from fully built-up poultry litter recycled into fish ponds with fish production levels of 4.5–5.0 t fish ha-1 is an economically effective, straightforward, and well-tested method of integrating poultry and fish (Kumar *et al.*, 2022). The resource utilisation of the components makes the production cost cheaper which enables the farmer to cut expenses thereby generating more income.

By incorporating livestock into crop-based farming, (Ngambeki *et al.*, 1992) the system's profitability can be improved through increased financial gains and better use of intermediate farm resources such manure, draught power, and crop wastes. The integration of different components on varying-sized land holdings typically results in higher profits and more employment than arable farming alone. When compared to the conventional rice cropping system, the integration of poultry, mushrooms, and fish with rice cultivation over a five-year period increased net farm income and on-farm labour. Additionally, the comparative analysis suggested that diversification and resource management integration can be productive, profitable, and manageable given access (Singh *et al.,* 1993 and Singh *et al*., 1997).

Role of IFS in food security

Integrated Farming System (IFS) seems to be the key solution to the increase demand for farm sustainability, stability, food production and nutrition improvement with limited resources for the small and marginal farm community. In the scenario of the marginal and the poor farmers, the IFS systems can partially or completely meet the dietary demands of farm families from a small plot of land. As IFS offers opportunities to use land and time for growing short-duration vegetable crops, pulses, and livestock feed, these systems represent the future of the Indian agricultural system and can help to provide the majority of the staple foods consumed by small and marginal farmers in India (Parmesh *et al*., 2022).

An integrated crop-livestock system amongst many other systems (ICLS) is a sustainable agricultural system that can contribute to improving food security. Crop-livestock interactions in marginal situations can sustainably enhance the production of both food crops and livestock. Animal products like milk and meat give people 13% of the calories and 28% of the protein they need. In addition to providing for food requirements like meat and milk, ICLS also makes 50% of the grains. Crop leftovers are the primary source of animal feed in the majority of ICLS. Increased agricultural residue production under ICLS can be used as livestock feed without displacing production of human food (Sekaran *et al*., 2021).

Livestock is frequently regarded as a valuable asset in rural poor households. Having more livestock enables poor families to diversify their income, invest in small-scale businesses, and overcome poverty. Through the provision of animal sourced foods like meat and milk, livestock provide quality nutrients in addition to playing a crucial part in the operation of ICLS farms which improves food and nutritional security (Sekaran *et al.*, 2021). Animal source foods naturally include higher accessible micronutrients, such as iron, vitamin A, vitamin B12, and calcium, which are linked to improved immunological responses and stronger immune systems. It has been demonstrated that eating meals from animal sources, even in tiny amounts, can help provide dietary sufficiency and prevent undernourishment and nutritional deficiencies.

CONCLUSION

The land holdings of the marginal and the small scale farmers are small in size, but if properly managed, the adoption of integrated farming by marginal and small-scale farmers will guarantee a significant income generation and a variety of food to sustain the livelihood. On-farm integration of crops and livestock is advantageous to health by providing nutritious food, and has significance in promoting food security. By recycling by-products and leftovers from various system components, IFS helps to increase net income while reducing production costs. The constant labour demand for a system of numerous crops and livestock keeps farm families actively involved in farming activities, offering a possibility for more employment generation.

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Chapter - 20

Bio-Agriculture Paramount for Sustainability: Achieving a Sustainable Future

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Crop yields are dropping as a result of chemical farming, resulting in unsustainable farming practises, increasing input requirements, poor soil quality, and insect and disease infestations. Climate change and pesticide abuse have exacerbated the situation. Organic agricultural systems have the ability to address these concerns while also benefiting the environment, preserving resources, and enhancing food quality. However, scientists are sceptical that organic materials can provide all nutrients in significant quantities because they necessitate more connection between farmers and crops. Organic farming requires more labour than chemical/mechanical farming, but the outcomes are likely to be limited due to the careful care taken. Biofertilizers, microbial fertilizers, and bio-pesticides are living organisms that improve plant nutrient availability and uptake. They contribute to soil fertility and eco-friendliness, controlling pests and diseases in agriculture through nontoxic processes. India's growing awareness of bio-fertilizers, biofuels, and bio-pesticides drives the market for nutritious, high-yielding, and less resource-intensive crops.

