Current Trends and Advances In AGRICULTURAL SCIENCES

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1. Biofortification: Process to Overcome the Nutrient Deficiency

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Abstract:

Nearly half of the world's population is known to suffer from micronutrient malnutrition, which is one of the greatest threats to mankind. Since plant breeding has aimed to increase yield or other major agronomic traits mainly rather than nutritional quality, other attempts to address the issue have mainly focused on industrial fortification or pharmaceutical supplementation. Women and young children are particularly prone to micronutrient malnutrition, also known as the "hidden hunger," which is primarily caused by inadequate dietary intake of micronutrients. Malnutrition or hidden hunger mitigation may be achieved through biofortification, the process of increasing the bioavailable amounts of key micronutrients in consumable parts of crop plants, agronomically or genetically. Crops are being targeted for greater micronutrient content by traditional and transgenic breeding techniques. Many cultivars have been released, and more traditional and transgenic varieties are in the breeding pipeline. Biofortification is a potential intervention for *addressing hidden hunger, as shown by the findings of efficacy and effectiveness studies. This chapter highlights different interventions to mitigate micronutrient malnutrition and future challenges of biofortification.*

Keywords:

Hidden hunger, Biofortification, Genetic improvement, Genetic engineering, micronutrients

1.1 Introduction:

Earlier, agricultural research in the lower income countries concentrated on boosting cereal production, which resulted in increased food grain production by manifold. In current scenario, agriculture must now produce more nutrient rich food grains in addition to more calories (Kennedy et al., 2003). Micronutrient malnutrition affects nearly half of the world's population as the majority of world's population relies on plant-based food for daily calory intake. Plant based foods contains generally lower level of key micronutrients, hence plant-based diets are unable to meet the recommended daily allowance (RDA). Since living beings are unable to synthesize these key micronutrients, they needed to be supplied through the diet (Bouis et al., 2011; Dutta et al., 2020; Sharma et al., 2021). Iron (Fe) and zinc (Zn) deficiency are two key micronutrient deficiency. Nearly 2 billion people are affected by zinc deficiency. Children and expectant mothers are more risk prone to Zn inadequacy. About 25% children and 37% pregnant women are anemic due to Fe deficiency (www.harvestplus.org). Such deficiency results in poor growth and development and affects longevity of life (Yadava et al., 2018). Biofortification is a process of breeding micronutrients into food crops, by which more micronutrients can be delivered over a long period of time in relatively inexpensive and sustainable way (Bouis, 1999; Heck et al., 2020). Though biofortified food crops cannot provide as high level of key micronutrients as provided by industrially fortified food, still daily intake can provide adequate amount of nutrients (Bouis et al., 2011). However, biofortification alone is not expected to eradicate micronutrient malnutritions in all population groups, so the issue of micronutrient malnutrition cannot be resolved by a single intervention, but biofortification complements well with other existing approaches to provide the most vulnerable populations with micronutrients in a cost-effective and sustainable manner (Meenakshi et al., 2010; Qaim et al., 2007). Rural populations that are undernourished due to inaccessibility to a variety of diets, supplemented foods, and industrially fortified foods may benefit from biofortification. The goal of the biofortification approach is to introduce the nutrient-rich traits into popular cultivars having desirable agronomic and dietary traits, like better yield. Contrary to existing interventions like industrial fortification and food supplementation, which start in urban areas, surplus production of these biofortified food crops may reach at markets, thus becoming available first to rural people and then urban people. An initial and one-time investment in a crop biofortification programme can result in micronutrient-dense popular cultivars available to the farmers to cultivate, in contrast to industrial fortification, where the continue flow of financial resources is necessary. The advantages of the initial investment can be multiplied by evaluating the performance of varieties bred for one country in other countries or locations and adapting them to those conditions. Agronomic interventions, conventional plant breeding, molecular plant breeding and transgenic biofortification are currently the most popular approaches in addition to industrial fortification interventions. Through increased application of fertilizers, agronomic biofortification can temporarily increase micronutrient levels. Though this can complement the plant breeding interventions, still further insight is needed. Like foliar application of Zn fertilizer resulted into increment of Z content in wheat grain up to 20 ppm, but only for the one season (Zou et al., 2012). Through conventional plant breeding, biofortification involves crossing of vitamins and mineral rich elite parents' generation after generation to create agronomically superior plants with optimum level of nutrients. When a crop lacks the genetic variability for the nutrient naturally or when it is impossible to successfully breed in sufficient quantities of bioavailable micronutrients, transgenic approaches are advantageous. Once a transgenic event has been created, it takes years of backcrossing and traditional breeding to transfer transgene ito elite parents and ensuring the stable inheritance of transgene. While transgenic breeding can occasionally provide micronutrient increments other than conventionally available cultivars, many countries do not have the necessary legal frameworks in place to permit the release and cultivation of such genetically modified varieties.

1.2 Interventions to Address Micronutrient Deficiencies:

The malnutrition caused by inadequacy of micronutrient in calorie-dense but vitamins and/or minerals deficient human diets is termed as "hidden hunger." A significant portion of the global population consumes diets that are deficient in key micronutrients such as iron, zinc, iodine, calcium etc., which has an impact on human health and longevity and, consequently, on national economies (White and Broadley, 2009). A brief description of different biofortification interventions is provided below –

1.2.1 Dietary Diversification:

The requirements of all essential nutrients cannot be satisfied by a one type of food. To meet all of the nutritional needs of our body, a balanced diet is necessary. Balanced diet refers to a selection of such food combinations that fulfills requirements of every nutrient needed for overall growth and development of human.

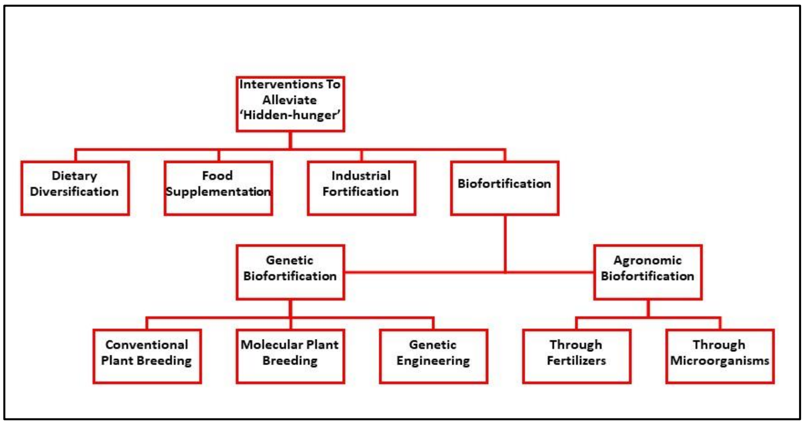

Figure 1.1: Different Interventions to Address Micronutrient Malnutrition

The importance of micronutrients is increased by the fact that availability of micronutrients in soil, genetic variability, fertilizer application, and package and practices to rear a crop all affect how much of micronutrients foods contain. Dietary diversification over the long term provides a healthy diet with an adequate balance of energy sources, necessary minerals, and dietary fiber content. Despite the fact that dietary diversity is an effective and sustainable method of preventing hidden hunger, different cultivation methods may affect the micronutrient concentration in a given food product (Thompson and Amoroso, 2010). While most people can get enough nutrition from foods like pulses, food grains, leafy vegetables, fruits, and animal products, some population groups, like pregnant women, require supplementation because their needs are higher (FAO, 2013). Children may need different amounts of nutrients at different stages of their growth. Therefore, for typical human nutrition and health, a mix of various types of nutritionally balanced foods is needed.

1.2.2 Food Supplementation:

The term "supplementation" refers to including additional micronutrients in a person's diet to make up for nutritional deficiencies. Pills or mineral tablets distribution schemes are one among the promising short-term approaches which has helped in improving nutritional health. This aids in easing severe mineral deficiencies, but it is not feasible for large populations thus must be replaced as soon as possible with biofortification. In developed nations with few cases of nutrient deficiencies, supplementation is concentrated on a relatively small group affected with certain insufficiencies. Supplementation is strongly advised in low-income nations which are highly malnutritional (Nantel and Tontisirin 2002). However, because people live in isolated, rural areas with difficult accessibility, supplementation programmes can be expensive and challenging to sustain in developing countries. Vitamin A supplementation was one of the most economical approaches globally which helped in increased child survival (Edejer et al., 2005; Shrimpton and Schultink, 2002). Because vitamin A supplementation is linked to a lower risk of death from all causes, it is frequently incorporated into national health policies (Imdad et al., 2010). Supplemental vit A was generally given to children at risk between the ages of 6 months and 5 years (UNICEF, 2007). Supplementation of other micronutrients like amino acids, folic acid, zinc, iron, and others that are deficient in the body is less common. Iron-folate supplementation is sometimes required to expectant mothers, but due to a lack of resources, this is uncommon in developing nations. However, to avoid maternal anaemia, low birth weights, and immature births, the WHO advises pregnant women to take 400 mg of folic acid daily in addition to 30-60 mg of iron (WHO, 2016b).

1.2.3 Industrial Fortification:

The process of food fortification involves adding nutrients to food in order to maintain or raise the standard of a population's diet. Food fortification is needed since people suffer from insufficiency of vitamins and minerals as they mostly rely on processed foods. Consumers can obtain the necessary amount of nutrients in their food thanks to industrial fortification, where certain amounts of nutrients are added to foods while processing. One sustainable and comparatively affordable public health measure is the augmentation of table salt with iodine. The number of countries with an iodine deficiency has decreased from 54 to 32 since 2003, and nearly three-fourth of the population has iodized salt in their reach globally (Andersson et al., 2012). Vitamin B-complex, Fe and Zn rich wheat flour and vitamin A-fortified edible oil are two additional examples of fortification. Since urban people have more access to industrially processed and fortified edibles, fortification may be more effective; however, it is challenging for rural consumers to get benefited from food fortification. There are a number of drawbacks associated with food fortification. It may be hard to find out the proper micronutrient amounts, consumers preference and others such as cooking may decrease nutrient content and nutrient bioavailability. To use food fortification strategies effectively and sustainably, stakeholders including policymakers, researchers, economists, etc. must actively coordinate.

In the recent years, traditional food fortification programmes are being supports by new public sector initiatives such as: Micronutrient Initiative (Canada), The Flour processing approach (Emory University), The “Mid-Day Meal Scheme” (India) and the “Global Alliance for Improved Nutrition” (GAIN, Geneva).

The International Zinc Nutrition Consultative Group and the “Network for Sustained Elimination of Iodine Deficiency” are two more significant international initiatives. Additionally, initiatives are being made to establish geographical standards for fortification. According to the “Flour Fortification Initiative”, which assesses global development, 26% of the world's marketed wheat flour is processed, helping 1.8 billion people globally.

Industrial processing only applies to marketed products, so it may not benefit in rural communities, where people obtain their food through noncommercialized channels. With such restrictions, it is obvious that industrial food fortification cannot, in the medium term, solve the issue of micronutrient deficiencies completely.

1.2.4 Biofortification:

To enhance the levels of micronutrients in edible parts, this can be achieved by traditional breeding or molecular breeding or by genetic engineering. Mineral element deficiencies in food crops may result from a variety of factors, including mineral-deficient soils, lowered mineral availability for uptake due to factors like high pH, limited distribution/translocation of ions, and mineral accumulation in parts of food crops that are not edible. Biofortification has been suggested as a long-term alternative to conventional interventions because their effectiveness in enhancing mineral nutrition is limited (Zhu et al., 2007). Biofortification focuses to raise not only the nutrient levels but also increased bioavailability in the consumable part of food crops and thus improving the mineral nutritional qualities of crops at the source. The only way to increase bioavailability is by breeding, whereas the former can be accomplished agronomically as well as genetically.

Plant breeding or genetic engineering, both are comparable, yet from agronomic approaches where the former approaches involve the change in genetic architecture of target crop. Although their scopes are different, both genetic engineering and plant breeding aim to develop such genotypes having alleles/combination of alleles that effectively accumulates bioavailable nutrients, but genetic engineering provides ways to introduce alleles from any source, whereas breeding attains this by combining the nutrient-dense high yielding lines and selecting those with favourable traits generation after generation.

Genetic engineering and plant breeding, in contrast to conventional intervention strategies, are both environmentally and economically feasible (Stein et al., 2008). On long terms, biofortification is also likely to be more feasible than traditional approaches because it avoids dependence on infrastructure for industrial fortification. In addition, plants absorb nutrients that are bioavailable *per se* and add to the food's flavour and test. Economic studies have demonstrated numerous promising health benefits of biofortification programmes, particularly when used in collaboration with traditional techniques (Buois 2002; Stein et al., 2008).

A. Conventional Plant Breeding Approaches:

By utilizing the natural genetic variation, plant breeding programmes aim to increase the amount and bioavailability of minerals in staple crops (Welch and Graham 2005). Discovering genetic variation for micronutrient traits, evaluating their stable inheritance under various environment and determining economic viability of breeding for higher nutrients availability in consumable parts keeping yield and quality parameters intact are some conventional breeding approaches. Conventional breeding, however, has its limitations since it relies on genetic diversity that is already present and usable in the crop to add nutritionally important traits or, rarely uses wild relatives with cross compatibility. One such successful event is quality protein maize (QPM), where years of traditional breeding efforts created cultivars with wide acceptance.

It has been anticipated that more Fe and Zn in the plant may, according to some reports, also lead to increased yield. This is the case with Fe and Zn in rice and wheat. Other biofortified crops have been released for both minerals and yield traits, such as the orange-fleshed sweet potatoes in Africa (Unnevehr et al., 2007). The majority of cereal varities have little variation in their kernel Fe and Zn contents (Bouis, 2003; Rawat et al., 2009). At CIMMYT, germplasm screening programmes in wheat for iron and zinc under various environments has provided insights into genetic variation. From maxica wheat accessions, Graham et al., (1999) found a range of 25.2-53.3 µg/g for zinc and 28.8-56.5 µg/g for iron. Wheat germplasm contains enough genetic diversity to significantly raise Fe and Zn concentrations in wheat grain. The concentrations of kernel Fe and Zn in the examined wheat lines showed a strong correlation.

These results suggested scope of simultaneous improvement of Fe and Zn content in wheat via plant breeding (Chhuneja et al., 2006). It has been reported that wild relatives have grain Fe and Zn content that is three to four times more than that of modern hexaploidy wheat cultivars (Rawat et al., 2009).

B. Molecular Plant Breeding Approaches:

Recent advances in plant breeding have enabled breeder to achieve the breeding targets in a faster, though more reliable way. There are several reports available on QTLs for grain micronutrient traits in cereals, particularly in wheat and rice. According to reports, wild wheat and *Aegilops* have genes for high grain Fe and Zn content on chromosomes 2 and 7. Three quantitative trait loci (QTLs) for grain Fe and Zn content have already been identified on chromosomes 2A and 7A in recombinant inbred lines (RIL) population of diploid wheat

(Tiwari et al., 2009, 2010). RIL population from tetraploid wheat *T. durum-T. dicoccoides*, Peleg et al., (2009) also identified three significant quantitative trait loci (QTLs) for kernel Fe and Zn concentrations. In a Hanxuan10 x Lumai14 double haploid wheat population, Shi et al., (2008) identified number of QTLs on chromosomes 1A, 2D, 3A, 4A, 4D, 5A, and 7A for Zn content. In rice a number of QTLs have been mapped on chromosome 1, 3, 5, 7 and 12 (Anuradha et al., 2012).

C. Genetic Engineering Approaches:

It has been successfully shown that genetic engineering has the potential to enhance the nutrient level in edible crops. Increased provitamin A concentrations have been developed in genetically modified (GM) tomato (De Steur et al., 2015). Biofortification goals such as increase soil uptake, improve micronutrient transport to shoots and grains, increase the sequestration of ions in endosperm, and decrease anti-nutritional factors in kernels can be achieved by genetic engineering. Suzuki et al., (2003) reported that human lactoferrin, a primary Fe-binding protein in milk, is expressed at very high levels in rice. The recombined lactoferrin was demonstrated to be completely iron saturated.

Similar to this, Goto et al., (1999) inserted ferritin from soybean into rice, and it was discovered that some transformants had iron contents twice as much as wild-type rice. Naqvi et al., (2009) created transgenic maize inbred and found simultaneous alteration of three distinct metabolic pathways specifically increased vitamin level in the endosperm. The transgenic kernels had 169 times as much beta-carotene, six times as much ascorbate, and twice as much folate.

D. Agronomic Approaches:

There are a number of non-genetic strategies that can be taken to enhance nutrient level in the consumable parts. Greater minerals availability in the soil for roots to uptake, these include management techniques, fertilizer application of key micronutrients, and enhancing soil organic matter.

Applying fertilizers and/or enhancing the solubility and mobility of minerals in the soil are two common agronomic practices to enhance the concentrations of elements in edible parts (White and Broadley 2009). The former is achieved by foliar or soil application of fertilizers, while later is achieved by use of micro-organisms. It is common practice to apply concentrated doses of fertilizers to the soil or the leaves of plants when growing crops cannot utilize nutrient available in the soil immediately. Foliar applications of soluble fertilizers are used when mineral elements are difficult to transfer to edible tissues.

1.3 Future Challenges for Biofortified Crops

Success of a crop biofortification programme is assessed on three parameters - if the raise in micronutrient level has significant impact on nutritional status; if the increased amount of micronutrient is bioavailable or not; if the farmers will adopt biofortified varieties or consumers will buy or consume it. Thus, crop biofortification faces following challenges –

1.3.1 Performance of Biofortified Crop:

High yields, pest and disease resistance, and other desirable agronomic traits can all be maintained while incorporating high nutrient and vitamins into the consumable foods. Farmers won't use biofortified staple crops if they lack desirable agronomic traits, or they are inferior in yielding ability, so every released cultivar must be competent enough with currently cultivated or already popular varieties to be successfully adopted by farmers

1.3.2 Acceptance of Genetically Modified Crops:

Several transgenic biofortified crops with novel agronomic traits are currently being developed (e.g., disease resistance). Although transgenic methods may shorten time to market, there is still a lot of opposition to transgenic crops. Also, many of the developing nations are not having regulations for testing and release of genetically modified biofortified crops.

1.4 Conclusion:

There are significant gaps in our understanding of biofortification; additional efficiency trials and studies are required to support and supplement the promising evidence we have so far. Transgenic methods have greater potential in achieving this than traditional breeding in the breeding multi-nutrients and vitamins into single variety, making breeding more cost-effective. Additionally, biofortification is secondary to current interventions, but each target country must be taken into account to determine the best combination of biofortification, supplementation, industrial fortification, and dietary diversification. Additionally, there needs to be better coordination between these programmes. The assessment of potential risks associated with excessive intake must be taken into consideration, along with food safety and quality assurance. Possible allergies and ill-effects linked to increased nutrient intake still need to be thoroughly researched while keeping environmental changes in mind. On food content information and health claims, it is important to highlight international standards and national regulations. The biofortification strategy needs to be modified to work within the country's regulatory framework. Approaches to biofortification should be balanced, and coordination with other public strategies needs to be prioritized. Although conventional breeding improvements are not regulated, the transgenic approach needs the proper regulatory framework to be adapted.

1.5 References:

1. Andersson, M., Karumbunathan, V., Zimmermann, M. B. (2012). Global iodine status in 2011 and trends over the past decade. *J. Nutr*. 142, 744–750.
2. Anuradha, K., Agarwal, S., Rao, V., Viraktamath, B. C., Sarla, N. (2012). Mapping QTLs and Candidate Genes for Iron and Zinc Concentrations in Unpolished Rice of Madhukar×Swarna RILs. *Gene* 508(2): 233–40.
3. Bouis, H. E. (1999). Economics of enhanced micronutrient density in food staples. *Field Crops Research* 60, 165–173.
4. Bouis, H. E. (2003). Micronutrient fortification of plants through plant breeding: can it improve nutrition in man at low cost? *Proc. Nutr. Soc*. 62, 403–411.