Keywords: Bio-agriculture, bio fertilisers, organic farming, sustainable

INTRODUCTION

Despite the application of maximum chemical inputs, crop output is dropping day by day in the current agricultural context. The vicious loop of chemical farming is now being exposed in the form of increasing crop unsustainableness, greater input requirements, poor soil quality, and repeating pest and disease infestation. Furthermore, yield interference has become relatively predictable in the face of unexpected climatic circumstances in response to an increase in biotic potential under the pretence of climate change.

Pesticide use has escalated, with major health repercussions for both humans and the environment. Organic farming systems have increased in favour over the previous decade as some remedies to the agricultural sector's present difficulties. Organic farming has the ability to increase food quality while also benefiting the environment and conserving non-renewable resources. Organic farming is a societal imperative for both consumers and producers. Organic farming may become a cure for transforming rural agriculture into a well-sustainable agriculture capable of laying the groundwork for sustainable agriculture, recouping conversion expenses, and ensuring soil sustainability.

Many specialists and skilled farmers are skeptical that organic materials can provide all nutrients in adequate quantities. Even if the problem is overcome, they feel the organic matter available is insufficient to meet the requirements. In reality, organic farming demands more connection between a farmer and his crop, such as observation, timely intervention, and weed control. Because it requires more labour than chemical/mechanical agriculture, a single farmer may produce more crops using industrial methods than he or she could use just organic methods. Because of the tremendous care taken with organic farming, it is practically clear that the effects would be kept to a minimum.

Importance of bio-agriculture in agriculture

Bio-agriculture, also known as sustainable agriculture or organic farming, is important for several reasons:

1. **Environmental Sustainability**: Bio-agriculture emphasizes the use of natural and organic methods to cultivate crops, minimizing the use of synthetic pesticides, herbicides, and fertilizers. This approach reduces the negative impact of conventional agriculture on the environment, such as soil erosion, water pollution, and biodiversity loss. It promotes soil health and fertility, conserves water resources, and protects ecosystems.

2. **Human Health**: Bio-agriculture focuses on producing nutritious, high-quality food that is free from synthetic chemicals. It promotes the use of organic fertilizers and biological pest control methods, which result in lower pesticide residues in food. By reducing exposure to harmful chemicals, bio-agriculture helps protect human health and reduce the risk of pesticide-related diseases and allergies.

3. **Sustainable Resource Management**: Bio-agriculture emphasizes the efficient use of resources such as water, energy, and nutrients. It promotes practices like crop rotation, composting, and integrated pest management, which help maintain soil fertility and reduce the need for external inputs. This approach contributes to long-term sustainability by minimizing resource depletion and reducing dependence on non-renewable resources.

4. **Biodiversity Conservation**: Bio-agriculture practices support biodiversity conservation by creating a habitat for beneficial organisms like pollinators, natural predators, and soil microorganisms. By avoiding the use of synthetic chemicals, bio-agriculture helps preserve the natural balance and diversity of ecosystems, supporting the survival of various plant and animal species.

5. **Climate Change Mitigation**: Bio-agriculture can play a role in mitigating climate change. Organic farming practices, such as agroforestry, cover cropping, and organic soil management, can sequester carbon in the soil and reduce greenhouse gas emissions. Additionally, sustainable land management practices in bio-agriculture can contribute to better soil structure and water retention, making agricultural systems more resilient to climate change impacts.

6. **Rural Development and Food Security**: Bio-agriculture provides opportunities for small-scale farmers, helping them improve their livelihoods and create sustainable rural communities. By adopting organic farming practices, farmers can reduce production costs, increase market access for organic products, and enhance their economic stability. Bio-agriculture also promotes food security by diversifying crop production, reducing dependence on external inputs, and improving the resilience of agricultural systems to climate change and other challenges.

Overall, bio-agriculture offers a holistic and sustainable approach to food production that considers the long-term well-being of the environment, human health, and socioeconomic factors. By adopting these practices, we can create a more resilient and sustainable food system for future generations.

Biofertilizers

Biofertilizers, also known as microbial fertilizers, are living microorganisms that enhance the nutrient availability and uptake of plants. They contain beneficial bacteria, fungi, or algae that establish a symbiotic or associative relationship with plants, promoting their growth and development. These microorganisms contribute to the fertility of the soil and provide essential nutrients to plants in a sustainable and eco-friendly manner. Biofertilizers are alive or dormant cells that are applied to soil, seed, or seedlings to improve nutrient availability and uptake from the soil (Fasusi *et al.*, 2021).

Biofertilizers have gained significant importance in modern agriculture due to their numerous benefits and environmentally friendly nature. Here are some key reasons why biofertilizers are important:

1. Nutrient enrichment: Biofertilizers are rich in nitrogen-fixing bacteria, phosphate solubilizing bacteria, and other beneficial microorganisms. These microorganisms convert atmospheric nitrogen into a form that can be directly utilized by plants, making nitrogen more accessible. They also help in the solubilization of phosphorus and other nutrients present in the soil, enhancing their availability to plants. This nutrient enrichment promotes plant growth and improves crop yields.
2. Soil fertility improvement: Biofertilizers improve soil fertility and health by enhancing the microbial activity and organic matter content of the soil. They stimulate the growth of beneficial microorganisms and improve the overall soil structure. By promoting a healthy soil ecosystem, biofertilizers contribute to long-term soil fertility and reduce the dependence on chemical fertilizers.
3. Environmental sustainability: Unlike chemical fertilizers, biofertilizers are environmentally sustainable. They do not contribute to soil degradation or water pollution caused by excessive fertilizer application. Biofertilizers reduce the need for synthetic fertilizers, minimizing the release of harmful chemicals into the environment. They also help in reducing greenhouse gas emissions by improving nutrient use efficiency in plants.

4. **Cost-effectiveness**: Biofertilizers offer a cost-effective alternative to chemical fertilizers. While the initial investment in biofertilizers may be higher, their long-term benefits outweigh the costs. They improve nutrient availability and reduce the need for synthetic fertilizers, resulting in cost savings for farmers. Moreover, biofertilizers can be produced locally, reducing transportation costs and dependence on imported fertilizers.

5. **Sustainable agriculture**: Biofertilizers play a crucial role in promoting sustainable agriculture practices. By minimizing the use of chemical inputs, they support organic farming methods and reduce the ecological footprint of agriculture. Biofertilizers also enhance soil biodiversity and contribute to the overall ecological balance, fostering sustainable food production systems.

Overall, biofertilizers offer a sustainable and environmentally friendly approach to agriculture, promoting soil fertility, improving crop yields, and ensuring long-term agricultural sustainability.

PGPR as biofertilizer

Plant growth promoting bacteria (PGPB) are beneficial bacteria that colonize the rhizosphere (the area around the plant roots) and promote plant growth by various mechanisms. Researchers see a lot of potential in employing these PGPB as biofertilizers to grow a wide range of crops in a variety of environmental and climatic settings (Gouda *et al*., 2018). They have gained significant attention as biofertilizers due to their ability to enhance nutrient availability, stimulate plant growth, and protect plants from diseases. Bacteria such as Bacillus megaterium, Anabaena, Azolla, Bradyrhizobium, Bacillus polymyxa, Rhizobium, and Sinorhizobium, among others, are thought to be important for increasing growth yield and providing sustainability to plant growth and development (Olanrewaju *et al*., 2017). Here are some key points about PGPB as biofertilizers:

1. **Nutrient solubilization**: PGPB can solubilize insoluble forms of nutrients, such as phosphorus, making them more accessible to plants. They produce organic acids and enzymes that break down complex compounds, releasing nutrients that would otherwise remain unavailable.

2. Nitrogen fixation: Certain PGPB is capable of fixing atmospheric nitrogen into a form that plants can utilize. They convert nitrogen gas (N_2) into ammonia (NH_3) through the process of nitrogen fixation, which can significantly increase the nitrogen content in the soil.

3. Production of plant growth-promoting substances: PGPB can synthesize and release growth-promoting substances like auxins, cytokinins, and gibberellins, which are phytohormones that regulate plant growth and development. These substances promote root growth, enhance nutrient uptake, and stimulate plant growth.

4. Disease suppression: Some PGPB possess antagonistic properties against plant pathogens. They produce antibiotics, siderophores (iron-chelating compounds), and enzymes that inhibit the growth of harmful microorganisms. By colonizing the rhizosphere, PGPB can protect plants from pathogenic infections.