5. Bouis, H. E., Hotz, C., McClafferty, B., Meenakshi, J. V., Pfeiffer, W. H. (2011). Biofortification: a new tool to reduce micronutrient malnutrition. *Food and Nutrition Bulletin* 32 (Suppl. 1), 31S–40S.
6. Buois, H. E. (2002). Plant breeding: a new tool for fighting micronutrient malnutrition. *J Nutr* 132:491S–494S.
7. Chhuneja, P., Dhaliwal, H. S., Bains, N. S., Singh, K. (2006). *Aegilops kotschyi* and *Aegilops tauschii* as sources for higher levels of grain iron and zinc. *Plant Breed*. 125, 529–531.
8. De Steur, H., Blancquaert, D., Strobbe, S., Lambert, W., Gellynck, X., Van, D. S. D. (2015). Status and market potential of transgenic biofortified crops. *Nat. Biotechnol*. 33, 25–29.
9. Dutta, S., Muthusamy, V., Hossain, F., Baveja, A., Chhabra, R., Jha, S. K., Yadava, D. K., Zunjare, R. U. (2020). Analysis of genetic variability for retention of kernel carotenoids in sub-tropically adapted biofortified maize under different storage conditions. *Journal of Cereal Science* 93, 102987.
10. Edejer, T. T., Aikins, M., Black, R., Wolfson, L., Hutubessy, R., Evans, D. B. (2005). Cost effectiveness analysis of strategies for child health in developing countries. *Br. Med. J*. 331, 1177–1182.
11. FAO, 2013. The state of food insecurity in the world, Rome Government of India (2011). State of the Economy and Prospects Economic Survey. Ministry of Finance, Government of India, New Delhi.
12. Goto, F., Yoshihara, T., Shigemoto, N., Toki, S., Takaiwa, F. (1999). Iron fortification of rice seed by the soybean ferritin gene. *Nat. Biotechnol*. 17, 282–286.
13. Graham, R., Senadhira, D., Beebe, S., Iglesias, C., Monasterio, I. (1999). Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. *Field Crop. Res*. 60, 57–80.
14. Heck, S., Campos, H., Barker, I., Okello, J. J., Baral, A., Boy, E., Brown, L., Birol, E. (2020). Resilient agri-food systems for nutrition amidst COVID-19: evidence and lessons from food-based approaches to overcome micronutrient deficiency and rebuild livelihoods after crises. *Food Security* 12, 823–830.
15. Imdad, A., Herzer, K., Mayo-Wilson, E., Yakoob, M. Y., Bhutta, Z. A. (2010). Vitamin A supplementation for preventing morbidity and mortality in children from 6 months to 5 years of age. *Cochrane Database Syst. Rev.*
16. Kennedy, G., Nantel, G., Shetty, P. (2003). The scourge of ‘‘hidden hunger’’: global dimensions of micronutrient deficiencies. *Food, Nutrition & Agriculture* 32, 8–16.
17. Meenakshi, J. V., Johnson, N., Manyong, V., DeGroote, H., Javelosa, J., Yanggen, D., Naher, F., et al. (2010). How cost-effective is biofortification in combating micronutrient malnutrition? An *ex-ante* assessment. *World Development* 38 (1), 64–75.
18. Nantel, G., Tontisirin, K. (2002). Policy and sustainability issues. 132: S839–S844.
19. Naqvi, S., Zhu, C., Farre, G., Ramessar, K., Bassie, L., Breitenbach, J., et al. (2009). Transgenic multivitamin corn through biofortification of endosperm with three vitamins representing three distinct metabolic pathways. *Proc. Nat. Acad. Sci. U.S.A*. 106, 7762–7767.
20. Peleg, Z., Cakmak, I., Ozturk, L., Yazici, A., Jun, Y., Budak, H. et al. (2009). Quantitative trait loci conferring grain mineral nutrient concentrations in durum wheat x wild emmer wheat RIL population. *Theor. Appl. Genet*. 119, 353–369.

21. Peleg, Z., Cakmak, I., Ozturk, L., Yazici, A., Jun, Y., Budak, H., et al. (2009). Quantitative trait loci conferring grain mineral nutrient concentrations in durum wheat x wild emmer wheat RIL population. *Theor. Appl. Genet*. 119, 353–369.
22. Qaim, M., Stein, A. J., Meenakshi, J. V. (2007). Economics of biofortification. *Agricultural Economics* 37, 119–133.
23. Rawat, N., Tiwari, V. K., Singh, N., Randhawa, G. S., Singh, K., Chhuneja, P., et al. (2009). Evaluation and utilization of Aegilops and wild Triticum species for enhancing iron and zinc content in wheat. *Genet. Resour. Crop. Evol*. 56, 53–64.
24. Sharma, D., Chhabra, R., Muthusamy, V., Zunjare, R. U., Hossain, F. (2021). Molecular characterization of elite maize (Zea mays L.) inbreds using markers associated with iron and zinc transporter genes. *Genetic Resources and Crop Evolution* 68, 1545–1556.
25. Shrimpton, R., Schultink, W. (2002). Can supplements help meet the micronutrient needs of the developing world? *Proc Nutr Soc* 61:223–229.
26. Stein, A. J., Meenakshi, J. V., Qaim, M., Nestel, P., Sachdev, H. P. S., Bhutta, Z. A. (2008). Potential impacts of iron biofortification in India. *Soc Sci Med* 66 (8):1797–1808.
27. Suzuki, Y. A., Kelleher, S. L., Yalda, D., Wu, L., Huang, J., Huang, N. et al. (2003). Expression, characterization and biological activity of recombinant human lactoferrin in rice. J. *Pediatr. Gastroenterol. Nutr.* 36, 190–199.
28. The United Nations Children's Fund (UNICEF), 2007. Vitamin A Supplementation: A Decade of Progress. UNICEF, New York, NY, ISBN: 978-92-806-4150-9.
29. Thompson, B., Amoroso, L. (2010). Combating micronutrients deficiencies: food-based approaches. Food and Agricultural Organization of the United Nations and CAB International, Rome.
30. Tiwari, V. K., Rawat, N., Chhuneja, P., Neelam, K., Aggarwal, R., Randhawa, G. S., et al. (2009). Mapping of quantitative trait loci for grain iron and zinc concentration in diploid A genome wheat. *J. Hered*. 100, 771–776.
31. Tiwari, V. K., Rawat, N., Neelam, K., Kumar, S., Randhawa, G. S., Dhaliwal, H. S. (2010). Substitution of 2S and 7U chromosomes of *Aegilops kotschyi* in wheat enhances grain iron and zinc concentration. *Theor. Appl. Genet*. 121, 259–269.
32. Unnevehr, L., Pray, C., Paarlberg, R. (2007). Addressing micronutrient deficiencies: alternative interventions and technologies. *AgBioforum* 10(3):124–134.
33. Welch, R. M., Graham, R. D. (2005). Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops. *J Trace Elem Med Biol* 18:299–307.
34. White, P. J., Broadley, M. R. (2009). Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytol* 182:49–84.
35. WHO, 2016b. WHO Recommendations on Antenatal Care for a Positive Pregnancy Experience. World Health Organization, Geneva.
36. Yadava, D. K., Hossain, F., Mohapatra, T. (2018). Nutritional security through crop biofortification in India: status & future prospects. *The Indian Journal of Medical Research* 148, 621–631.
37. Zhu, C., Naqvi, S., Gomez-Galera, S., Pelacho, A. M., Capell, T., Christou, P. (2007). Transgenic strategies for the nutritional enhancement of plants. *Trends Plant Sci* 12(12):548–555.
38. Zou, C. Q., Zhang, Y., Rashid, A., Ram, H., Savasli, E., Arisoy, R. Z., Oritz-Monasterio, I., et al. (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant Soil* 361, 119–130.

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2. Novel Plant Breeding Techniques: A Solution to Climate Change

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Abstract:

Climate change poses a significant threat to global food security, as it results in reduced crop productivity worldwide. As the global population is expected to exceed 10 billion in the coming years, ensuring food security has become a major concern. Meeting the ever-increasing demand for food production is a challenging task due to the continuously changing environment, crop diseases, and increasing population. Plant breeders are using conventional breeding methods based on plant biology to increase production.

However, these traditional approaches are time-consuming and require significant space and inputs to release improved crop varieties after making crosses. Recent advances in genomics, high-throughput phenomics, sequencing and breeding methodologies, and state-of-the-art genome-editing tools integrated with artificial intelligence offer new opportunities for accelerated development of climate-resilient crops. In recent years, researchers have made remarkable achievements using these technologies, leading to revolutionary developments. Using a comprehensive approach, novel breeding techniques show potential in addressing climate change and producing crop varieties that are better adapted to the changing environment.

Keywords:

Climate change, food security, next-generation breeding, genomics, genome editing, CRISPR/Cas, abiotic stress, crop improvement

2.1 Introduction:

As the world population grows at an alarming rate while available land is decreasing, modern agricultural practices are struggling to produce enough food to sustain approximately 10 billion people by 2050 (Hickey *et al.*, 2019). Climate change and the consequent rise in CO2 levels have had a negative impact on water-use efficiency, biosecurity, and crop quality, as well as increased the frequency of abiotic stressors like heat, salinity, and drought, as well as biotic stressors like pests and diseases. Furthermore, climate change is projected to cause biodiversity loss, particularly in less hospitable environments. Drought alone is expected to lower crop yield in half of the world's arable land by 50% over the next five decades (Dhankher *et al.,* 2018). It has been projected that, for each degree Celsius increase in the global average temperature, global yields of major crops like wheat, rice, maize, and soybean could decrease by 6.0%, 3.2%, 7.4%, and 3.1%, respectively (Zhao *et al.*, 2017). Plant breeding has played an important role in altering agriculture to fulfill the growing demand for food throughout history. **Figure 2.1** highlights some of the key milestones achieved in the history of plant breeding. The ultimate objective of plant breeding is to develop genetically superior genotypes/varieties that are suitable for specific environments, leading to higher production (Falconer and Mackay, 1996). The advent of molecular biology and biotechnology has resulted in a massive rise of genetic data connected to genes and QTLs (Quantitative Trait Loci), which can aid in the acceleration of breeding operations (Wang, 2007). Progress in precise phenotyping and genotyping provides enormous opportunity to establish crop varieties that can adjust to changing climatic circumstances, hence enhancing plant breeding activities to create climate-resilient cultivars (Gobu *et al.*, 2020). As a result, developing climate-resilient cultivars using novel breeding strategies is crucial for ensuring food security in harsh climatic situations.

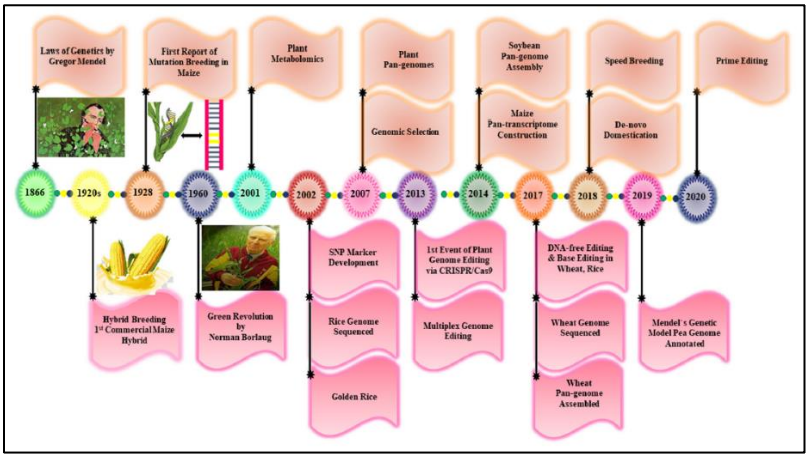

Figure 2.1 Representations of the key milestones achieved by conventional and modern plant breeding. (Razzaq *et al.,* 2021)

Classical plant breeding typically involves hybridization and rigorous screening to select elite crop varieties (Purugganan and Fuller, 2009). This method includes genetic diversity by intercrossing plants with novel agronomic traits, such as wild relatives or crop landraces, in order to select the best genotypes with extraordinary qualities. (Lavarenne *et al.,* 2018). Wild populations are a valuable resource for crop improvement because they offer greater genetic diversity and the opportunity to introduce desired traits. For example, hybridization among species can introduce diverse genetic recombination, which may provide an excellent chance to combat climate stresses (Becker *et al.,* 2013). Conventional breeding approaches, on the other hand, have limited utility due to genetic drag, genetic erosion, hybridization bottlenecks, and labarious selection processes. (Abberton *et al.,* 2016). Developing a crop variety with desirable qualities might take 10-20 years using traditional methods, making it a difficult and time-consuming process. (Fischer *et al.,* 2014). In contrast, modern breeding approaches have made significant progress in overcoming the obstacles posed by conventional methods over the last three decades.

The advancement of omics technologies has had a substantial impact on crop improvement efforts. These technologies have provided crop breeders with powerful tools and have played a vital role in omics-assisted breeding programs aiming at improving different agronomic traits. Omics technology is a modern molecular tool that helps us understand the functional genomic systems within organisms. The term "omics" is derived from the Greek word "ome," which means "whole." Omics disciplines study different kinds of biological molecules that make up whole biological systems. Some of the key omics disciplines include genomics (study of an organism's entire genome), transcriptomics (study of an organism's complete set of RNA transcripts), proteomics (study of set of proteins produced in an organism), metabolomics (study of complete set of small molecules/metabolites of an organism), and phenomics (study of complete set of observable traits of an organism). The integration of omics technologies into crop breeding programs has provided breeders with a wealth of information about the genetic and molecular basis of agronomic traits. This knowledge allows for more precise and efficient selection of desirable traits during the breeding process. Omics-assisted breeding programs can identify genetic markers associated with specific traits, accelerate the breeding process, and enhance the overall effectiveness of crop improvement efforts.

2.2 Marker Assisted Breeding:

Recent advances in biotechnology have opened up new avenues for crop improvement by offering a better understanding of the genetic variables that determine desired features. The use of molecular markers such as restriction fragment length polymorphism (RFLP), Rapid Amplified Polymorphic DNA (RAPD), Simple Sequence repeat (SSR), Cleaved amplified polymorphic sequence (CAPS), and Single Nucleotide Polymorphism (SNP) has significantly helped this process and revolutionized plant genetics (Nadeem *et al.,* 2018). Crop breeding's ultimate goal is to create high-performing varieties with numerous desirable features, such as high yield, higher quality, tolerance/resistance to biotic and abiotic stress, and good environmental adaptation. Traditional breeding, on the other hand, can be tough, time-consuming, and problematic in combining all of these qualities in a single genotype. Marker-assisted selection (MAS) provides an alternate method for combining all necessary qualities into a single variety by applying molecular markers connected to the genes/QTLs of interest in breeding operations. This strategy has become a vital component of genotype/germplasm improvement, with the ability to change from phenotype-based (conventional breeding) to a combination of phenotype and genotype-based selection, which is of great importance in modern breeding programs. (Tester *et al.,* 2010).

The integration of MAS strategies into breeding programs offers significant advantages over traditional phenotype-based breeding, mainly due to its efficiency and convenience in transferring the genes/QTLs of interest into the plant genome. By utilizing molecular markers linked to target traits, selection can be carried out specifically for these genotypes, reducing the breeding cycle by conducting off-season nurseries and enabling more generations to be grown per year (speed breeding). Furthermore, the technique minimizes the required population size because many lines can be removed in earlier breeding generations after MAS. The success of MAS techniques has been demonstrated in a variety of key crops, particularly for features with simple inheritance regulated by one or a few genes (Collard *et al.,* 2008).

Two major strategies are employed in MAS for breeding programs: (i) marker-assisted-backcrossing (MABC), which involves backcrossing of desirable alleles into elite germplasm, and (ii) marker-assisted gene pyramiding (MAGP), which involves stacking of multiple genes from different sources into elite breeding lines. The success of MAS is dependent on discovering major QTLs for complex traits, which account for an important portion of phenotypic variation. Major QTLs for important crops have been found and characterized, and successful applications of MABC and MAGP for yield or yield component traits have been reported. Marker assisted breeding allows for the introgression of genetic markers linked with agronomic traits into elite crop genetic backgrounds, resulting in the development of varieties that are better adaptable to climate changes.

2.3 Genome Sequencing Technology:

The rapid availability and falling cost of high-throughput genome sequencing technology is enabling the collection of massive amounts of genetic data. DNA samples can be preferentially enriched before sequencing to capture the diversity of specific gene families within big groups. Sanger sequencing is impractical for investigating plant genomes due to its low throughput and expensive sequencing costs. In 2005, Roche introduced the 454-pyrosequencing platform, which revolutionized genome sequencing. Since then, several sequencing platforms developed by companies such as Illumina, ABI, Life Technologies, PacBio, Oxford Nanopore, and Complete Genomics have been commercially released, changing the landscape of genome sequencing. Depending on their chemistry, second-generation sequencing (SGS) approaches are classified as ligation-based or synthesis-based approaches (Goodwin *et al.,* 2016). The rapidly falling cost of genome-wide genotyping enables large scale assessments of crop species diversity to capture traits related to the climate. There are two main strategies used: low SNP density strategies like reduced representation sequencing (RRS) and high SNP density strategies like whole-genome resequencing (WGR). However, high-density genotyping assays, such as SNP chips, allow for large-scale genotyping using SNP-specific oligonucleotide probes rather than direct sequencing. Genotyping by sequencing (GBS) variants can be used for traditional quantitative trait loci (QTL) analyses as well as modern approaches such as genome-wide association studies (GWAS). GWAS uses previous recombinations in different association panels to find genes associated with phenotypic traits (Yuan *et al.,* 2019). The widespread use of GWAS is improving our understanding of the genetics of important climate-specific traits like drought and heat tolerance (Yuan *et al.,* 2019).

2.4 Genome Editing: A Revolutionary Tool:

In recent years, advances in genome editing technology have enabled breeders to precisely add or remove any DNA sequence in the genome, which has shown substantial potential to alter crop improvement (Scheben *et al.*, 2017; Belhaj *et al.*, 2015). Some approaches have been used for more than two decades, such as transcription activator-like effector nucleases (TALENs) and zinc finger nucleases (ZFNs). However, type II clustered regularly interspaced short palindromic repeat (CRISPR)/CRISPR-associated protein (Cas) system from Streptococcus pyogenes, which was developed in the last decade (Jinek *et al.*, 2012), has been the most versatile tool for introducing desirable or novel traits and expediting the development of climate-smart crop varieties.

Zinc finger nucleases (ZFN) and Transcription activator-like effector nucleases (TALENs) are gene-editing techniques that use restriction enzymes. ZFN functions by using a zinc finger DNA binding domain to locate a specific target DNA sequence and a restriction endonuclease domain to cut the DNA at that site. TALENs also use a DNA binding domain and restriction domain like ZFN, but their DNA binding domain has wider range of potential target sequences. However, the main challenges that researchers and manufacturers faced in both techniques were the difficulty of protein engineering, as well as the high cost and time consuming.

The CRISPR/Cas-9 system is the most effective, efficient, and accurate way of genome editing in all live cells, and it is widely used in various fields. It is made up of two important components: guide RNA (gRNA) and CRISPR-associated (Cas-9) proteins. CRISPR/Cas-9 genome editing comprises three steps: recognition, cleavage, and repair. The designed sgRNA recognizes the target sequence in the gene of interest via complementary base pairing. The Cas-9 nuclease then creates double-stranded breaks at a site located 3 base pairs upstream to protospacer adjacent motif. The double-stranded break is finally repaired by either non-homologous end joining or homology-directed repair cellular mechanisms. The utilization of CRISPR/Cas system has led to significant advancements in plant genome engineering, contributing to the development of climate-resilient crops (Puchta, 2017; Li *et al.*, 2013; Shan *et al.*, 2013). Several studies have shown that this technology has the ability to improve agronomic traits and increase stress tolerance to diverse abiotic and biotic stresses.