5. Induced systemic resistance: PGPB can trigger the plant's defense mechanisms, leading to systemic resistance against diseases. They can activate the plant's immune response, making it more resistant to various pathogens. This can help reduce the reliance on chemical pesticides.

6. Environmental sustainability: The use of PGPB as biofertilizers promotes sustainable agriculture. By enhancing nutrient availability and improving plant growth, they can reduce the need for synthetic fertilizers, minimizing the environmental impact associated with their production and use.

7. Crop-specific applications: Different PGPB strains may have specific effects on different crops. For example, some PGPB are more effective in promoting the growth of legumes, while others are beneficial for cereals or vegetables. Understanding the crop-specific requirements and selecting appropriate PGPB strains can optimize the benefits.

It's important to note that the effectiveness of PGPB as biofertilizers may vary depending on several factors, including the specific bacterial strains used, the crop and soil conditions, and the overall management practices. Further research and field trials are necessary to determine the best practices for the application of PGPB as biofertilizers in different agricultural systems.

Biopesticides

Biopesticides are a type of pest management tool derived from natural materials, such as plants, bacteria, fungi, or minerals. They are designed to control pests, including insects, weeds, and plant diseases, while minimizing harm to the environment, beneficial organisms, and human health. Unlike conventional chemical pesticides, biopesticides often have specific modes of action and target pests, making them more selective and environmentally friendly.Bio-pesticides are naturally occurring molecules derived from living organisms (natural enemies) or their products (microbial products, phytochemicals) or by-products (semiochemicals) that control pests through nontoxic processes (Salma and Jogen, 2011).

The importance of biopesticides lies in several key aspects:

1. Environmental friendliness: Biopesticides generally have minimal adverse effects on ecosystems and non-target organisms. They break down more quickly in the environment and leave fewer residues compared to synthetic pesticides, reducing contamination of soil, water, and air.
2. Reduced health risks: Biopesticides are often considered safer for human health and agricultural workers. They have lower toxicity levels, decreasing the risk of acute or chronic health issues associated with exposure to chemical pesticides.
3. Sustainable agriculture: Biopesticides play a crucial role in promoting sustainable agricultural practices. They offer effective pest control without depleting natural resources or causing long-term environmental damage. By preserving beneficial organisms and promoting ecological balance, they contribute to the overall health of agricultural systems.
4. Resistance management: Overreliance on chemical pesticides has led to the development of resistant pest populations, making pest control increasingly challenging. Biopesticides provide an alternative mode of action, helping to mitigate resistance development and prolong the effectiveness of pest management strategies.
5. Market demand and regulatory support: With growing concerns about food safety, environmental impact, and consumer preferences for organic and sustainable

products, the demand for biopesticides is increasing. Regulatory agencies worldwide are also encouraging the development and use of biopesticides, supporting their registration and ensuring their safety and efficacy.

6. Integrated Pest Management (IPM): Biopesticides are an integral part of IPM programs, which aim to combine multiple pest management strategies for optimal results. By integrating biopesticides with other methods like cultural practices, biological control, and monitoring, farmers can effectively manage pests while minimizing chemical inputs.

Overall, biopesticides offer a promising alternative to conventional chemical pesticides, addressing environmental concerns, human health risks, and sustainability goals in agriculture. Their continued development and adoption can contribute to a more environmentally friendly and sustainable approach to pest management.

Biocontrol agents

Biocontrol agents, also known as biological control agents or natural enemies, are living organisms that are used to control pests and diseases in agriculture. They can include various organisms such as predators, parasites, pathogens, and herbivores. These agents play a crucial role in integrated pest management (IPM) strategies, which aim to minimize the use of chemical pesticides and promote sustainable agriculture practices.

Here are some key points highlighting the importance of biocontrol agents in agriculture:

1. Effective Pest Control: Biocontrol agents can effectively suppress pest populations by directly consuming or parasitizing them. For example, ladybugs and lacewings are natural predators that feed on aphids, thereby reducing their numbers. This reduces the reliance on synthetic chemical pesticides, which can have adverse effects on the environment and human health.

2. Reduced Chemical Usage: Biocontrol agents provide an environmentally friendly alternative to chemical pesticides. By integrating them into pest management strategies, farmers can reduce the quantity and frequency of pesticide applications. This helps minimize chemical residues on crops, protect beneficial insects, and prevent the development of pesticide resistance in pests.

3. **Targeted Action**: Biocontrol agents often exhibit a high degree of specificity, meaning they target particular pests or diseases without harming beneficial organisms or non-target species. This specificity allows for precise pest management, minimizing the disruption to the ecosystem and preserving biodiversity.

4. **Long-Term Sustainability**: Incorporating biocontrol agents into agricultural systems promotes sustainable practices. Unlike chemical pesticides, which require continuous application, biocontrol agents can establish and sustain themselves over time, providing ongoing pest control without the need for repeated interventions. This leads to long-term benefits for both the environment and the farmer's economic viability.

5. **Low Environmental Impact**: Biocontrol agents are typically considered safe for the environment, as they occur naturally or can be carefully selected and introduced. They have minimal negative impacts on water resources, air quality, and soil health. Biocontrol agents can also be used in organic farming systems, which aim to minimize synthetic inputs and preserve ecological balance.

6. **Resistance Management**: Continuous use of chemical pesticides can lead to the development of resistance in pests, rendering these pesticides ineffective. By integrating biocontrol agents into pest management, the risk of resistance development is reduced. Biocontrol agents offer a complementary approach to chemical control, helping to prolong the effectiveness of pesticides when they are necessary.

Overall, biocontrol agents play a vital role in sustainable agriculture by providing effective pest control, reducing chemical usage, and promoting long-term environmental and economic sustainability. By harnessing the power of nature's own pest regulators, farmers can protect their crops while minimizing the negative impacts associated with conventional pest control method.

Bio-stimulants

These are substances or microorganisms that are applied to plants or soil to enhance plant growth, development, and overall productivity. They are used in agriculture to promote nutrient uptake, improve stress tolerance, and enhance crop quality. Biostimulants are defined as substance(s) and/or microorganisms that, when applied to crops or the rhizosphere, stimulate natural processes that improve nutrient uptake, nutrient efficiency, abiotic stress tolerance, and crop quality (Pereira, 2019). A plant biostimulant is any substance or microorganism applied to crops or soils with the aim to enhance nutrition efficiency, abiotic stress tolerance, and/or crop quality traits regardless of its nutrients content (Du Jardin, 2015).

The role of bio-stimulants in agriculture is multifaceted and can vary depending on the specific product and application. Some common roles and benefits of bio-stimulants include:

1. Enhanced nutrient uptake: Bio-stimulants can improve the absorption and utilization of nutrients by plants. They may contain compounds that enhance root development, increase nutrient availability, or stimulate microbial activity in the soil, leading to improved nutrient uptake and assimilation.

2. Increased stress tolerance: Bio-stimulants can help plants withstand various environmental stresses such as drought, extreme temperatures, salinity, or disease pressure. They often contain substances that stimulate plant defense mechanisms, enhance the synthesis of stress-related proteins, or promote the production of antioxidants, which protect plants against stress-induced damage.

3. Improved plant growth and development: Bio-stimulants can enhance plant growth parameters such as root and shoot development, vegetative growth, flowering, and fruit set. They may contain growth-promoting substances like plant hormones (e.g., auxins, cytokinins, and gibberellins), amino acids, vitamins, or other organic compounds that stimulate physiological processes and metabolic activities in plants.

4. Enhanced crop quality: Bio-stimulants can contribute to the improvement of crop quality characteristics such as color, flavor, nutritional value, shelf life, and post-harvest preservation. They can influence the synthesis of secondary metabolites in plants, including antioxidants, vitamins, pigments, and essential oils, which are responsible for the sensory and nutritional attributes of crops.

5. Environmental sustainability: The use of bio-stimulants can contribute to more sustainable agricultural practices. They often contain natural or biodegradable

substances and can reduce the reliance on synthetic fertilizers and pesticides, leading to decreased environmental impacts and improved soil health.

It's important to note that while bio-stimulants can provide numerous benefits to plants and agricultural systems, their effectiveness may vary depending on factors such as crop species, soil conditions, climatic conditions, and application methods. Additionally, the regulatory frameworks and definitions of bio-stimulants may vary across countries or region.

Market prospects

One of the important drivers driving the market in India is increased public awareness of the benefits of bio-fertilizers, biofuels, and bio-pesticides. Furthermore, there is an increase in demand for bio agriculture to produce nutritious, high-yielding, and less resource-intensive crops. This, combined with increased food consumption due to the country's growing population, is fueling the market's expansion. The market prospects of agriculture are generally positive due to several factors. Here are some key points to consider:

1. **Growing global population**: The world's population continues to increase, which leads to higher demand for food and agricultural products. As a result, the agricultural sector has the potential to expand and meet the rising food requirements.