For instance, Ogata *et al.* (2020) employed CRISPR/Cas9-mediated frame shift mutations to generate rice mutant lines for the OsERA1 gene under drought stress, resulting in increased drought tolerance and promoting primary root development under normal conditions. In another study, Pan et al. (2020) showed that the ZmSRL5 gene is essential for the formation of cuticular wax structure in maize, which provides protection against different stressors. The loss of functional mutant maize progenies revealed that the ZmSRL5 gene is important in drought response by maintaining the cuticle wax structure.

2.4.1 Base Editing:

Recent study has demonstrated that a single base modification can have significant impact on desirable traits in plants (Henikoff *et al.,* 2003). Therefore, there is a need for an effective technology that can generate accurate and efficient point mutations in plants. CRISPR-Cas9-driven base editing is a revolutionary method for transforming one DNA base to another without the use of a repair template. (Komor *et al.*, 2016). For instance, cytidine deaminases can convert cytosine (C) to uracil (U), which is then treated as thymine (T) during DNA repair and replication, leading to the creation of a C•G to T•A substitution. This method has been applied successfully in crops such as wheat, maize, and tomato. (Zhang *et al.,* 2017), and it may also be beneficial in gene functional analysis and crop breeding to generate stress-tolerant cultivars.

2.4.2 Prime Editing:

Prime editing is a novel genome engineering approach that can introduce a wide range of base-to-base conversions as well as insertions and deletions using prime editing guide RNA (pegRNA) (Anzalone *et al.*, 2019). This innovative technology has enormous potential to precisely modify targeted genome sequences and facilitate functional genomics studies. It can also help with the introduction of genes for adaptation to various climatic conditions, which will speed up the breeding of climate-smart cultivars in the near future (Marzec & Hensel, 2020).

2.5 Next-Generation Plant Phenotyping Platforms:

Plant phenotyping has played a pivotal role in the successful domestication of crops over thousands of years. The term "phenome" refers to the entire phenotypic profile of a plant, and phenotype is a combination of observable genetic expression and its interaction with the environment (Houle *et al.,* 2010). Plant phenomics has developed as a rapidly growing research platform, comprising the multidimensional application of advanced tools and techniques for the detailed evaluation of plant growth, structure, function, and behavior in a given environment. This field involves the acquisition, organization, and analysis of large-scale phenotypic data sets, and the development of intelligent models for predicting plant growth under various scenarios (Houle *et al.*, 2010). Plant phenotyping is an important method for studying the relationship between plants and their environment. It can be undertaken at many levels of resolution, from the genome to the whole plant, in diverse climatic conditions, and in both field and controlled environments.

2.6 Mutation Breeding:

Mutation breeding is a technique used to induce mutations in plant genomes to generate genetic variation that can be used for crop improvement. The method involves treating plants with chemical or physical mutagens to create random mutations in their DNA, which can result in changes in various traits, such as yield, quality, and resistance to biotic and abiotic stresses. The mutated plants are then screened for desirable traits, and those with beneficial mutations are selected for further breeding. Targeting Induced Local Lesions in Genome (TILLING) is a powerful technique that has emerged from mutation breeding. It involves the creation of a large population of mutated plants through chemical mutagenesis, followed by the identification of desirable mutations through DNA screening. TILLING has revolutionized the identification of novel alleles in crops, enabling the discovery of new genes responsible for desirable traits such as drought tolerance, disease resistance, and increased yield. Mutation breeding and TILLING have been proven to be useful methods for identifying allelic variants responsible for crop adaptation to abiotic and biotic stresses caused by climate change. These techniques offer a fast and cost-effective way to introduce genetic diversity into crops and select for desirable traits, which can ultimately lead to the development of new varieties that are better adapted to changing environmental conditions.

2.7 Speed Breeding:

Speed breeding has become effective in producing more generations of crops in a year by using a pro-longed photoperiod of 22 hours of daylight followed by 2 hours of night light. Through a shorter breeding cycle, speed breeding has successfully increased the genetic gain of the crops (Watson et al., 2018). Today's globe needs more genetic progress to offset the effects of rising food demand and climatic change brought by rapid population growth. It has revolutionized agriculture by facilitating various activities like crossing, backcrossing, rapid gene identification, mapping populations, trait pyramiding, and transgenic pipeline development (Hickey *et al.,* 2019).

Speed breeding allows for up to four generations of *B. napus* and six generations of *Hordeum vulgare, Triticum aestivum, Pisum sativum, Cicer arietinum*, and *B. distachyon* in a single season, which is a remarkable improvement over conventional breeding (Watson et al., 2018). It is also an efficient and cost-effective platform for conducting crop improvement projects that integrate genomics and phenomics. It is possible to rapidly analyze the risks associated with gene-edited crops across multiple generations by integrating speed breeding with next-generation metabolomics technologies (Razzaq et al., 2019). Therefore, the integration of speed breeding technology with next-generation OMICS tools is an exciting way forward for accelerating crop breeding programs.

2.8 Conclusion:

The challenges that climate change poses to agricultural production and food security have have made the role of plant breeders even more crucial. As the impacts of climate change continue to affect food quality, availability, and accessibility, plant breeding has emerged as a powerful tool to combat these challenges in agriculture. To meet the demand for future food production, it has become crucial to develop new crop varieties, including novel crops. As a result, plant breeders are diligently exploring new tools and technologies to dealing with climate change challenges.

These technologies can accelerate the breeding process, facilitate the screening of elite germplasm under stress conditions, and enable the development of genome-edited non-transgenic plants that can adapt to environmental stress, thus ensuring food security. In comparison to traditional breeding approaches, novel plant breeding techniques can give a more sustainable strategy to boosting production in the face of biotic and abiotic stressors.

2.9 References:

1. Abberton, M., Batley, J., Bentley, A., Bryant, J., Cai, H., Cockram, J., de Oliveira, A. C., Cseke, L. J., Dempewolf, H., De Pace, C., Edwards, D., Gepts, P., Greenland, A., Hall, A. E., Henry, R., Hori, K., Howe, G. T., Hughes, S., Humphreys, M., Lightfoot, D., … Yano, M. (2016). Global agricultural intensification during climate change: a role for genomics. *Plant biotechnology journal,* 14(4), 1095–1098.
2. Anzalone, A. V., Randolph, P. B., Davis, J. R., Sousa, A. A., Koblan, L. W., Levy, J. M., Chen, P. J., Wilson, C., Newby, G. A., Raguram, A., & Liu, D. R. (2019). Search-and-replace genome editing without double-strand breaks or donor DNA. *Nature,* 576(7785), 149–157.
3. Becker, M., Gruenheit, N., Steel, M., Voelckel, C., Deusch, O., Heenan, P. B., McLenachan, P. A., Kardailsky, O., Leigh, J. W., & Lockhart, P. J. (2013). Hybridization may facilitate in situ survival of endemic species through periods of climate change. *Nature Climate Change*, 3(12), 1039–1043.
4. Belhaj, K., Chaparro-Garcia, A., Kamoun, S., Patron, N. J., & Nekrasov, V. (2015). Editing plant genomes with CRISPR/Cas9. *Current opinion in biotechnology,* 32, 76–84.
5. Collard, B. C., & Mackill, D. J. (2008). Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences,* 363(1491), 557–572
6. Dhankher, O. P., & Foyer, C. H. (2018). Climate resilient crops for improving global food security and safety. *Plant, cell & environment,* 41(5), 877–884.
7. Falconer, D. S., & Mackay, T. F. C. (1996). Introduction to quantitative genetics. Essex. UK: Longman Group, 12.
8. Fischer, R., Byerlee, D., and Edmeades, G. (2014). Crop Yields and Global Food Security. Canberra, ACT: ACIAR, 8–11.
9. Gobu, R., Shiv, A., Kumar, A.C., Basavaraj, P.S., Harish, D., Adhikari, S., Ramtekey, V., Hudedamani, U., Sujatha, M. (2020). Accelerated crop breeding towards development of climate resilient varieties. In *Climate change and Indian agriculture: challenges and adaptation strategies*. (pp. 49-69). ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana, India.
10. Goodwin, S., McPherson, J. D., & McCombie, W. R. (2016). Coming of age: ten years of next-generation sequencing technologies. *Nature reviews. Genetics*, 17(6), 333–351.
11. Henikoff, S., & Comai, L. (2003). Single-nucleotide mutations for plant functional genomics. *Annual review of plant biology,* 54, 375–401.
12. Hickey, L. T., N Hafeez, A., Robinson, H., Jackson, S. A., Leal-Bertioli, S. C. M., Tester, M., Gao, C., Godwin, I. D., Hayes, B. J., & Wulff, B. B. H. (2019). Breeding crops to feed 10 billion. *Nature biotechnology,* 37(7), 744–754.
13. Houle, D., Govindaraju, D. R., & Omholt, S. (2010). Phenomics: the next challenge. *Nature reviews. Genetics,* 11(12), 855–866.
14. Jinek, M., Chylinski, K., Fonfara, I., Hauer, M., Doudna, J. A., & Charpentier, E. (2012). A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. *Science (New York, N.Y.)*, 337(6096), 816–821
15. Komor, A. C., Kim, Y. B., Packer, M. S., Zuris, J. A., & Liu, D. R. (2016). Programmable editing of a target base in genomic DNA without double-stranded DNA cleavage. *Nature*, 533(7603), 420–424.

16. Lavarenne, J., Guyomarc'h, S., Sallaud, C., Gantet, P., & Lucas, M. (2018). The Spring of Systems Biology-Driven Breeding. *Trends in plant science*, 23(8), 706–720.
17. Li, J. F., Norville, J. E., Aach, J., McCormack, M., Zhang, D., Bush, J., Church, G. M., & Sheen, J. (2013). Multiplex and homologous recombination-mediated genome editing in Arabidopsis and Nicotiana benthamiana using guide RNA and Cas9. *Nature biotechnology*, 31(8), 688–691.
18. Marzec, M., & Hensel, G. (2020). Prime Editing: Game Changer for Modifying Plant Genomes. *Trends in plant science*, 25(8), 722–724.
19. Nadeem, M. A., Nawaz, M. A., Shahid, M. Q., Doğan, Y., Comertpay, G., Yıldız, M., Hatipoğlu, R., Ahmad, F., Alsaleh, A., Labhane, N., Özkan, H., Chung, G., & Baloch, F. S. (2018). DNA molecular markers in plant breeding: Current status and recent advancements in genomic selection and genome editing. *Biotechnology & Biotechnological Equipment*, 32(2), 261–285.
20. Ogata, T., Ishizaki, T., Fujita, M., & Fujita, Y. (2020). CRISPR/Cas9-targeted mutagenesis of OsERA1 confers enhanced responses to abscisic acid and drought stress and increased primary root growth under nonstressed conditions in rice. *PloS one*, 15(12), e0243376.
21. Pan, Z., Liu, M., Zhao, H., Tan, Z., Liang, K., Sun, Q., Gong, D., He, H., Zhou, W., & Qiu, F. (2020). ZmSRL5 is involved in drought tolerance by maintaining cuticular wax structure in maize. *Journal of integrative plant biology*, 62(12), 1895–1909.
22. Puchta H. (2017). Applying CRISPR/Cas for genome engineering in plants: the best is yet to come. *Current opinion in plant biology*, 36, 1–8.
23. Purugganan, M. D., & Fuller, D. Q. (2009). The nature of selection during plant domestication. *Nature*, 457(7231), 843–848.
24. Razzaq, A., Kaur, P., Akhter, N., Wani, S. H., & Saleem, F. (2021). Next-Generation Breeding Strategies for Climate-Ready Crops. *Frontiers in plant science*, 12, 620420.
25. Razzaq, A., Sadia, B., Raza, A., Khalid Hameed, M., & Saleem, F. (2019). Metabolomics: A Way Forward for Crop Improvement. *Metabolites*, 9(12), 303.
26. Scheben, A., Batley, J., & Edwards, D. (2017). Genotyping-by-sequencing approaches to characterize crop genomes: choosing the right tool for the right application. *Plant biotechnology journal*, 15(2), 149–161.
27. Shan, Q., Wang, Y., Li, J., Zhang, Y., Chen, K., Liang, Z., Zhang, K., Liu, J., Xi, J. J., Qiu, J. L., & Gao, C. (2013). Targeted genome modification of crop plants using a CRISPR-Cas system. *Nature biotechnology*, 31(8), 686–688.
28. Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science (New York, N.Y.),* 327(5967), 818–822
29. Wang, J. K. (2007). Simulation modeling in plant breeding: Principles and applications. *Agricultural sciences in China*, 6(8), 908-921.
30. Watson, A., Ghosh, S., Williams, M. J., Cuddy, W. S., Simmonds, J., Rey, M. D., Asyraf Md Hatta, M., Hinchliffe, A., Steed, A., Reynolds, D., Adamski, N. M., Breakspear, A., Korolev, A., Rayner, T., Dixon, L. E., Riaz, A., Martin, W., Ryan, M., Edwards, D., Batley, J., … Hickey, L. T. (2018). Speed breeding is a powerful tool to accelerate crop research and breeding. *Nature plants*, 4(1), 23–29.
31. Yuan, Y., Scheben, A., Batley, J., & Edwards, D. (2019). Using genomics to adapt crops to climate change. In *Sustainable Solutions for Food Security: Combating Climate Change by Adaptation* (pp. 91-109). Springer International Publishing Switzerland.
32. Zhang, Y., & Gao, C. (2017). Recent advances in DNA-free editing and precise base editing in plants. *Emerging topics in life sciences*, 1(2), 161–168.

33. Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Ciais, P., Durand, J. L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C., Peng, S., … Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences of the United States of America,* 114(35), 9326–9331.

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3. Integrated Farming System for Doubling Farmers' Income

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Abstract:

Integrated fish farming systems refer to the production, integrated management and comprehensive use of aquaculture, agriculture and livestock, with an emphasis on aquaculture. Asia has a long and rich history of integrated fish farming. Written records from the first and second centuries B.C. documented the integration of aquatic plant cultivation and fish farming. From the ninth century, records showed fish farming in the paddy field. From the fourteenth to sixteenth centuries, there were records of rotation of fish and grass culture; and by the 1620s, the mulberry-dike fishpond, the integration of fish and livestock farming and complex systems of multiple enterprises integrated with fish farming were developed. Integrated fish farming is the methods by which fish is cultured along with paddy, piggery, poultry or any livestock, or flower culture. This type of farming practices helps to improve economic sustainability of the farmers. It also helps to develop climate resilient culture system by improving production potential, reserving biomass, increase food security without any negative effect on environment. Thus, in future, integrated farming system will help in sustainable development of human and environment both.

Keywords:

Agriculture, diversification, food security, income doubling

3.1 Introduction:

Integrated farming system is the farming of different agricultural practices such as crop cultivation, livestock rearing, poultry farming, fish farming and agroforestry in a mutually beneficial way to maximize production and income. Integrated farming can help in doubling farmers' income by providing multiple sources of income and reducing dependence on a single crop or activity. It can be a sustainable and profitable approach for farmers to double their income. However, it requires careful planning, proper management, and technical expertise. Governments and organizations can provide support in terms of training, credit facilities, and market linkages to help farmers adopt integrated farming practices. Integrated farming system (IFS) is a sustainable agricultural production system that aims to optimize the use of natural resources, increase productivity, and improve livelihoods. IFS approach promotes the efficient use of resources by utilizing the by-products of one farming activity as inputs for another. For example, the manure produced by livestock can be used as organic fertilizer for crop production. Similarly, the crop residues can be used as feed for livestock, and the livestock waste can be used for biogas production. This approach not only reduces waste but also improves soil health and fertility, leading to increased crop yields.In an IFS, crop production is often combined with livestock production, which helps to diversify income streams for farmers. Livestock provides additional income through the sale of milk, eggs, meat, and other products. Forestry and fishery components in an IFS provide additional benefits such as soil conservation, water conservation, and biodiversity conservation. Trees planted in and around the farm help to prevent soil erosion, provide shade for livestock, and improve microclimatic conditions. Fish ponds provide an additional source of protein, which is essential for the health and well-being of the rural population.The IFS approach promotes the efficient use of natural resources, increases productivity, and helps to mitigate the adverse effects of climate change. The system is also socially and economically sustainable, providing a means of livelihood for small-scale farmers, enhancing food security, and reducing rural poverty.The system provides multiple benefits, including increased productivity, soil conservation, water conservation, and biodiversity conservation. The IFS approach has the potential to transform rural livelihoods, enhance food security, and mitigate the adverse effects of climate change.

Why Diversification Is Needed in Farming System?

Diversification in agriculture refers to the practice of growing a variety of crops or integrating multiple farming activities on a single farm. There are several reasons why diversification is necessary in agriculture

- By diversifying their crops or activities, farmers can reduce the risk of crop failure due to weather or other environmental factors. For example, if a farmer relies on a single crop and that crop fails due to drought or disease, the farmer will suffer a significant financial loss. However, if the farmer has multiple crops or activities, they can still generate income from other sources, which helps to cushion the impact of crop failure.
- Diversification can help farmers to generate a more stable income throughout the year. For example, by integrating livestock production with crop production, farmers can generate income from both sources, which helps to balance out the income stream. This can be particularly important for small-scale farmers who may not have access to financial safety nets.
- Growing a variety of crops can help to improve soil health by reducing soil erosion, increasing soil fertility, and reducing the build-up of pests and diseases. Crop rotation, which involves planting different crops in different seasons, is a common practice used to improve soil health.
- Diversification can help to promote environmental sustainability by reducing the use of chemical inputs, conserving water, and reducing greenhouse gas emissions. For example, integrating livestock production with crop production can help to reduce the use of synthetic fertilizers and pesticides, while also providing a source of organic fertilizer for crops.
- It can help to improve food security by increasing the variety of foods available to local communities. This can be particularly important in regions where food availability is limited.

So, diversification is necessary in agriculture to manage risk, stabilize income, improve soil health, promote environmental sustainability, and enhance food security. By diversifying their crops or activities, farmers can create a more resilient and sustainable farming system that can adapt to changing environmental and economic conditions.

3.2 Principle of IFS:

IFS is based on the idea that farming activities can complement and enhance each other creating more efficient, sustainable and profitable system.The main principles of this system are mainly crop diversification, recycling of nutrients, conservation of natural resources, optimization of resource and input in a farming system along with integrated crop and nutrient management.

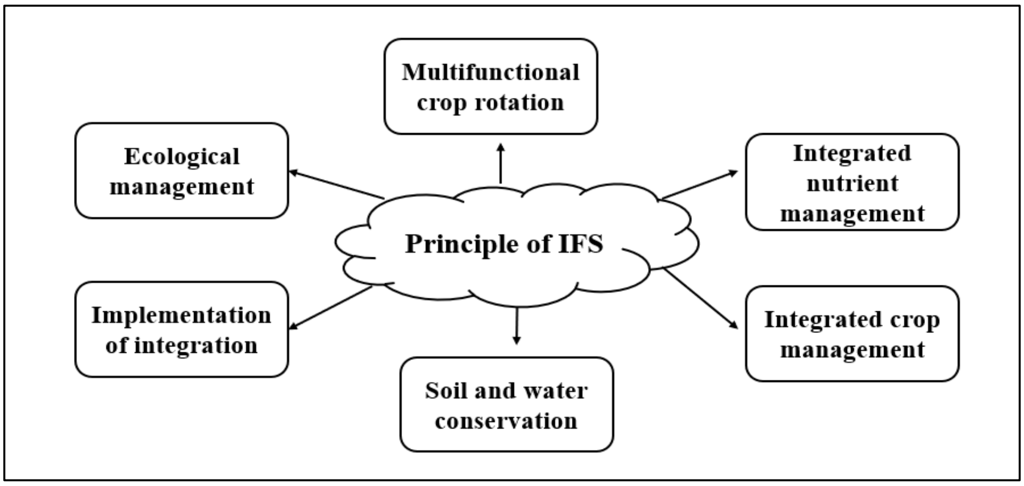

Figure 3.1: Principle of IFS

3.3 Objectives of IFS:

A. The objectives of IFS are to optimize resource use, increase productivity, improve livelihoods, promote environmental sustainability, enhance food security, and mitigate climate change. By achieving these objectives, IFS can contribute to a more sustainable and resilient agricultural system. The objectives of IFS are-
B. To optimize the use of natural resources: IFS aims to make the best possible use of natural resources, such as land, water, and energy, by integrating different farming activities. By using the by-products of one activity as inputs for another, IFS reduce waste and maximizes resource efficiency.
C. To increase productivity: By combining different farming activities, IFS can increase productivity and yield. For example, livestock waste can be used as organic fertilizer for crops, which improves soil health and leads to increased crop yields. Livestock can also provide draft power for land preparation and transportation, reducing the need for expensive machinery.
D. To improve livelihoods: IFS provides opportunities for small-scale farmers to diversify their income streams by integrating different farming activities. Farmers can generate

additional income from various sources, such as the sale of milk, meat, eggs, crops, and fish. This diversification helps to reduce the risks associated with single-crop or single-livestock farming and provides more stable incomes for farmers.

E. To promote environmental sustainability: IFS aims to reduce the negative impacts of agricultural production on the environment by promoting practices such as agroforestry, conservation tillage, and integrated pest management. These practices can help to prevent soil erosion, improve soil health, conserve water, and reduce greenhouse gas emissions.
F. To enhance food security: IFS can contribute to food security by increasing agricultural productivity, diversifying income streams for farmers, and providing a more diverse range of foods for local consumption.
G. To mitigate climate change: IFS can help to mitigate the adverse effects of climate change by promoting practices that reduce greenhouse gas emissions, such as the use of renewable energy, carbon sequestration, and sustainable land use practices.

3.4 Approaches of IFS:

There are several approaches or components to implement IFS, including crop-livestock integration, agroforestry, fish farming, multiple cropping, and renewable energy. These approaches can be combined in different ways to create a more diverse and sustainable farming system.

A. Crop-livestock integration: This approach involves integrating crop and livestock production on the same farm. Livestock can provide manure for crops, while crop residues can be used as feed for livestock. This approach helps to optimize resource use and increase productivity.
B. Agroforestry: Agroforestry involves planting trees and other perennial crops on the farm. The trees can provide shade, conserve soil moisture, and improve soil fertility. They can also provide a source of fuelwood and timber. Agroforestry can be integrated with crop and livestock production to create a more diverse and sustainable farming system.
C. Fish farming: Fish farming can be integrated with crop and livestock production to provide a source of protein and income. Fish ponds can be stocked with fish species that are well adapted to the local conditions. The fish waste can be used as fertilizer for crops, and the fish can be sold for food.
D. Multiple cropping: Multiple cropping involves growing two or more crops on the same piece of land in a single growing season. This approach can help to optimize resource use and increase productivity. Multiple cropping can be combined with livestock production and agroforestry to create a more diverse and resilient farming system.
E. Renewable energy: Renewable energy can be integrated into IFS by using solar panels, wind turbines, or biogas digesters to generate electricity. The electricity can be used for lighting, cooking, and other farm activities. Biogas digesters can also produce fertilizer and reduce greenhouse gas emissions.
F. Soil and water conservation: Soil and water conservation practices are essential components of an IFS. Soil erosion can be reduced by planting cover crops, terracing, contouring, and conservation tillage. Water conservation can be achieved through rainwater harvesting, irrigation efficiency, and water recycling.

G. Value addition and marketing: Value addition and marketing are important components of an IFS. Value addition involves processing raw agricultural products into value-added products such as jams, pickles, and juices. Marketing involves selling agricultural products in local or regional markets, which helps to generate income for farmers and promote food security.

3.5 Doubling Farmers' Income Through IFS

IFS is a farming system that combines different farming practices such in a mutually beneficial way to maximize production and income. Integrated farming can help in doubling farmers' income by providing multiple sources of income and reducing dependence on a single crop or activity. Here are some of the ways in which integrated farming can help in doubling farmers' income-

A. Diversification of Income:

IFS can play a vital role in income diversification for farmers. Income diversification refers to the practice of generating income from multiple sources, which can help to reduce the risk of financial losses due to a single crop failure or market downturn.

- In crop cum livestock IFS the integration can provide farmers with an additional source of income through the sale of milk, meat, and other animal products.
- It can also involve integrating trees and other perennial crops into the farming system, which can provide an additional source of income through the sale of timber, fruits, and other non-timber forest products.
- IFS can involve integrating fish production with crop and livestock production, which can provide an additional source of income through the sale of fish.
- It can involve adding value to farmed products through processing and packaging, which can create additional income opportunities for farmers. For example, fruits can be processed into jams, pickles, and juices, while milk can be processed into cheese, yogurt, and other dairy products.
- IFS can also involve diversifying the market channels through which farmers sell their products. This can include selling products directly to consumers through farmers' markets or community-supported agriculture (CSA) programs or selling products to local or regional processors, which can help to create more stable income streams for farmers.

By diversifying their income sources, farmers can become more resilient to economic and environmental challenges and improve their livelihoods.

B. Sustainable Development:

IFS can contribute significantly to sustainable development by promoting the efficient use of natural resources, reducing environmental impact, and improving social and economic conditions.

- IFS can promote the efficient use of natural resources such as water, soil, and energy. For example, by integrating livestock and crops, farmers can use animal manure as a fertilizer, reducing the need for synthetic fertilizers.
- IFS can promote soil health through the use of organic fertilizers, crop rotations, and intercropping.
- It can promote biodiversity by incorporating a range of crops, trees, and other vegetation into the farming system. This can also help to provide habitat for wildlife and promote ecosystem services such as pollination and pest control.
- IFS can help to mitigate the impacts of climate change by reducing greenhouse gas emissions through practices such as use of renewable energy.
- This system can provide social and economic benefits to farmers by creating additional income opportunities, improving food security, and promoting rural development.
- IFS can also promote sustainable value chains by integrating small-scale producers into the market and creating opportunities for value addition and marketing. Thus, it can help to reduce food waste, increase market access for small-scale farmers, and promote social and environmental sustainability.

C. Nutritional Food Security:

IFS can improve nutritional food security by promoting the production and consumption of a diverse range of food products, including crops, livestock, fish, and fruits. Here are some ways in which IFS can improve nutritional food security:

- IFS can promote the production of nutrient-rich varieties of crops and livestock that are suited to the local environment.
- IFS can also improve access to nutritious food by promoting local production and consumption, reducing the reliance on imported food products. Additionally, it can improve access to food for vulnerable populations through initiatives such as community gardens and school feeding programs.
- Farmers can process fruits and vegetables into jams, pickles, and other value-added products, increasing their market value and promoting their consumption through IFS.
- IFS can improve soil health through the use of organic fertilizers and crop rotations, which can increase the nutrient content of crops and improve their nutritional value.
- IFS can promote the integration of trees and crops, to improve soil health and increase the availability of nutrient-rich foods such as fruits and nuts.
- It can also enhance food safety by promoting the use of natural pest control methods and reducing the use of harmful chemicals in food production.

D. Employment Generation:

IFS can contribute to employment generation by promoting entrepreneurship in rural areas. Crop-livestock integration can create additional income opportunities for farmers by selling livestock products such as milk, meat, eggs and also provide a source of organic fertilizer for crop production. Additionally, agroforestry can provide employment opportunities in activities such as pruning, harvesting and processing of forest products. This can create employment opportunities in processing, marketing, and distribution of value-added products. IFS develop sustainable fisheries by integrating fish production with crops and livestock which can create employment options.Farmers can sell surplus electricity generated from biogas to the grid or use it for other productive activities. IFS can also promote rural tourism by developing farm-based tourism activities such as farm stays, nature walks etc to create additional income opportunities in the area.

E. Efficient Use of Resources:

IFS can enhance the efficient use of resources by optimizing the use of inputs, reducing waste and improving resource use efficiency. Livestock waste can be used as fertilizer for crops, reducing the need for chemical fertilizers and promoting the efficient use of nutrients.Additionally, it can promote the use of drip irrigation systems and other water-management technologies to reduce water wastage, improve water retention and increase water use efficiency.

Farmers can use solar-powered irrigation systems, biogas plants and solar dryers to reduce energy consumption and improve resource use efficiency.Organic waste of IFS can be used for composting, biogas production and reducing waste disposal.IFS can promote the use of conservation agriculture practices, such as minimum tillage and cover cropping, to reduce soil degradation and improve resource use efficiency.

F. Increase in Productivity:

IFS can increase productivity by synergistic interactions among different farming components.It can enhance intercropping, where different crops are grown together in the same field to increase productivity by improving soil fertility, reducing pest infestations, and increasing yields.Diversification can promote income generation and reduce the dependence on a single crop or livestock species.IFS can promote sustainable fisheries by integrating fish production with crops and livestock. This can increase productivity by promoting nutrient cycling, reducing pest infestations, and improving water use efficiency, leading to increased fish yields.

G. Input Cost Reduction:

IFS reduce input cost by enhancing resource use efficiency, reducing the dependence on external inputs and promoting the use of locally available resources. IFS promote nutrient management by integrating livestock and crops, reducing the cost of inputs, while improving soil fertility and crop productivity.Itinfluences integrated pest management (IPM) by promoting natural pest control methods like the use of biological control agents. This can reduce the need for chemical pesticides, leading to lower input costs.

Proper water management can reduce the cost of irrigation and promote efficient use of resources.IFS also promote energy management by using renewable energy sourcesand reducing the use of fossil fuels. This can reduce energy costs, while promoting sustainable energy use. In IFS livestock can be fed on crop residues and agro-industrial by-products, reducing the cost of feed and promoting resource use efficiency.Thus, by adopting IFS, farmers can reduce input costs, improve profitability, and promote sustainable agriculture.

H. Value Addition of End Product:

IFS contribute to value addition by promoting the integration of different farming components and adding value to agricultural products. Processing of agricultural products such as fruits, vegetables, fish and grains is promoted to add value and increase shelf-life.

In livestock milk can be processed into yogurt, cheese, and other dairy products, while meat can be processed into sausages, surimi and other value-added products. Organic production can reduce the use of chemical inputs and add value to organic products by providing a premium price.

Farmers can also form producer groups and cooperatives to jointly process and market their products, which can lead to increased bargaining power and higher prices through IFS.

3.6 Different Integrated Farming Systems:

There are different integrated framing systems based on the compatible combination of culture practices. The nomenclature of IFS is generally based on the name of primary and secondary crop culture. The different standard and profitable IFS practices adopted by the farmers are as given in the table.

Table 3.1: The Different Standard and Profitable IFS Practices Adopted by The Farmers

Sr. No	Name of IFS	Primary crop SD	Secondary crop SD	Primary production	Additional production
Plant cum livestock culture					
1	Agroforestry	Forestland	Chicken-5-10 birds/m^2 Cow- 1-2/ha Goat-4-5/ha	Fruit, leaf, timber, honey	Animal meat, milk, eggs
Agri-aqua based culture					
2	Paddy cum fish culture	Paddy	2000 - 3000 fish fingerling/ ha	20-30 quintal/ha	500-750 kg/ha/year
3	Makhana cum fish culture	Makhana - 80kg/ha	6000 fish fingerling/ha	1500 kg/ha	1500 - 2000 kg/ha/ year
5	Sericulture cum fish system	5000-6000 fish fingerling/ha	Mulberry plants	Fish- 3-4t/ha/year	30 tonnes mulberry leaves/ha, 3.75 tonnes vegetable/ha
6	Horti cum fish system	5000-6000 fish fingerling/ha	500 - 1000 plant/ha	3-4 t/ha/year	2 t/ha/year
7	Aquatic weed & fish system	6000-8000 fry/ha	Aquatic weeds	2-3 t/ha/year	6-8 t/ha/year

Sr. No	Name of IFS	Primary crop SD	Secondary crop SD	Primary production	Additional production
Animal husbandry-fish based system					
8	Cattle cum fish system	7000-8000 fish fingerling/ha	5-6/ha	3-4 ton /ha/year	9000 L milk, 10 ton/ha dung
9	Pig cum fish system	Do	40-45/ha	Do	4000 kg Pig meat
10	Goat cum fish system	Do	50-60/ha	Do	700-900 kg Goat meat
11	Poultry cum fish system	Do	1000/ha	Do	1 lakh eggs, 1500 kg meat
12	Duck cum fish system	Do	200-300/ha	Do	6000 eggs, 500-700 kg meat

3.7 Opportunities of IFS:

IFS offer a range of opportunities to farmers, rural communities, and the broader society. Here are some of the opportunities -

- IFS can provide opportunities for increased income by diversifying production.
- This can lead to improved livelihoods and economic development in rural areas.
- It can promote sustainable farming by reducing the use of external inputs, improving resilience to climate change and environmental impacts.
- IFS can generate employment opportunities in rural areas by adding value to agricultural products, and promoting local economic development.
- IFS can also contribute to nutritional food security by promoting the consumption of diverse and nutritious foods. This can improve health outcomes, especially in vulnerable populations.
- This can lead to reduced input costs, improved productivity, and improved environmental sustainability.
- IFS promote value chain integration by integrating different farming components and adding value to agricultural products leading to local economic development.

3.8 Challenges of IFS:

IFS offer many opportunities, there are also several challenges that need to be addressed to effectively implement and promote IFS.

- Lack of awareness and knowledge about IFS among farmers and extension workers can hinder its adoption and promotion.
- IFS require a range of inputs and resources, which may not be readily available or affordable to smallholder farmers, especially in remote areas.
- It requires value addition and market access to generate income and improve livelihoods.
- IFSinclude supportive policies, regulations, incentives as well as adequate institutional capacity to maintain policy and institutional support.

- Women, youth, and marginalized groups may face additional barriers to accessing resources, knowledge, and benefits from IFS due to social inequities.

3.9 Future Perspective of IFS:

IFS have a promising future, as they offer a range of benefits, including increased income, employment generation, nutritional food security, resource use efficiency, climate change mitigation and value chain integration. Technology and innovation can play a significant role in promoting IFS, by improving access to inputs and resources and enhancing market access and value addition. Emerging technologies such as precision agriculture, digital platforms and climate-smart solutions can enhance the efficiency of IFS.

Future perspectives of IFS include the integration of climate-smart solutions like conservation culture to enhance the resilience and sustainability. It can improve market-oriented production by integrating different farming components, adding value to agricultural products, and promoting local economic development. Knowledge and capacity development are essential for the promotion and scaling-up of IFS. Development and dissemination of knowledge and skills among farmers, extension workers, researchers and policymakers are necessary to enhance the effectiveness and sustainability of this system.

3.10 Conclusion:

IFS is a sustainable and holistic approach to agriculture that can bring about multiple benefits. It offers a promising future, as it can be adapted to different contexts and needs, and can contribute to various development goals including poverty reduction, gender equality and environmental sustainability. However, promoting and scaling-up IFS requires addressing various challenges, such as limited access to inputs, markets, inadequate policy support and limited institutional capacity. To unlock the full potential of IFS, there is a need for a multi-stakeholder approaches that involve farmers, extension workers, policymakers, researchers and other stakeholders. Overall, IFS is a promising approach that can contribute to sustainable farming practices, rural development and food security in a better way.

3.11 References:

1. Dashora, L.N., Singh H. (2014). Integrated farming system-need of today. *International Journal of Applied Life Sciences and Engineering*.;1(1):28-37.
2. Gupta, V., Rai, P.K., Risam, K.S. (2012) Integrated crop-livestock farming systems: A strategy for resource conservation and environmental sustainability. *Indian Research Journal of Extension Education*, Special 2:49-54.
3. Rathore, V.S., Tanwar, S.P., Kumar, P., Yadav, O.P. (2019) Integrated farming system: Key to sustainability in arid and semi-arid regions. ICAR.
4. Singh, J.P., Ravisankar, N. (2015) Integrated farming systems for sustainable agricultural growth: Strategy and experience from research. InProceedings of National Seminar on "Integrated Farming Systems for Sustainable Agriculture and Enhancement of Rural Livelihoods;13-14.
5. Jayanthi, C., Vennila, C., Nalini, K., Vivek, G. (2007). Farmer participatory integrated farming system for improving livelihood of small and marginal farmers. In: proceedings

of third national symposium on integrated farming systems and its role towards livelihood improvement held at PDCSR, Modipuram from October 26–28;1–3.
6. Jayanthi, C., Sakthivel, N., Sankaran, N., Thiyagarajan, T.M. (2006). Integrated farming system: A path to sustainable agriculture. Tamil Nadu Agricultural Univ., Coimbatore, India.
7. Chaubey, D., Prakash, V., Yadav, T.C. and Singh, G. (2018). Doubling of Farmers' Income though Integrated Farming System Approaches in Bihar *International Journal of Current Microbiology and Applied Sciences*, 7(**12**): 1602-1613
8. Saxena, R., Naveen. P.S., Balaji, S.J., Usha, R.A. and Joshi, D. (2017). Strategy for Doubling Income of Farmers in India. Plicy paper 31. National Institute of Agricultural Economics and Policy Research (NIAP), New Delhi.
9. Suhas, P.W. and Singh, D. (2017). Doubling Farmers' Income: Challenges and Opportunities. Proceedings of National Workshop on Doubling Farmers' Income through Scaling-up: KISAN– MITrA (Knowledge-based Integrated Sustainable Agriculture Network - Mission India for Transforming Agriculture). No: 3 pp 2-3. March 15- 16, 2017. New Delhi.
10. www.justagriculture.in

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4. Integrated Weed Management – A Step towards Sustainability

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Abstract:

Integrated Weed Management (IWM) represents a pivotal stride towards sustainability in modern agriculture. Weeds, unwanted plants competing with crops, have long vexed farmers, prompting the excessive use of chemical herbicides, with adverse environmental and economic consequences. IWM seeks to redress this by offering a holistic approach that integrates various weed control techniques, acknowledging the complex dynamics of agricultural ecosystems. IWM methods encompass cultural practices, biological control, mechanical weed removal, and judicious herbicide use. By diversifying tactics, IWM diminishes the likelihood of herbicide-resistant weeds, preserving the effectiveness of vital chemical options. Furthermore, IWM fosters soil health, reduces erosion, and enhances biodiversity. This multifaceted approach not only safeguards crop yields but also upholds the ecological balance and ensures the long-term sustainability of agricultural systems. Crucially, IWM aligns with the principles of sustainable agriculture, mitigating the environmental footprint while securing food production. As our world grapples with food security and environmental degradation, Integrated Weed Management stands as a compelling strategy to harmonize the needs of the present with the imperatives of the future.

4.1 Introduction:

An integrated weed management may be defined as the combination of two or more weed-control methods at low input levels to reduce weed competition in a given cropping system below the economical threshold level. It has proved to be a valuable concept in a few cases, though much is still to be done to extend it to the small farmers' level. Integrated Weed Management (IWM) approach aims at minimizing the residue problem in plant, soil, air and water.

An IWM involves the utilization of a combination of mechanical, chemical and cultural practices of weed management in a planned sequence, so designed as not to affect the ecosystem.

The nature and intensity of the species to be controlled, the sequence of crops that are raised in the rotation, the standard of crop husbandry, and the ready and timely availability of any method and the economics of different weed-management techniques are some of the potent considerations that determine the success for the exploitation of the IWM approach.

4.2 Why Integrated Weed Management:

The continuous use of the same method leads to the buildup of tolerant weeds. Therefore, the suitable combination of different weed control methods or integrated weed management (System Approach) should be practice for minimizing the losses caused by various weeds.

Herbicides have become one of the most important components in weed control because of use of high yielding varieties which created economic incentive for farmer to reduce weed.