2. **Technological advancements**: The agriculture industry is experiencing significant technological advancements, such as precision farming, automation, and the use of drones and sensors. These technologies enhance productivity, reduce costs, and optimize resource utilization, making agriculture more efficient and profitable.

3. **Sustainable and organic farming**: There is a growing consumer preference for sustainably produced and organic food products. This trend creates opportunities for farmers to adopt environmentally friendly practices, gain certification for organic farming, and access premium markets.

4. **Climate change and food security**: Climate change poses challenges to agriculture, such as unpredictable weather patterns, water scarcity, and increased pest outbreaks. As a result, there is a growing focus on climate-resilient farming practices

and technologies, including drought-resistant crops, precision irrigation, and greenhouse cultivation. These solutions contribute to food security and present market prospects for companies involved in climate-smart agriculture.

5. **Urbanization and vertical farming**: With increasing urbanization, there is a need to produce food closer to urban centres. Vertical farming, hydroponics, and aquaponics are gaining popularity as innovative approaches to cultivate crops in urban areas, using limited space and reducing transportation costs. These methods offer potential market opportunities and diversification in the agricultural sector.
6. **International trade and export opportunities**: Agriculture remains an essential sector for many countries' economies, and international trade in agricultural products continues to grow. Developing countries with competitive advantages in specific crops can benefit from export opportunities, while import-dependent countries seek to ensure a stable food supply through trade relationships.
7. **Value-added products and diversification**: Agriculture is not limited to traditional crop and livestock production. Value-added products such as processed foods, functional foods, and biofuels are gaining significance. Farmers and agribusinesses can explore diversification into these areas, providing new market prospects and revenue streams.

It's important to note that the agriculture sector also faces challenges such as market volatility, price fluctuations, access to finance, and changing government policies. However, with innovative approaches, technological integration, and a focus on sustainability, the market prospects for agriculture remain promising overall.

The future of bio-agriculture: A bright future ahead

The future looks very bright for bio-agriculture, also known as biotechnology in agriculture. Bio-agriculture involves the application of biological techniques and processes to enhance agricultural productivity, sustainability, and the nutritional value of crops. Here are a few reasons why the future of bio-agriculture is promising:

1. **Increased food production**: As the global population continues to grow, there is an increasing demand for food. Bio-agriculture offers solutions to increase crop yields and improve the quality of food produced. Through genetic engineering, scientists

can develop crops that are resistant to pests, diseases, and environmental stresses, leading to higher agricultural productivity.

2. **Environmental sustainability**: Bio-agriculture focuses on developing sustainable farming practices that reduce the environmental impact of agriculture. For example, genetically modified (GM) crops can be engineered to require fewer pesticides and fertilizers, reducing their runoff into water bodies. Additionally, bioagricultural techniques like precision farming and biological control of pests help minimize resource wastage and promote ecological balance.

3. **Improved nutritional value**: Bio-agriculture can contribute to enhancing the nutritional content of crops. Scientists can modify crops to produce higher levels of essential nutrients or develop biofortified varieties that are naturally enriched with vitamins and minerals. This has the potential to address malnutrition and improve public health.

4. **Disease resistance**: Crop diseases can devastate agricultural yields and lead to food shortages. Bioagricultural techniques, such as the development of disease-resistant crop varieties through genetic engineering, offer effective strategies to combat plant diseases. This can help farmers protect their crops and ensure stable food production.

5. **Innovation and research**: The field of bio-agriculture is constantly evolving, with ongoing research and technological advancements. Scientists are continuously discovering new ways to improve crop traits, increase productivity, and address agricultural challenges. This innovation-driven nature of bio-agriculture fuels its potential for further growth and development.

While bio-agriculture offers numerous benefits, it is important to address potential concerns related to the technology, such as biosafety, regulation, and public acceptance. These factors play a crucial role in shaping the future trajectory of bio-agriculture. Overall, with its potential to increase food production, promote sustainability, improve nutritional value, and combat agricultural challenges, bio-agriculture holds great promise for a brighter future in agriculture

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