4.3 Concept of Integrated Weed Management:

Uses a variety of technologies in a single weed management with the objective to produce optimum crop yield at a minimum cost taking into consideration economic and socio economic constrains under a given agro ecosystem.

4.4 Components of Integrated Weed Management:

The goal of IWM is to incorporate different methods of weed management into a combined effort to control weeds.

Just as using the same herbicide again and again can lead to resistance, reliance on any one of the methods below over time can reduce its efficacy against weeds.

Two major factors to consider when developing an IWM plan are

- Target weed species
- Time, resources, and capabilities necessary to implement these tactics

Advantages of Integrated Weed Management:

- ➢ It shifts the crop weed competition in favour of crop
- ➢ Prevents weed shift towards perennial nature
- ➢ Prevents resistance in weeds to herbicides
- ➢ No danger of herbicide residue in soil or plant
- ➢ No environmental pollution
- ➢ Gives higher net return.

Principles of Integrated Weed Management:

- IWM place the crop in competitive advantage over the weeds by manipulating the crop habitat by utilizing some biological differences between crop and weeds.
- In IWM measures should be directed to reduce the survival mechanism of weeds in the soil.
- Crop cultural practices should be incorporated to discourage the establishment of the perennial and parasitic weeds.
- Any individual element of the weed management should be friendly and it should not be harmful to the environment.
- IWM practices should be flexible according to the need

4.5 Methods of Weed Management:

For designing any weed control programme in an area one must know the nature and habitat of the weeds in that area, how they react to each environmental changes and how they respond to herbicides.

Managing weeds in three different ways:

- **Prevention**
- **Eradication**
- **Control**

4.5.1 Preventive strategies:

Prevention of introduction and spread of weeds in an entirely new locality is termed as preventive method. It is essential to know that how weeds disseminate. By taking following measures weed spread can be prevented from entering into a new locality.

Sowing of weed free clean seed: The seed contaminated with weed seed is a good source of spread of weeds. It becomes hard to separate the weed seed from the crop seed. For example, cruciferous crops like radish, cauliflower, cabbage, broccoli etc. are well mixed with the seed of Satyanashi (*Argemone mexicana*). Such impure seed should be discarded for sowing.

Use of clean implements: While operating agricultural implements like cultivator, harrow, and seed drill etc. in weed infested field, care must be taken that multiplication part of weed like rhizome, bulb, tubers, stem is not being carried along. The agricultural implements should be cleaned properly. Only then these should be used in other fields. This helps in controlling spread of the weeds.

Removal of weeds along canal and irrigation channel: Weed seed get transported through water and reach the field. Removal of weeds growing along the sides of canal or irrigation channel is necessary.

Care in transplanting of seedling: Many horticultural plants like all transplanted vegetables, flowers, and fruits are transplanted in the field with soil attached to their root. Infestation of soil with weed may contaminate a new field.

Use of well rotten manure: Weed seeds have good viability. The seed of hirankhuri (*Convolvulus arvensis*) remain viable for as long as 50 years. Doob (*Cynodon dactylon*) and motha (*Cyperus rotundus*) seed viability lasts for two and five years, respectively. For making manure the cowdung is generally heaped. If the heaping period is short, the seed do not lose its viability and grows in the field wherever manure is applied. So only well rotten manure should be used.

Avoiding passing of cattle from weed infested area: Grazing in weed infested field followed by allowing passage of cattle in new field favours dissemination of weed seed. The weed seeds after passing through alimentary canal of the animal come out through dung, where it gives rise to weed. Some weed seeds also stick to the legs and skin of the animals and get transported to some other place where it germinate and grow as a weed.

Crop management practices. All such practices which favour the growth of main crop only disfavour the growth of weed. The following management practices have smothering effect on weed and must find place in crop land to prevent weed spread:

- Proper crop rotation prevents establishment of weeds.
- Higher plant population per unit area smothers the growth of weed.
- Proper placement of fertilizer in the root zone of the seed favours the growth of crop only. The weeds deprive of nutrients and their growth is restricted.
- Fast and vigorous growing varieties by virtue of their larger leaf canopy cause smothering effect on the growth of weed. Such crops should receive preference to prevent spread of the weed.

Enforcement of weed Laws: In India, many noxious weeds grow in the fields and pose great economic and health hazard. Noxious weeds are those perennial weeds which are reproduced by seeds, stem, roots, and other reproductive parts as well and are very difficult to control. *Parthenium hysterophorus, Striga* sp., *Cyperus rotundus, Cynodon dactylon* etc. are noxious weeds that grow in many horticultural crops. In India , no weed laws are in force except in Karnataka where Parthenium has been declared as a noxious weed.

Quarantine Laws: Quarantine laws impose legal restrictions on the movement of the agricultural material. If there were adequate quarantine laws, the *Parthenium* and *Argemone* which widely grows in vegetable and flower field may not have entered India. Creating isolation between widely weed infested area and new area is essential by enforcing and observing quarantine properly.

Use of pre-emergence herbicides: Herbicides which are used before the emergence of weeds either before or after planting of crop, is a good preventive measure for preventing weed infestation. Such herbicides either inhibit seed germination or kill young seedlings before they get established.

Eradication: It infers that a given weed species, its seed & vegetative part has been killed or completely removed from a given area & that weed will not reappear unless reintroduced to the area. Because of its difficulty & high cost, eradication is usually attempted only in smaller areas such as few hectares or few thousand m2 or less.

Eradication is often used in high value areas such as green houses, ornamental plant beds & containers. This may be desirable and economical when the weed species is extremely noxious and persistent as to make cropping difficult and economical.

4.5.2 Weed Control Methods:

Weed control is the process of limiting infestation of the weed plant so that crops can be grown profitably. Thus, weed control is one of the aspects of weed management.

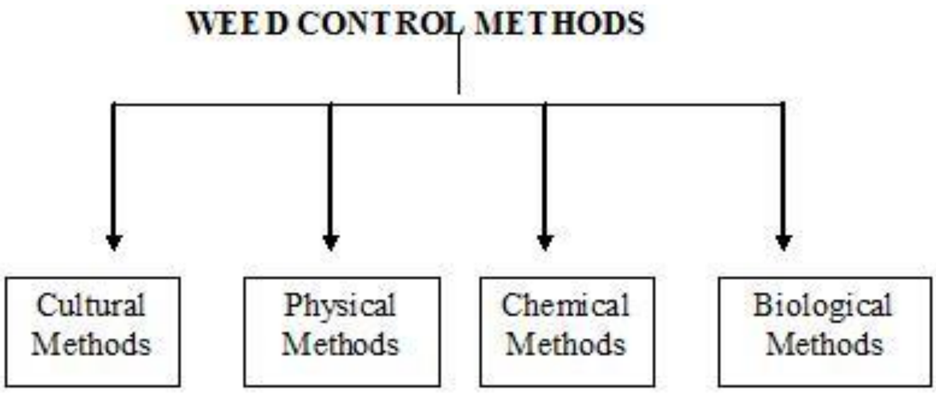


Figure 4.1: Weed Control Methods

4.5.3 Cultural Methods of Weed Control:

Several cultural practices like tillage, planting, fertilizer application, irrigation etc., are employed for creating favourable condition for the crop. These practices if used properly, help in controlling weeds. Cultural methods, alone cannot control weeds, but help in reducing weed population.

Proper crop stands and early seedling vigour - Lack of adequate plant population is prone to heavy weed infestation, which becomes, difficult to control later. Therefore, practices like

a. Selection of most adopted crops and crop varieties
b. Use of high viable seeds
c. Pre plant seed and soil treatment with pesticides, dormancy breaking chemicals and germination boosters
d. Adequate seed rates are very important to obtain proper and uniform crop stand capable of offering competition to the weeds.

Selective Crop Simulation:

Vigorous crop plants compete better with weeds as they close the ground very quickly. Selective simulation can be achieved by

a. application of soil amendments like gypsum or lime may correct the soil conditions in favour of crop.
b. manures and fertilizers application of proper kind in adequate quantities improve the crop growth.
c. Inoculation of crop seeds with suitable nitrogen fixing and phosphorous solubilising organisms may help in selective simulation of some crops e.g. Legume crop and non legume weed. Selective simulation in wide row crops like maize, sugarcane, cotton can be achieved by foliar application of nutrients.

Proper Planting Method:

Any planting method that leaves the soil surface rough and dry will discourage early growth. In summer, furrow planting of crops reduces the weed problems. Because in this method irrigation water restricted initially to the furrow only. In transplanted crops farmers get opportunity to prepare weed free main field.

Planting Time: Peak period of germination of seasonal weeds coincides with crop plants. So little earlier or later than normal time of sowing is beneficial by reducing early crop weed competition. For example, using photo insensitive varieties we can make adjustments with regarding to time of planting.

Crop Rotation: Growing of different crops in recurrent succession on the same land is called as crop rotation. Monocropping favours persistence and association of some weeds. Crop rotation is effective in controlling of crop associated and crop bound weeds such as *Avena fatua* in wheat and *Cuscuta* in lucerne. The *Orobanchae* sp. In tobbaco can be controlled by crop rotation.

Stale Seedbed: Stale seedbed is one where initial 1 to 2 flushes of weeds are destroyed by harrowing before planting or sowing of the crop. This is achieved by soaking a well-prepared field with either irrigation or after receiving rain and allowing the weeds to germinate.

Smother Crop / Competitive Crop: This crop germinates very quickly and develop large canopy, capable of efficient photosynthesis within short period. They possess both surface and deep roots. Competitive crop covers the ground quickly than non-competitive crop. e.g., Cowpea, Lucerne, berseem, groundnut and sun hemp.

Growing of Intercrops: Inter cropping suppresses weeds better than sole cropping and thus provides an opportunity to utilize crops themselves as tools of weed management. Many short duration pulses viz., green gram and soybean effectively smother weeds without causing reduction in the yield of main crop.

Summer Fallowing: The practice of summer tillage or off-season tillage is one of the effective cultural methods to check the growth of perennial weed population in crop cultivation. In the month of April, May and June farmers expose their lands to sun in order to control many soils born pests, including weeds. Roots, rhizomes and tubers of shallow rooted perennials like Bermuda grass and nut sedge.

Field Preparation:

- The field has to be kept weed free. Flowering of weeds should not be allowed. This helps in prevention of buildup of weed seed population in the fields.
- Irrigation channels are the important sources of spreading weed seeds. It is essential, therefore, to keep irrigation channels clean.
- Deep ploughing in summer, exposes underground parts like rhizomes and tubers of perennial and obnoxious weeds to scorching summer sun and kills them.
- Conventional tillage which includes 2 to 3 ploughings followed by harrowing decreases the weed problem.
- Running blade harrows cuts weeds and kills them.
- In lowland rice, puddling operation incorporates all the weeds in the soil which would decompose in course of time.

Planting Method:

- Sowing of clean crop seeds without weed seeds should be done. It is a preventive method against introduction of weeds.
- Sowings are taken up one to three days after rainfall or irrigation depending on soil type. Weeds already present in the soil start geminating within two or three days.
- Sowing operation with seed drill removes some of the germinating weeds.
- Transplanting is another operation which reduces weed population. Since, the crop has an additional advantage due to its age.

Solarization:

Method of heating the surface by using plastic sheets on moist soil trap the soil radiation. In this method the soil temperature is further increased by 5 to 100^{c}. Israel has so far made maximum use of this technique. However, this is costly technique.

4.6 Use of Fertilizers or Selective Crop Stimulation:

The band (near to crop roots) of nitrogen for cereals, sugarcane, and suagrbeet etc. is said to resulted in their vigorous growth that carries them beyond weed competition. Some fertilizers like calcium cyanamide and ammonium sulphate directly destroy the delicate weeds. **Irrigation and Drainage**

- Depending on the method of irrigation, weed infestation may be increased or decreased.
- Frequent irrigation or rain during initial stage of crop growth induces several flushes of weeds.

- In lowland rice, where standing water is present most of the time, germination of weeds is less.
- Continuous submergence with 5 cm water results in reducing weed population whereas under upland situation, weed population and weed dry matter is very high

Varieties:

Short stature, erect leaved varieties permit more light compared to tall and leafy traditional varieties. Weeds continue to germinate for long time in 'dwarf varieties resulting in high weed growth.

4.7 Physical (Mechanical & Manual) Methods of Weed Control:

Physical force either manual, animal or mechanical power is used to pull out or kill weeds. Depending on weed and crop situation one or combination of these methods are used.

Hand-weeding:

- Pulling out weeds by hand or uprooting weeds by using small hand tool is known as hand weeding.
- Two aspects are important in hand weeding: the number of hand weedings to be done and the interval between two hand weedings.
- The number of hand weedings to be done depends on crop growth, weed growth and critical period of crop-weed competition.
- The number of hand weedings range from 2-4 for most of the field crops.
- The interval between two weedings depends on the quickness of weed growth which interferes with crop growth. Generally, it is 15-20 days

Hand hoeing:

- The entire surface soil is dug to a shallow depth with the help of hand hoes, weeds are uprooted and removed.
- After hand hoeing, the field is subjected to drying to avoid re-establishing of uprooted weeds.

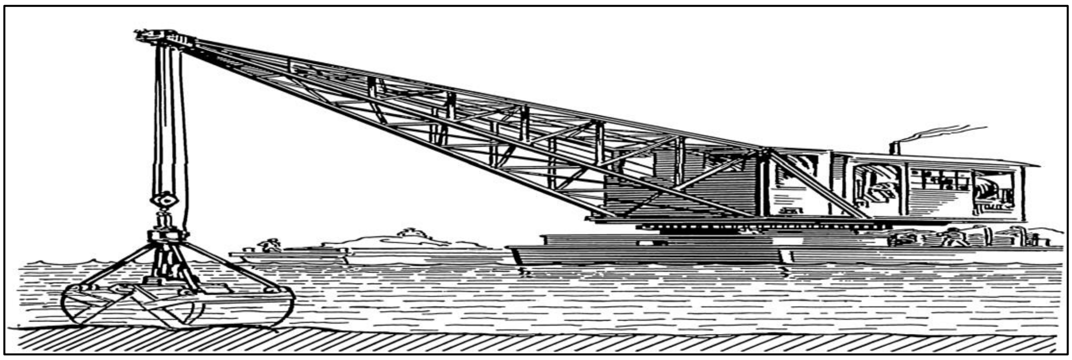
Digging: Digging is very useful in the case of perennial weeds to remove the underground propagating parts of weeds from the deeper layer of the soil. They can be eliminated by digging with crowbar or Pick axe etc.

Mowing and cutting:

Mowing is cutting of uniform growth from the entire area up to the ground level. Cutting is the topping/cutting of the weeds little above ground level. It is done with help of axes and saws. It is mostly practiced against brushes and trees.

Dredging and Chaining:

Mechanical pulling of aquatic weeds along with their roots & rhizomes from the mud is known as dredging. In case of chaining, a very big & heavy chain is pulled over the bottom of a ditch with tractors along with embankments of ditch.



Burning and Flaming:

It is cheapest method to eliminate the mature unwanted vegetation in non-cropped areas and range lands. Flaming is used in western countries for selective weed control in crops like cotton, onion, soybean and fruit orchards. It is the momentary exposure of green weeds to as high as 1000oC from flame throwers to control in row weeds.

Soil Solarization:

It is effective against weeds which are produced from seeds. Covering the soil with transparent, very thin plastic sheets of 20-25 mm polyethylene (PE) film during hottest part of summer months for 2-4 weeks. This increases the temperature by 10-12 0 C over the un-filmed control fields.

Tillage:

Tillage removes weeds from the soil resulting in their death. It may weaken plants through injury of root and stem pruning, reducing their competitiveness or regenerative capacity: Pre plant tillage helps in burying the existing weeds.

Mulching:

The mulch provides a physical barrier on the soil surface and must block nearly all light reaching the surface so that the weeds which emerge beneath the mulch do not have sufficient light to survive. E.g.- Polythene sheets, natural materials like paddy husk, ground nut shells, saw dust etc. The efficiency of polythene sheet is more (more polythene) if it is applied in continuous sheet. It is effective against annual weeds and perennial weeds.

Flooding:

Flood kills weeds by excluding oxygen from their environment. Flooding is a worldwide crop husbandry method of controlling weeds in rice fields. It helps in controlling weeds like Kans *Cyperus spp*. (*Saccharum Spontaneous*) which grows luxuriantly in heavy ill- drained soils during rainy season.

4.8 Biological Methods of weed control:

Insects, herbivorous fish, other animals, disease organisms, and competitive plants are all used to inhibit their growth. Weeds cannot be eradicated using biological management methods, although the number of weeds can be controlled. This strategy does not work for all sorts of weeds. The best targets for biological control are introduced weeds. Two significant examples of early period biological weed control are the control of Opuntia spp. (prickly pear) in Australia and lantana in Hawaii with particular insect bioagents.

Table 4.1: Different bio-agents used for weed control:

Weed	**Bio-agent**	**Reporting Country**	**Type of Bioagent**
Chondrilla juncea	Puccina chondrillina	Australia	Plant pathogen
Eupatorium riparium	Entyloma compositarum	USA	Plant pathogen
Hydrilla verticillata	Hydrellia pakistanae	USA	Shoot fly
Orobanche cornea	Sclerotinia sp.	USA	Plant pathogen
Parthenium hysterophorus	i)Zygogramma bicolorata ii)Epiblema strenuana iii) Conotrachelus sp.	India Australia Australia	Leaf eating beetle Stem galling insect Stem galling insect

Weed	**Bio-agent**	**Reporting Country**	**Type of Bioagent**
Rumex spp.	i) Uromyces rumicis ii) Gastrophysa viridula	USA USA	Plant pathogen Beetle
Cyperus rotundus	Bactra verutana	India, Pakistan, USA	Shoot boring moth
Echinochloa spp. (In rice fields)	i)Emmalocera sp. ii) Tripos spp .	-	i)Stem boring moth ii) Shrimp
Tribulus terrestris	Microlarinus lareynii and M. lypriformis	USA	Pod weevil

Table 4.2: Some Commercial Bioherbicides used in weed control

Product	**Content**	**Weed controlled**
De-Vine	A liquid suspension of fungal spores of Phytophthora palmivora. It causes root rot in the weed.	Strangler-vine. (Morrentia odorata) in citrus orchards.
Collego	Wettable powder containing fungal spores of Colletotrichum gloesporiodes Sub sp. aeschynomone	Joint vetch (Aeschynomone sp). In rice fields. The bioherbicide causes stem and leaf blight in the weed.
Bipolaris	A suspension of fungal spores of Bipolaris sorghicola.	Johnson grass (Sorghum halepense)
Biolophos	A microbial toxin produced as fermentation product of Streptomyces hygroscopicus.	Non-specific, general vegetation
Luboa-2	Colletotrichum gloesporiodes Spp. Cuscuta	Cuscuta

4.9 Allelopathy as a Weed Management:

Allelopathy is a natural process that can be used in crop production as a tool for biological weed management. Allelochemicals could be utilised to develop new methods to tackle weed resistance to herbicides. White mustard seed germination was entirely suppressed by sunflower extracts (*Sinapis alba* L.). *Phalaris minor* Retz., *Chenopodium album* L., *Coronopus didymus* L., *Medicago polymorpha* L., and *Rumex dentatus* L. were all inhibited by an annuionone derived from aqueous extract of sunflower (cv. Suncross-42 leaves).

4.10 Chemicals Methods of Weed Control:

Chemicals that are used to kill plants or weeds are called herbicides. Chemical weed control functions on the basis that certain chemicals are capable of killing some plants weeds without significantly affecting other plants or crops.

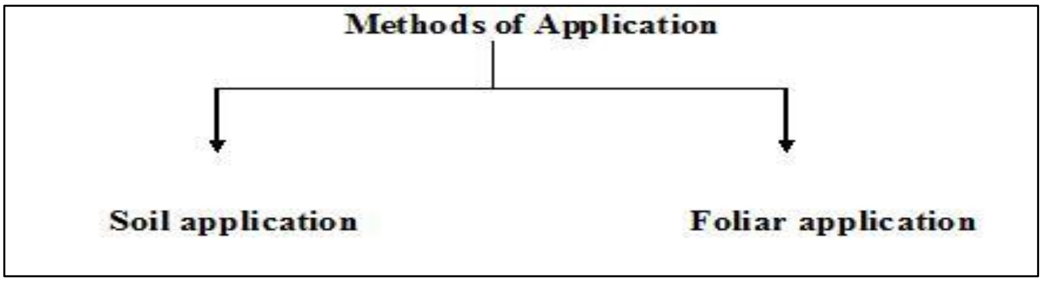


Figure 4.2: Methods of Application

4.10.1 Soil Application:

A. Soil Surface Application:

Herbicides are usually applied to soil surface to form a uniform herbicide layer. The applied herbicides, due to their low solubility may penetrate only few centimeters into the soil. Weeds germinating in the top layers are killed due to incidental absorption of herbicides. eg. triazines, ureas and anilide.

Soil incorporation: Some herbicides are applied to soil surface and incorporated into the soil either by tillage or irrigation for their effectiveness. eg. volatile herbicides *viz*., aniline and carbamate

Sub-surface application: Perennial weeds like *Cyperus rotundus* and *Cynodon dactylon* are controlled by injecting herbicides to the lower layers of the soil at several points.

B. Foliar Application:

Band application: Herbicides are applied as narrow bands over or along the crop row. The weeds in between the crop rows can be controlled by intercultivation or band application of herbicide. This method is useful where labour is expensive and intercultivation is possible. eg. Weeds in maize can be controlled effectively by spraying atrazine on seed row at the time of sowing.

Blanket application: Application of herbicide over the entire leaf area. Selective herbicides are applied by this method.

Directed Application: Herbicide are applied directly to weeds between crop rows, avoiding the crop foliage. Care is taken to avoid spray fluid falling on the crop. eg. Late weeds in cotton can be controlled by spraying non selective herbicide by directed spray.

Spot application: Herbicides are applied or poured on small patches of weeds, leaving the relatively wee free patches untreated. It minimizes the herbicide usage per unit area.

Benefits of chemical method:

- Herbicides can be applied for weed control in crop rows and where cultivation is impossible.
- Pre-emergence herbicides provide early season weed control.
- Cultivation & manual methods of weed control may injure the root system.
- Herbicides reduce the need for pre-planting tillage. They are extremely useful in minimal\zero tillage.
- Herbicides can control many perennial weeds which cannot be controlled by other methods. Eg: *Cyperus* sp.,

4.11 Conclusion:

Integrated weed management is a science-based decision-making approach that includes multiple weed control methods rather than relying on a single method to reduce weed populations below an economic threshold. This strategy is more effective since any weeds that are left over from one method can be controlled with another. As a result, this technique aids in the reduction of seed bank status in the field. Many difficulties, such as shifts in weed flora and the development of resistance in weed plants, can be prevented by using this strategy. The requirement of the day is for an integrated weed control strategy, and this method must be promoted in order to achieve long-term respite from these unwelcome plants. Integrated weed management approach is environmentally friendly as farmers are not entirely dependent on herbicides.

4.12 References:

1. M. A. Altieri and M Liebman 1988. Weed management in agro ecosystems Ecological approaches. Boca Raton, FL: CRC Press.354 p.
2. D. D Buhler 1996. Development of alternative weed management strategies. J. Prod. Agric. 9:501–505.
3. Harker, K.N.; O'Donovan, J.T. Recent weed control, weed management, and integrated weed management. *Weed Technol.* **2003**, *27*, 1–11.
4. R. H Walker and G. A Buchanan 1982.Crop manipulation in integrated weed management systems. Weed Sci. (Suppl.) 30:17–24.
5. M Liebman and E Dyck 1993. Crop rotation strategies for weed management. Ecol. Applic. 3:92–122.

6. Bond, W.; Grundy, A.C. Non-chemical weed management in organic farming systems. *Weed Res.* **2001**, *41*, 383–405
7. Bàrberi, P. Weed management in organic agriculture: Are we addressing the right issues? *Weed Res.* **2002**, *42*, 177–193.
8. R. E Blackshaw J. R Moyer K. N Harker and G. W Clayton 2005. Integration of agronomic practices and herbicides for sustainable weed management in a zero-till barley field pea rotation. Weed Technol. 19:190–196.
9. Gunsolus, J.L.; Buhler, D.D. A risk management perspective on integrated weed management. *J. Crop. Prod.* **1999**, *2*, 167–187
10. Mas, M.T., Verdú, A.M.C. Tillage system effects on weed communities in a 4-year crop rotation under Mediterranean dryland conditions. *Soil Tillage Res.* **2003**, *74*, 15–24.
11. Qasem, J.R.; Foy, C.L. Weed allelopathy, its ecological impacts and future prospects: A review. *J. Crop. Prod.* **2001**, *4*, 43–119.
12. Pannacci, E.; Lattanzi, B.; Tei, F. Non-chemical weed management strategies in minor crops: A review. *Crop Prot.* **2017**, *96*, 44–58.
13. Mortensen, D. A., Bastiaans, L., and Sattin, M. 2000. The role of ecology in the development of weed management systems: an outlook. Weed Res. 40 :49
14. Swanton, C. J., Mahoney, K. J., Chandler, K., and Gulden, R. H. 2008. Integrated weed management: knowledge-based weed management systems. Weed Sci. 56 :168–172.
15. Mortensen, D. A., Bastiaans, L., and Sattin, M. 2000. The role of ecology in the development of weed management systems: an outlook. Weed Res. 40 :49–62.

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5. Polymer Coated Fertilizers and Their Scope in Modern Agriculture

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Abstract:

Increasing fertilizer prices coupled with lower nutrient use efficiency (NUE) have not only cut down the crop productivity and nutritional quality, but also have severe environmental consequences like greenhouse gas (GHG) emission, ground water contamination etc. Polymer coated fertilizers (PCFs) are promising tool, where the fertilizer is encapsulated with synthetic or natural polymers, which release the nutrient gradually upon decomposition of the polymer by microbial break down. The main advantage of PCFs is that it releases the nutrient over an extended period of time synchronising with the plant demand, thus mitigating environmental hazard and maximizing NUE. In this book chapter, we have tried to discuss, after thorough literature review, about different kinds of slow-release fertilizers (SRFs), their mechanism of nutrient release and commonly used polymers in SRF formulation. Potentials of PCFs in regulating nutrient release, enhancing nutrient uptake and crop productivity has also been dealt with lucidly.

Keywords:

Polymer coated fertilizers, Nutrient use efficiency, Crop productivity

5.1 Introduction:

According to the United Nations (UN, DESA 2019) the world population will reach to around 9.7 billion by 2050. The Food and Agriculture Organization (FAO) has predicted that the world foodgrain production must increase by 70% by the year 2050 to feed this ever-growing population [5]. Unanimously, the world agriculture will face much challenges to accommodate this large population with foodgrains. Fertilizers are one of the most crucial agricultural inputs in order to increase crop productivity [2, 27]. The essential nutrients required for plant growth is supplied through fertilizers, which enhances the crop growth and yield and deficiency of one or more nutrients can result in drastic reduction in yield. Fertilizers can be supplied via soil application (uptake through plant roots) or foliar application (uptake through stomata) [10, 37].

Considering the indispensable role of fertilizers in enhancing crop yield, it is imperative to boost up the fertilizer consumption by the crops [18]. But it is a matter of great concern that very little fraction of the conventionally used fertilizers are taken up by the crops, i.e., 30-35% of nitrogen [9], 10-15% of phosphorus [31], 30-50% of potassium and 1-2% of the micronutrients [12] applied are utilized by the plants and rest are subjected to various losses such as volatilization, leaching, fixation in clay inter-layer *etc*. These unutilized nutrients are not only responsible for economic loss in terms of poor yield, but also leads serious environmental hazards [7]. These include GHG emission, global warming, eutrophication, ground water contamination and so on [33, 38]. So, all these factors in combination, have raised worldwide concern among scientists as well as farmers, which have necessitated development of such fertilizer formulation that can improve crop yield and apparent nutrient recovery on one hand and minimize environmental hazard of the left-over nutrients on the other [6, 35]. One of the recent advancements in this direction is slow-release fertilizers (SRFs) and controlled release fertilizers (CRFs) [16], where the nutrient element is coated with different polymeric substances or some inert, impermeable membrane which, through its various mechanisms, extends the nutrient release time and supresses the nutrient release rate, thereby increasing the duration for which plant roots remain in contact with the nutrient solution. Scientists have illustrated minute differences between these two. In SRFs the release rate of nutrient is mostly unpredictable and determined mainly by soil and climatic conditions, whereas, for CRFs the quantity and nutrient release pattern can be quantified prior to its application [41] although laymen use these two terms (SRFs and CRFs) synonymously as SRFs. These polymers coated SRFs have certain definite characteristics which make them distinctive from the conventionally used fertilizers both in terms of nutrient utilization efficiency and environmental sustainability. These are:

- These enable the growers to manage the rate and timing of nutrient discharge so that fertilizers applied at the beginning of the season can provide the plant roots with nutrients in optimum quantity and in balanced proportion through its controlled agrochemical delivery system [3, 24].
- The extent of nutrient liberation ranges from few weeks to several months depending upon the thickness and degradability of coating material. Release through this extended period minimizes nutrient losses and environmental hazards [4, 25].
- Polymer coated urea have been proven to reduce NO_3^- leaching [45], N_2O discharge [14] and NH_3 volatilization [32].

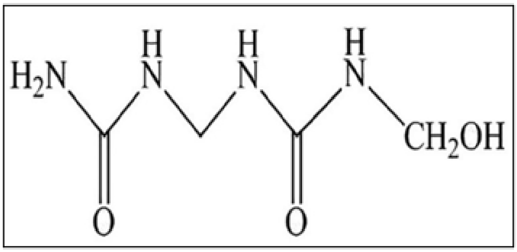
5.2 Slow-Release Fertilizers (SRFs):

SRFs are one of the hotspot research areas now-a-days to combat with the low NUE of the traditional fertilizers and these chemically engineered fertilizer formulations are proving themselves as a ray of hope. They release the plant nutrient gradually through an extended period with the decomposition of the surrounding polymer or inert material through various biotic and abiotic means.

The acceptability of these SRFs obviously depends upon the cost of coating material, their eco-friendliness and degradability. Due to their gradual release pattern, unlike the traditional fertilizers where majority of the nutrients gets discharged within a week of application, neither the plant roots are subjected to toxic nutrient overdose nor the unutilized nutrients can be removed from the root zone. On the basis of the composition of coating material, [39] categorized the SRFs into three broad categories.

5.2.1 Uncoated N- Based Fertilizers:

Oldest category of CRFs where the controlled-release is achieved by increasing the structural complexity of the nutrient element by chemical combination or complexation. Higher structural complexity makes it less accessible to various disintegrating forces and release of nutrient from this chemical complex depends upon available soil moisture, pH, soil temperature, microbial load *etc* [23]. *e.g.*- Urea formaldehyde (Figure 5.1) and Crotonylidene diurea (Figure 5.2)



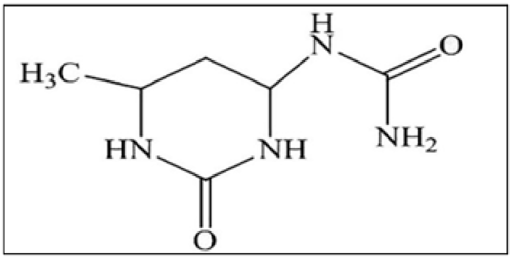


Figure *5.1:* Urea formaldehyde **Figure *5.2:* Crotonylidene diurea**

5.2.2 Coated N- Based Fertilizers:

Here the nutrient element is coated by an impermeable material resistant to decomposition by physical, chemical or biological means. This coating, being relatively water insoluble, acts as a physical barrier to the nutrient release on one hand, and supplies additional nutrients on the other. *e.g.,* sulphur coated urea supplies sulphur (S) additional to N, phosphor gypsum coated urea supplies S and Ca additional to N (Figure 5.3). Here coating thickness and durability are the main controller of nutrient release [30].

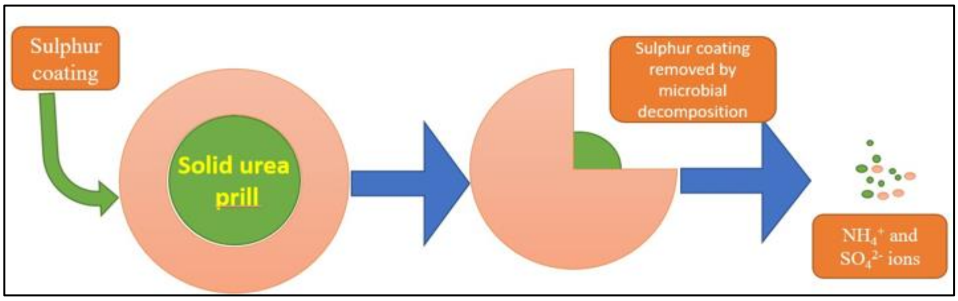


Figure 5.3: Decomposition of sulphur coating and release of N from SCU

5.2.3 Polymer Coated Nutrient Fertilizers:

Polymer coated fertilizers are the latest advancement in the field of fertilizer research, where the soluble nutrient is surrounded by a wide range of polymeric substances, both natural and synthetic. Natural polymers like starch, cellulose, chitosan and synthetic polymers like polyethylene, polyurethane, alkyd resin *etc.* are widely used [41].

Now-a-days super absorbent polymers, a branch of cross-linked hydrophilic polymers, are widely used as a coating material. These polymers, besides controlling the nutrient release rate, can absorb moisture 5-10 times of their body weight and can retain enormous quantity of water. Due to this behaviour, these polymer-based fertilizers are gaining popularity in enhancing the water use efficiency (WUE) too besides NUE. Bio-degradable polymers, unlike synthetic polymers, are eco-friendly and promote soil microbial population by acting as a food and water source for the microbes [23]. Corncob [43] and Cotton stalks [44] are effective source of bio-origin polymers.

5.3 Mechanisms of Nutrient Release:

As already mentioned earlier, the polymer coated SRFs, unlike the traditional fertilizers, release the nutrient in more gradual manner. This release is dependent upon the biodegradability and mechanical properties of the coating material, thickness of polymer coating and different soil properties (temperature, moisture content *etc*).

After soil application of these polymer coated fertilizers, moisture present in the soil penetrates through the polymer coating and as a result the hydrophilic polymers gets swelled up and the encapsulated nutrients become activated. This phenomenon is followed by dissolution of nutrients, development of osmotic pressure and diffusion of the nutrients through the polymer coating gradually over several months, with concentration gradient being the driving force [40].

Meanwhile, these polymers being source of moisture and carbon substrates, are decomposed by soil microbes and complete release of nutrients occur. Several models have also been proposed by various scientists to envisage the kinetics of nutrient release from the polymer coated CRFs such as Fickian diffusion model [11], Higuchi model [29] *etc*. which are beyond the scope of this chapter.

5.4 Polymers Commonly Used in Polymer Coated CRF Formulation:

5.4.1 Synthetic Polymers:

The SRFs can be formulated by using either hydrophilic or hydrophobic polymers. These polymers are based on resin or thermoplastic material. Hydrophobic polymers when used as a coating material, the coating gets porous and partially degraded in soil. Nutrient release through this porous membrane due to diffusion pressure [15]. Hydrophilic polymers absorb water and gets swelled up and nutrients diffuses out as result of dissolution.

A. Hydrophilic polymers:

Hydrophilic polymers (super absorbent polymers) are three dimensional polymers with cross linking networks that are able to absorb and retain water quite a few times of their body weight. Hydrogels are recommended widely as a water saving tool for rainfed farms which run short of soil moisture, and specially in arid regions [46] where they reduce the dependence on irrigation.

Polymer matrix was also prepared from poly acrylic acid (PAA) via solution polymerization technique by [42] for the slow release of potassium-di-hydrogen-phosphate (KH_2PO_4). Polysulfone (PSF) and polyacrylonitrile (PAN) are also used to coat conventional NPK fertilizers for precise nutrient delivery.

B. Hydrophobic polymers:

Hydrophobic polymers, as the name indicate, are insoluble in water due to the absence of polar character. Polyethylene (PE), Polypropylene (PP), Ethylene-vinyl acetate (EVA), Polyurethane (PU), Polystyrene (PS) *etc*. are the mostly used hydrophobic polymers used in CRF formulation [30]. [43] reported that about 80% N was released during 180 days in water at 25^0 C from 100% PE coated fertilizer, whereas, 98% N was discharged during only 98 days in case of 50% PE coating.

5.4.2 Natural Polymers:

Natural polymers are more preferred to their synthetic counterparts due to their renewable origin, easy biodegradability and better stimulative effect on crop yield and soil health. Polysaccharides (starch, lignin, cellulose, chitosan *etc*.) are regarded as the most outstanding category of bio-polymers. [8] prepared a polymer composite from starch-g-poly (L-lactide) and loaded it with urea to use as a SRF. Similarly, [26] formulated a urea loaded SRF where the polymer was synthesized from starch-g-poly (vinyl acetate).

Chitosan is another important bio-origin polymer having antiviral, antifungal properties as well as acts as a source of N [13]. [15] prepared a new nitrogenous SRF formulation from in-situ hydrogelation of chitosan and salicylic aldehyde in presence of urea. Agricultural waste such as wheat straw is also a potential source of raw material for the synthesis of different polymers [17] which have been used as coating materials in SRF formulation.

5.5 Nano Clay Polymer Composite (NCPC) Based Fertilizers:

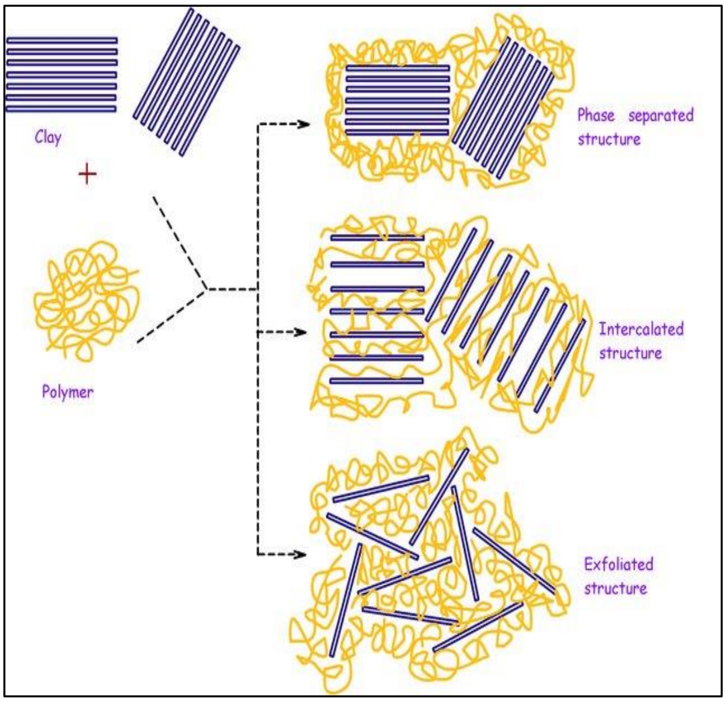


Figure 5.1: Nano clay polymer composite (modified from Mukhopadhyay *et el.*, 2014)

NCPC based fertilizers (Nitrogen- NCPC, Potassium- NCPC, Iron-NCPC, Zinc- NCPC and Multi nutrient- NCPC) are being used widely now-a-days and are making a paradigm shift in the fertilizer industry. In these NCPC based fertilizers, the clay polymer composite is loaded with the nutrient element (either N, K or micronutrients). The clay polymer composite is prepared with acrylic acid-acrylamide as super-absorbent, NNMBAD as cross-linker and nano clay prepared from either kaolinite, illite or smectite as diffusion barrier [21, 36]. The mechanism of this NCPC based fertilizer is to separation and exfoliation of nano clay into its structural units (silicate layers) and formation of cross linkage between these units. When the NCPC is loaded with urea (for N) or micronutrient salt, the nutrient element gets arrested within the cross-linkages.

Prolonged release of nutrient from these NCPC based fertilizer results in higher NUE. [36] in their leaching experiment, found that the cumulative P and total mineral N recovery increased to the extent of (+57.3 and +16.2 %), (+55.2 and +15.4%) and (+88.3 and +27.3%) with the use of fertilizer loaded NCPC synthesized with kaolinite, illite and smectite respectively when compared with conventional fertilizers.

5.6 Effect of Polymer Coated CRFs on Nutrient Release:

[20] conducted an experiment where they prepared zincated NCPC with acrylic acid-acrylamide copolymer using graded amount of clay and nano-clay and compared the release pattern of DTPA-Zn with conventionally used $ZnSO_4.7H_2O$ (Table 1) in two different soil order.

It is clear from the table that $ZnSO_4.7H_2O$ had maintained higher DTPA-Zn at initial period of incubation (15 days) which gradually decreased afterwards. Contrary to this, reverse trend was noticed in case of polymer composites, where lower DTPA-Zn

Table 5.1: Release of DTPA-Zn as affected by different polymer combination

	DTPA- Zn content in soil-I (ppm)				DTPA- Zn content in soil-II (ppm)			
Treatment	**15 days**	**30 days**	**45 days**	**60 days**	**15 days**	**30 days**	**45 days**	**60 days**
T1	1.86	2.84	5.33	6.53	1.87	2.68	4.44	5.53
T2	1.66	2.46	4.71	6.08	1.78	2.49	4.16	5.13
T3	1.44	2.06	4.61	5.52	1.33	2.26	3.94	4.27
T4	1.14	2.28	4.96	5.79	1.5	2.68	4.13	5.13
T5	1.12	2.39	4.59	5.41	1.11	2.42	3.53	4.47
T6	0.95	1.97	4.34	5.17	0.87	2.12	3.07	3.87
T7	5.12	3.31	2.97	2.5	5.01	2.03	2.82	2.43
CD (p= 0.01)	0.17	0.11	0.17	0.17	0.16	0.05	0.07	0.08

[T1: 8% clay; T2: 10% clay; T3: 12% clay T4: 8% nano clay; T5: 10% nano clay; T6: 12% nano clay and T7: Conventional Zn sources ($ZnSO_4$. $7H_2O$).] -Source- [20]

content at the initial period was followed by higher content of the same at the later period of incubation (Figure 5.5, 5.6). The role of polymer composites in decelerating Zn- release increased with increase in clay content and was more conspicuous when nano-clay was used as diffusion barrier in the polymer matrix, which was attributed to their better exfoliation tendency. It makes clear sense that at initial period of plant growth, the root density being less, plant cannot uptake much nutrient. The uptake capacity increases gradually with the development of root system. This explains why micronutrient use efficiency is limited only to 1-2% using conventional micronutrient fertilizers and how polymer composite fertilizers can play a crucial role in improving the NUE.

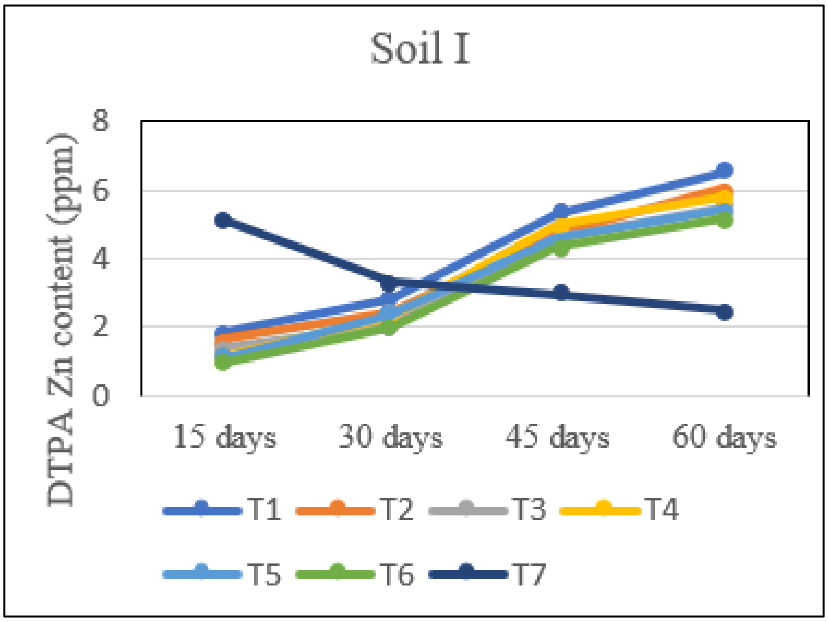


Figure 5.5: Release pattern of DTPA- Zn in Soil-I

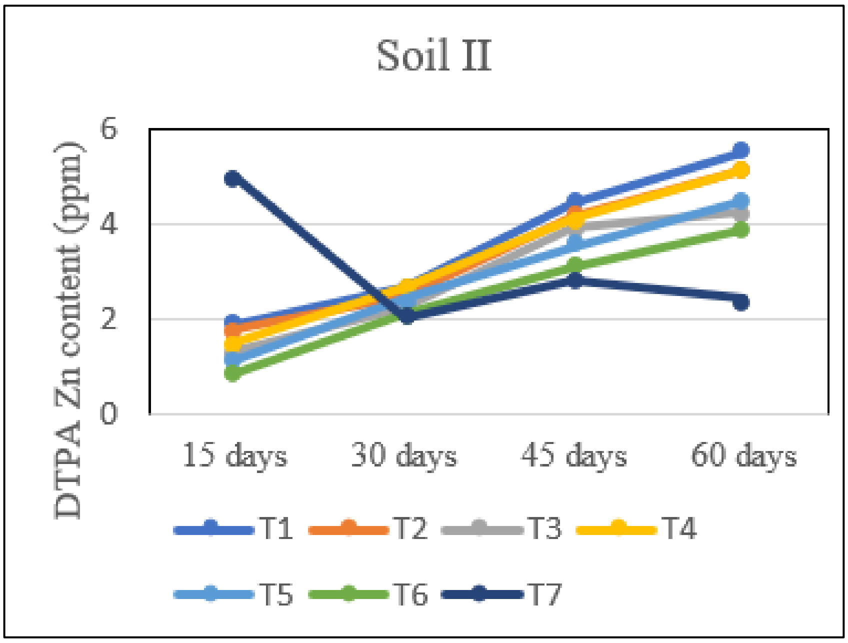


Figure 5.6: Release pattern of DTPA- Zn in Soil-II

Similar kind of experiment was conducted by [34] on P supplying capacity of indigenous rock phosphate (RP), (from two sources viz., Udaipur and Purulia) as these are easily available but most of them are of low solubility and their P concentration is also less [19], which leads to importation of RP from foreign countries involving higher cost. Citric acid loaded in NCPC was applied to solubilize RP and release plant available P.

The P supplying capacity of RP was compared with DAP in a greenhouse experiment on wheat followed by rice (Table 5.2).

Table 5.2: Yield and P uptake by wheat and rice as influenced by rock phosphate treated with citric acid loaded NCPC

	Total yield (g/pot)		Total P uptake (mg/kg)	
Treatment	Wheat	Rice	Wheat	Rice
URP+ CA-NCPC	15.98	15.70	17.11	16.91
PRP+ CA-NCPC	15.89	16.19	16.95	18.02
DAP	16.08	15.40	18.05	16.90
Control	12.72	11.11	11.91	6.80
CD (0.05)	0.25	1.60	1.15	2.46

[URP- Udaipur rock phosphate; PRP- Purulia rock phosphate; CA-NCPC- Citric acid loaded nano clay polymer composite; DAP- Di ammonium phosphate] Source- [34]

The rate of P release due to solubilization of RP was found to be good enough to maintain available P content at par with DAP. Citric acid loaded NCPC acted as a slow-release P fertilizer as evidenced from Table 5.2. Yield of both rice and wheat as well as total P uptake by these crops due to RP application was comparable to DAP. Higher rice yield in RP treated pots compared to DAP indicates the better residual effect of RP as a phosphorus source.

5.7 Future Direction of Research:

The research about polymer coated CRF is still in its budding stage and many more facets are yet to be unveiled. Future researchers should focus on developing inexpensive CRFs which are eco-friendly and do not have any detrimental effect on soil health as well as on the environment. This novel technology can only be disseminated from laboratory to farmer’s field with multi-locational field trials so that farmers are compelled to acknowledge the real practical advantage of this novel technology. One more point to focus on is upscaling the production of this CRFs on an industrial scale. The residual effect of CRFs applied in a crop, if any, on the subsequent crop also needs to be explored.

5.8 Conclusion:

The traditionally used fertilizers leave environmental footprint by polluting ground water, emitting greenhouse gas *etc*. Moreover, plants cannot utilize these nutrients to full extent. Polymer coated fertilizers are advanced technology where the nutrients are supplied through controlled agrochemical delivery system by virtue of its barrier property towards nutrient diffusion. This results in better recovery efficiency of applied nutrients and ultimately crop growth and yield. Nutricote, Osmocote, Polyon *etc*. are widely used coating material used for this purpose. NCPC based Zn containing micronutrient fertilizer results in gradual Zn release, which makes it more accessible to plant roots. Researchers are engaged in evaluating the effect of polymer coated CRFs on various crops and cropping system as well as on the NUE of various nutrients under diverse soil and climatic conditions.

5.9 References:

1. Abd El-Aziz M, Salama D, Morsi S, Youssef A, El-Sakhawy M. Development of polymer composites and encapsulation technology for slow-release fertilizers. Reviews in Chemical Engineering. 2020; 38: 603-616.
2. Abd Elwahed MS, Abd El-Aziz ME, Shaaban EA, Salama DM. New trend to use biochar as foliar application for wheat plants (*Triticum aestivum*). Journal of Plant Nutrition. 2019; 42: 1180–1191.
3. An X, Wu Z, Yu J, Cravotto G, Liu X, Li Q, Yu B. Copyrolysis of biomass, bentonite, and nutrients as a new strategy for the synthesis of improved biochar-based slowrelease fertilizers. ACS Sustainable Chemistry & Engineering. 2020a; 8: 3181–3190.
4. An X, Wu Z, Yu J, Ge L, Li T, Liu X, Yu B. High efficiency reclaiming phosphate from an aqueous solution by bentonite modified biochars: A slow-release fertilizer with a precise rate regulation. ACS Sustainable Chemistry & Engineering. 2020b; 8: 6090–6099.

5. Bernard B, Lux A. How to feed the world sustainably: An overview of the discourse on agroecology and sustainable intensification. Regional Environmental Change. 2017; 17: 1279–1290.
6. Chandre MS, Lal M, Naresh RK, Yadav S, Kumar R, Kumar R, Chand SW, Varsha N, Chandana P, Lavanya N. Role of polymer coated fertilizers (PCFS) an advance technology for improving nutrient use efficiency and crop productivity: A review. International Journal of Chemical Studies. 2019; 7: 2667–2679.
7. Chen J, Lü S, Zhang Z, Zhao X, Li X, Ning P, Liu M. Environmentally friendly fertilizers: A review of materials used and their effects on the environment. Science of the Total Environment. 2018; 613: 829–839.
8. Chen L, Xie Z, Zhuang X, Chen X, Jing X. Controlled release of urea encapsulated by starch-g-poly (L-lactide). Carbohydrate Polymer. 2008; 72: 342–348.
9. Congreves KA, Otchere O, Ferland D, Farzadfar S, Williams S, Arcand MM. Nitrogen use efficiency definitions of today and tomorrow. Frontiers of Plant Science. 2021; 12: 637180.
10. Corradini E, De Moura MR, Mattoso LH. A preliminary study of the incorparation of NPK fertilizer into chitosan nanoparticles. Express Polymer Letters. 2010; 4: 509–515.
11. Du C, Zhou J, Shaviv A, Wang H. Mathematical model for potassium release from polymer-coated fertiliser. Biosystems Engineering. 2004; 88: 395–400.
12. Fageria N K, Baligar V C, Li YC. Nutrient uptake and use efficiency by tropical legume cover crops at varying pH of an Oxisol. Journal of Plant Nutrition, 2014; 37: 294-311.
13. Hassan H, Salama A, El-ziaty AK, El-Sakhawy M. New chitosan/silica/zinc oxide nanocomposite as adsorbent for dye removal. International Journal of Biological Macromolecules. 2019; 131: 520–526.
14. Hyatt CR, Venterea RT, Rosen CJ, McNearney M, Wilson ML, Dolan MS. Polymer-coated urea maintains potato yields and reduces nitrous oxide emissions in a Minnesota loamy sand. Soil Science Society of America Journal. 2010; 74: 419-428.
15. Iftime MM, Ailiesei GL, Ungureanu E, Marin L. Designing chitosan based eco-friendly multifunctional soil conditioner systems with urea-controlled release and water retention. Carbohydrate Polymer. 2019; 223: 115040.
16. Jantalia CP, Halvorson AD, Follett RF, Rodrigues Alves BJ, Polidoro JC, Urquiaga S. Nitrogen source effects on ammonia volatilization as measured with semi-static chambers. Agronomy Journal. 2012; 104: 1595–1603.
17. Liang R, Yuan H, Xi G, Zhou Q. Synthesis of wheat straw-g-poly (acrylic acid) superabsorbent composites and release of urea from it. Carbohydrate Polymer. 2009; 77: 181–187.
18. Mahmoud SH, Salama DM, El-Tanahy AM, El-Bassiony AM. Effects of prolonged restriction in water supply and spraying with potassium silicate on growth and productivity of potato. Plant Archives. 2019; 19: 2585–2595.
19. Mamata B, Narayanasamy G, Biswas DR. Phosphorus supplying capacity of phosphate rocks as influenced by compaction with water-soluble P fertilizers. Nutrient Cycling in Agroecosystems. 2004; 68:73–84.
20. Mandal N, Datta SC, Manjaiah KM, Dwivedi BS, Kumar R, Aggarwal P. Zincated nanoclay polymer composites (ZNCPCs): Synthesis, characterization, biodegradation and controlled release behaviour in soil. Polymer-Plastics Technology and Engineering. 2018; 57: 1760-1770.
21. Mandal N, Datta SC, Manjaiah KM. Synthesis, characterization and controlled release study of Zn from Zincated nanoclay polymer composites (ZNCPCs) in relation to

equilibrium water absorbency under Zn deficient Typic Haplustepts. Annals of Plant and Soil Research. 2015; 17: 187-195.

22. Mukhopadhyay R, De N. Nano clay polymer composite: Synthesis, characterization, properties and application in rainfed agriculture. Global Journal of Bioscience and Biotechnology. 2014; 3, 133-138.
23. Nardi P, Ulderico N, Di Matteo G, Trinchera A, Napoli R, Farina R, Subbarao GV, Benedetti A. Nitrogen release from slow-release fertilizers in soils with different microbial activities. Pedosphere. 2018; 28: 332–340.
24. Naz M, Sulaiman S. Slow-release coating remedy for nitrogen loss from conventional urea: A review. Journal of Control Release. 2016; 225: 109–120.
25. Ni B, Liu M, Lü S, Xie L, Zhang X, Wang Y. Novel slow-release multielement compound fertilizer with hygroscopicity and moisture preservation. *Industrial* & *Engineering Chemistry Research*. 2010; 49: 4546–4552.
26. Niu Y, Li H. Controlled release of urea encapsulated by starch-g-poly (vinyl acetate). Industrial & Engineering Chemistry Research. 2012; 51: 12173–12177.
27. Osman SA, Salama DM, Abd El-Aziz ME, Shaaban EA, Abd Elwahed MS. The influence of MoO_3-NPs on agro-morphological criteria, genomic stability of DNA, biochemical assay, and production of common dry bean (Phaseolus vulgaris L.). Plant Physiology and Biochemistry. 2020; 151: 77–87.
28. Owusu-Sekyere A. Micronutrients use efficiency and dry matter yield of annual crops as affected by inorganic and organic amendments. Journal of Plant Nutrition. 2021; 44: 2245-2257.
29. Paul DR. Elaborations on the Higuchi model for drug delivery. International Journal of Pharmaceutics. 2011; 418: 13–17.
30. Rahman NS, Yunus R, Ishak CF, Hanif Khan S. Laboratory evaluation on ammonia volatilization from coated urea fertilizers. Communications of Soil Science and Plant Analysis. 2018; 49: 717–724.
31. Roberts TL, Johnston AE. Phosphorus use efficiency and management in agriculture. Resources, Conservation and Recycling. 2015; 105: 275-281.
32. Rochette P, MacDonald JD, Angers DA, Chantigny MH, Gasser MO, Bertrand N. Banding of urea increased ammonia volatilization in a dry acidic soil. Journal of Environmental Quality. 2009; 38:1383-1390.
33. Rodrigues MÂ, Santos H, Ruivo S, Arrobas M. Slow-release N fertilisers are not an alternative to urea for fertilisation of autumn-grown tall cabbage. European Journal of Agronomy. 2010; 32: 137–143.
34. Roy T, Biswas DR, Datta SC, Sarkar A, Biswas SS. Citric acid loaded nano clay polymer composite for solubilization of Indian rock phosphates: A step towards sustainable and phosphorus secure future. Archives of Agronomy and Soil Science. 2018; 64: 1564-1581.
35. Salama DM, Osman SA, Abd El-Aziz ME, Abd Elwahed MSA, Shaaban EA. Effect of zinc oxide nanoparticles on the growth, genomic DNA, production and the quality of common dry bean (Phaseolus vulgaris). Biocatalysis and Agricultural Biotechnology. 2019; 18: 101083.
36. Sarkar S, Datta SC, Biswas DR. Synthesis and characterization of nanoclay–polymer composites from soil clay with respect to their water-holding capacities and nutrient-release behaviour. Journal of Applied Polymer Science. 2014; 131.

37. Shebl A, Hassan AA, Salama DM, Abd El-Aziz ME, Abd Elwahed MS. Template-free microwave-assisted hydrothermal synthesis of manganese zinc ferrite as a nanofertilizer for squash plant (*Cucurbita pepo* L). Heliyon. 2020; 6: e03596.
38. Shengsen W, Ashok A, Yuncong L, Min Z. A rapid technique for prediction of nutrient release from polymer coated controlled release fertilizers. Open Journal of Soil Science. 2011; 1: 40–44.
39. Thomas DL, Andis K, Dumroese R. Using polymer coated controlled-release fertilizers in the nursery and after outplanting. Forest Nursery Notes. Winter. 2009; 5- 12.
40. Timilsena YP, Adhikari R, Casey P, Muster T, Gill H, Adhikari B. Enhanced efficiency fertilisers: a review of formulation and nutrient release patterns. Journal of the Science of Food and Agriculture. 2015; 95: 1131–1142.
41. Trenkel ME. Slow-and controlled-release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture. International fertilizer industry association, (IFA), Paris, France, 2010; pp. 1–163.
42. Tyliszczak B, Polaczek J, Pielichowski J, Pielichowski K. Synthesis of control release KH_2PO_4-based fertilizers with PAA matrix modified by PEG. Molecular Crystals and Liquid Crystals. 2010; 523: 297/[869]–303/[875].
43. Wen P, Han Y, Wu Z, He Y, Ye BC, Wang J. Rapid synthesis of a corncob-based semi-interpenetrating polymer network slow-release nitrogen fertilizer by microwave irradiation to control water and nutrient losses. Arabian Journal of Chemistry. 2017; 10: 922–934.
44. Wen P, Wu Z, He Y, Ye BC, Han Y, Wang J, Guan X. Microwave-Assisted synthesis of a semi-interpenetrating polymer network slow-release nitrogen fertilizer with water absorbency from cotton stalks. ACS Sustainable Chemistry & Engineering. 2016; 4: 6572–6579.
45. Wilson ML, Rosen CJ, Moncrief JF. Effects of polymer coated urea on nitrate leaching and nitrogen uptake by potato. Journal of Environmental Quality. 2010; 39: 492-499.
46. Xu S, Li X, Wang Y, Hu Z, Wang R. Characterization of slow-release collagen-g-poly (acrylic acid-co-2-acrylamido2-methyl-1-propane sulfonic acid)–iron (III) superabsorbent polymer containing fertilizer. Journal of Applied Polymer Science. 2019; 136: 47178.

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6. Molecular Breeding and Its Current Scenario in Crop Improvement

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Abstract:

Plant breeding is the important branch for the sustainability of agriculture. Crop improvement in broad way is not only to increase quantity and better quality but it also saves the agricultural resources. Production of better plant variety depends on the identification of plant characters. Environment is the major factor which interact with plant to produce phenotype. Selection of ideal plant is tedious job due to variable influence of environment. Genes present in genome is not affected by the external conditions.

So, validation of plant using molecular breeding concept is advantageous over conventional breeding techniques. Molecular breeding existing technologies can manipulate the DNA to achieve remarkable success to improve nutritional quality, biotic and abiotic stress management in agriculture. Molecular breeding fastens the way of plant selection with higher accuracy and significant result.

6.1 Introduction:

Food is the prime requirement for the survival of a living organism. Increasing population with urbanization leads to more food demands and reduce farming area, respectively. In addition, climate change effects, emerging insect pest of crop reduce the crop production as well as productivity. Traditional crop breeding approaches used different germplasm of crop either individual or combinations for crop improvement up to certain limit.

Molecular breeding add value to traditional breeding approaches and also create new varieties by its own using genome editing technologies. It helps to produce climate resilient, biotic stress resistance, better quality plant with higher productivity. Molecular breeding is faster, time saving and accurate technique to mitigate current challenges in food production.

Plant breeding with direct and indirect implementation of molecular biology is called molecular breeding. In broad sense, direct way means molecular biology provide assistance to breeding technique like Marker assisted backcrossing (MABC) - the transfer of gene of interest eliminating linkage drag and recovery of genetic background of recurrent parent. Indirect use means genetic manipulating by inserting transgene, double stranded break (DSB) followed by DNA repair mechanism and change expression level of gene using RNA interference (RNAi) technology.

6.2 Existing Molecular Breeding Technologies:

6.2.1 QTL Mapping:

Quantitative trait loci (QTL) mapping is one of the widely used method to identify the location of the group of gene or loci on chromosome governing the quantitative trait. It also clarity the number of genes influence the expression of a quantitative trait, level of influence of each gene/locus on the trait, gene action is responsible for the trait and which alleles are having favorable effect on the trait. Quantitative trait-related loci may be dispersed throughout the genome or grouped together.

Polygenes control quantitative features, which exhibit discontinuous variation and are strongly impacted by the environment. Both phenotypic and genotypic data require to identify the QTL. To find QTLs, regression and likelihood statistics are used. Having at least 200 plants is thought to be a desirable standard.

High-resolution mapping requires larger populations. The mapping population must first be phenotypically assessed. If the map will be used for QTL investigations, before further QTL mapping. Biparental populations with Recombinant Inbred Lines (RILs) and Double Haploid (DH) are thought to be superior. However, for joint linkage and association analysis, NAM and MAGIC populations are also used. Higher the genome size, more markers are required for analysis.

6.2.2 Marker Assisted Selection (MAS):

The process of identifying the gene of interest and specific loci associated with a trait using molecular markers, such as is known as Marker-Assisted Selection (MAS). This technique is utilized in both plant and animal breeding. Molecular markers exhibit qualitative inheritance patterns. MAS is an indirect selection method where the desired trait is chosen based on a marker that is linked to it, rather than directly selecting for the trait itself. Selecting plants based on their phenotypes can sometimes negatively affect the efficiency of the selection process.

Essential requirements of MAS: 1) The identified DNA marker(s) should co-segregate or be closely related to the trait (**preferably 1 cM or less**). 2) Emergence of effective DNA marker screening methods that can feasibly manage vast populations. 3) The screening method needs to be reasonably priced, simple to use, and highly reproducible.

MAS can be helpful for qualities that are challenging to quantify, have poor heredity, or express themselves later in development. However, because genotype does not exhibit the effects of the environment, molecular selection of plants allows for effective selection. Types of MAS are given below:

A. Marker assisted backcrossing
B. Marker assisted recurrent selection
C. Marker assisted gene pyramiding
D. Genomic selection

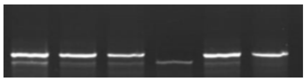
A. Marker Assisted Backcrossing:

The simplest kind of MAS is marker-assisted backcrossing, where the objective is to introduce a key gene into a superior cultivar or breeding line (the recurrent parent) from a source that is agronomically inferior.

Two types of selection are recognized by Hospital, 2003. Third type of selection is recombinant selection (Collard and Mackill 2008).

1st stage of selection – foreground selection

- Choice of target gene or QTL
- Valuable for assessing traits that are challenging to evaluate



- Also advantageous for identifying recessive genes

2nd stage of selection – Recombinant selection

- Employing adjacent markers to select recombinants positioned between the target locus and flanking marker
- Reduces the presence of unwanted donor chromosome segments (referred to as linkage drag), which can adversely impact agronomic performance.
- Require large population sizes and it depends on distance of flanking markers from target locus. (Closer the distance, higher population size)

3rd stage of selection - Background selection

- Use unlinked (unlinked to the target locus) markers to select against donor. Markers should be polymorphic between donor and recurrent parents.
- Promotes the recovery of the recurrent parent genome more quickly.
- Savings of 2, 3 or even 4 backcross generations may be possible
- Minimum 5 markers per chromosomes are ideal for this.

B. Marker Assisted Recurrent Selection (MARS):

Conventional phenotypic recurrent selection focuses on choosing individuals based on offspring performance, followed by intercrossing between individuals demonstrating optimal progenies, to increase the frequency of desirable alleles in the population. Phenotypic selection has low efficiency due to environmental influence.

MARS could be helpful to reduce this environmental error in selection of multiple Quantitative Trait Loci (QTLs). MARS could increase recurrent selection's effectiveness and speed up the process, primarily by assisting in the integration of several advantageous genes or QTLs from various sources using recurrent selection based on multi-parent populations. (Asima Gazal *et al., 2015).*

C. Marker Assisted Gene Pyramiding:

The technique called "gene pyramiding" is employed to combine multiple desirable genes from different parents into a single genotype. This process aims to develop genotypes that possess all of the desired genes. Gene pyramiding serves two main purposes: 1) enhancing trait performance by combining two or more complementary genes, and 2) broadening the genetic diversity of released cultivars (Ye and Smith, 2008). Typically, gene pyramiding is used to improve qualitative traits such as disease and insect resistance. The process of gene pyramiding can be divided into two stages. The first stage involves creating a pedigree to accumulate all the target genes in a single genotype referred to as the root genotype. The second stage, known as the fixation phase, focuses on converting the target genes into a homozygous state (Joshi and Nayak, 2010). Various methods are employed during the fixation phase to accumulate the genes in a single parent. It includes three types of methods to cumulate the genes in a single parent as following:

a. Stepwise Transfer:

The donor parent (DP1) and recurrent parent (RP1) are crossed to create the F1 hybrid (Figure 6.1) and the third backcross generation (BC3) of backcrossing produces the improved recurrent parent (IRP1). Then, to pyramid multiple genes, this improved recurrent parent is crossed with another donor parent (DP2). Pyramiding is more accurate because it involves one gene at a time, but this technique is less desirable because it takes time.

b. Simultaneous Transfer:

The pyramiding is done in the pedigree step itself in the second strategy, where the recurrent parent (RP1) is crossed with the both donor parents simultaneously resulting in F1 hybrids that are then intercrossed to produce improved F1 (IF1), which is then backcrossed with the recurrent parent to produce the improved recurrent parent (IRP). However, when the donor parents are different, this method is less likely to be used because there is a chance.

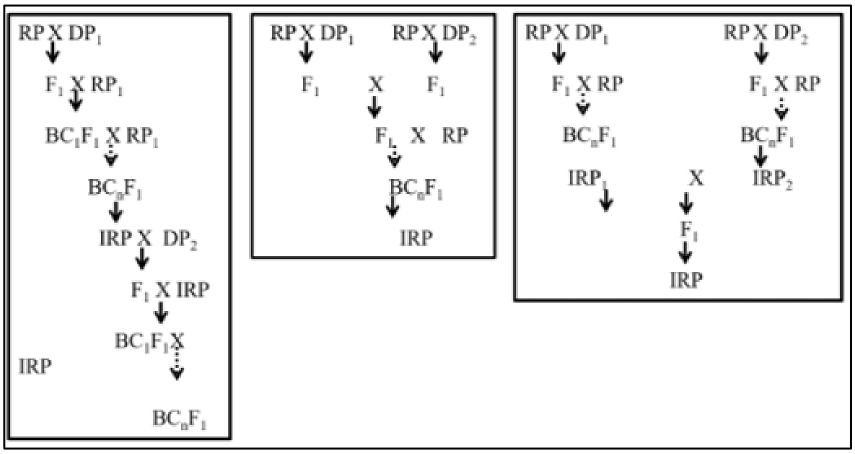


Figure 6.1: Strategies of gene pyramiding: Simultaneous transfer, stepwise transfer and Simultaneous and stepwise transfer

c. Simultaneous and Stepwise Transfer:

The third technique combines the first two and involves backcrossing numerous donor parents with a recurrent parent (RP1) at the same time, up to the BC3 generation. Pyramided lines are created by intercrossing the backcross populations with the specific gene. This is the most preferable strategy because it not only saves time but also completely ensures that the genes will be fixed.

D. Genomic Selection:

The genomic selection (GS) scheme was proposed by Meuwissen et al. (2001). Linkage mapping is limited by poor resolution, few alleles and need for mapping populations. QTL mapping cannot detect minor QTLs with low heritability. Association mapping is prone to false positives and unable to explain all the variance of a trait. MABC improves only for introgressed QTL. MARS is based on significant major and minor QTLs.

6.2.3 RNA Interference (RNAI) and Genome Editing Tools:

RNAi is double stranded RNA (dsRNA) inducing phenomenon for gene silencing or knockdown of gene. micro-RNA (miRNA) and small short interfering RNA (siRNA). in case of siRNA, dsRNA cleaved by dicer protein and form 21bp dsRNA with 2bp overhang at 3 ends. Its further binding with argonaute protein to form RNA induced silencing complex (RISC). Passenger strand remove from complex and guide strand binds with complementary mRNA and reduce the translation process by cleave mRNA of interest. In miRNA inducing silencing process, hairpin loop primiRNA cleaved by DROSHA and DGCR8 protein to nearly 70 nucleotide made RISC complex and transport to cytoplasm and bind to mRNA. This finally results in reduce gene expression.

One of the latest molecular breeding aspects is manipulation of DNA sequences using genome editing tools like CRISPER-Cas9 (Clustered Regulatory Interspersed Short Palindromic Sequences), TALENs (Transcription Activator-Like Effector Nucleases) and ZFNs (Zinc Finger Nucleases). When a virus attacks a bacterium, it destroys the bacterial genome while leaving portions of the viral genome at specific locations. This is known as Crisper mechanism. Bacterial systems create Cri RNA, which is complementary to viral RNA, when the same virus attacks again. The Cas protein recognizes a specific nucleotide sequence on Cri RNA called PAM (Protospacer Adjacent Motif), resulting in an interaction of RNA and proteins. DNA double strand breaks are caused by Cas 9, which is complementary to g RNA (guide RNA). Simply said, tracer RNA is a gene in the CRISPR system that activates cri RNA by maturing it and producing it along with it. CriRNA in the RNA fragment comes from the spacer sequences previously snipped by the bacteria.

The zinc-finger nucleases TALENs and ZFNs, which have distinct DNA-binding and DNA-cleavage domains, have emerged as the class of targeting agents that has demonstrated to be the most adaptable and successful in recent years. TALENs are fusion proteins made of the Fok1 endonuclease and the bacterial TALE protein, and their specificity is based on protein-DNA interaction. It typically consists of 33 to 35 modules of amino acids, each of which targets a specific nucleotide. This means that scientists can identify any particular

DNA sequence they choose by assembling various TALEN moieties. The crystal structure of a trio of fingers linked to DNA revealed that each finger makes remarkable modular contact with 3 bp of DNA on average (Pavletich and Pabo 1991). This implied that by creating innovative assemblies, numerous distinct sequences could be tackled. Cleavage is done by heterodimer of type II restriction enzyme *Fok1*.

6.3 Current Scenario of Molecular Breeding in Crop Improvement:

6.3.1 Molecular Breeding for Biotic and Abiotic Stress Resistance:

As said before field screening of a plant for disease and abiotic stress have environmental interference but molecular aspect gives better way to select the desirable plant. In recent times, areas affected by drought have experienced a significant decline in rice yields. This decline is primarily attributed to the increased frequency and severity of drought stress. Researchers (Kumar et al., 2014) conducted a study using grain yield as a selection criterion and identified 14 quantitative trait loci (QTLs) that have a significant impact on high-yielding rice cultivars in drought-prone regions. Among these QTLs, some exhibited positive effects on rice grain production under drought conditions in both lowland and upland ecosystems. These QTLs proved valuable in enhancing rice productivity in drought-affected areas across different genetic backgrounds.

By employing a well-planned marker-assisted backcross breeding strategy, the yield of prominent rice varieties like IR64 and Vandana has been successfully increased, and ongoing efforts are focused on introgressing QTLs into several other well-known varieties. Marker-assisted breeding has also played a significant role in the development of high-yielding rice cultivars resistant to bacterial blight (BB). For instance, Samba Mahsuri, a BB-susceptible variety, has been improved through the stacking of *Sub1* and *Sub4* BB-resistant genes, while other combinations involving the BB resistance gene, *Sub1* QTL, and yield QTL have been developed (Mohapatra *et al.,* 2021).

6.3.2 Molecular Breeding in Quality Improvement:

A. Modifying Carotenoid Levels in Vegetable Crops:

Vitamin-A deficiency is a common problem in many developing regions, leading to childhood blindness and other health issues. To combat this, Ingo Potrykus, Peter Beyer, and their colleagues developed "golden rice" by genetically modifying rice genotypes with carotenoid biosynthetic genes to increase the availability of vitamin-A precursors in the diet (Ye *et al*, 2000). Golden rice has shown potential for manipulating carotenoid biosynthesis in other crops (DellaPenna & Pogson, 2006). One advantage of increasing carotenoid levels is the potential for more vibrantly colored vegetables, which can be more appealing to consumers. Therefore, enhancing carotenoid levels is beneficial not only for nutrition but also for aesthetics. Breeding programs have successfully improved the nutritional value of sweet potatoes, specifically the orange-fleshed variety, which has the potential to enhance the health of millions of people in developing countries. This type of sweet potato contains carotenoids that can be transformed into vitamin A when consumed, providing an important source of this essential nutrient for the body.

Phil Simon and Gold man (2007) at the University of Wisconsin, USA have identified molecular markers associated with genes related to carotenoid content in carrots and used them to identify carrot lines with higher levels of carotenoids, which are now being utilized by commercial seed companies. Through traditional breeding, the overall levels of carotenoids in carrots have significantly increased in the past 40 years, reaching up to 1,000 ppm carotenoids on a fresh weight basis (Simon and Gold man, 2007).

Genetically modified potato, which normally accumulates lutein and violaxanthin, to accumulate zeaxanthin instead (Römer *et al*, 2002). This modification also resulted in increased levels of α-tocopherol (vitamin E). The carotenoid and tocopherol pathways are linked, so modifications aimed at one pathway may have effects on the other.

B. Anthocyanins in Barley:

Barley grain can have a range of colors, such as yellow, purple, red, and blue, which can also appear in other parts of the seed, Pigments are important for protecting the plant under various biotic and abiotic stress conditions, as well as providing valuable health benefits (Koes *et al*., 2005). Pigments also have a physiological function in attracting pollinators and seed dispersers (Chaves-Silva *et al*., 2018). Additionally, anthocyanins play a role in preventing different chronic diseases in humans (Li *et al*., 2021). Only dominant alleles of Ant1 and Ant2 loci (Gordeeva *et al*., 2019), and both genes lead to anthocyanin accumulation in the pericarp. Classical and molecular techniques have been utilized to create new barley varieties with improved anthocyanin accumulation and diverse colors. However, genetically-modified organisms (GMOs) may face market challenges due to consumer attitudes and perception. To address this, CRISPR/Cas9 has emerged as a promising non-transgenic method for generating mutations. Gasparis *et al*. (2018) demonstrated that an optimized RNA-guided Cas9 system can create homozygous knockout mutants in the offspring of transgenic barley plants. Transcriptional repressors such as AtMYBL2 and FaMYB1 have been identified and shown to negatively regulate anthocyanin biosynthesis in Arabidopsis and strawberry, respectively (Matsui *et al*., 2008). Inhibiting these repressors could enhance anthocyanin content. A better understanding of the molecular mechanisms governing anthocyanin repression may improve breeding efforts in barley using non-transgenic methods.

C. Molecular Approaches for Calcium Biofortification in Finger Millet:

Calcium is a crucial nutrient for both plants and animals, and it is essential for structural integrity and signaling processes. In humans, insufficient calcium intake has been linked to several diseases, which can have severe long-term health consequences. Unfortunately, major food crops do not contain much calcium. However, finger millet, which is an underutilized crop, has exceptionally high levels of calcium and is a promising nutritional security crop. To develop crops with higher calcium content, it is crucial to understand the genetic variation and molecular mechanisms involved in calcium uptake, transport, and accumulation in grains. The goal of this research is to provide a comprehensive overview of the molecular mechanisms involved in regulating calcium nutrition and highlight the importance of biofortification. By identifying potential candidate genes and regulatory elements in finger millet, it may be possible to alleviate calcium malnutrition and develop nutraceuticals or designer crops. Finger millet can serve as a model for understanding the mechanisms of calcium accumulation in grains and may pave the way for developing crops with elevated calcium levels.

Researchers used association mapping studies to find QTLs for calcium content and discovered two minor QTLs connected to grain calcium content on linkage groups 3 and 8, respectively (Yadav *et al*., 2014). Despite having a few small QTL, chromosome 8 may also contain genes or areas that contribute to mineral accretion (Srinivasachary *et al.,* 2007). Rice chromosome 3 and finger millet LG 3 share co-linearity, and rice chromosome 3 also contains Ca2+ QTLs. These results show that to uncover all the genes that regulate this complicated feature and its variance in a population, a comprehensive, genome-wide search is required.

Two calcium-binding proteins, Calcineurin-B and Calreticulin, were found in finger millet seeds using peptide mass fingerprinting (Singh *et al.,* 2016). Their expression was examined throughout seed development and grain filling (Singh *et al.,* 2014). Finger millet transcriptome sequence data showed that Ca2+ transporter genes were significantly expressed in genotypes of the plant with high seed Ca2+, offering a viable explanation for the high calcium buildup in finger millet. Through genetic engineering or marker-assisted selection techniques, calcium biofortification programmes can make use of this genetic information. In order to speed up breeding for high grain Ca2+ in finger millet, closely related markers to the found genes (EcCIPKs) can be used.

Genetic modification is an alternate strategy for raising the calcium (Ca2+) content of important food crops. To increase the concentration of calcium (Ca2+) in the edible portions of plants, three transgenic approaches can be used. The first technique involves expressing calcium (Ca2+) transporter proteins such Ca2+ ATPase and Ca2+/H+ antiporters in order to boost the calcium (Ca2+) storage capacity. The second strategy involves overexpressing calcium (Ca2+) channel proteins to increase calcium (Ca2+) buildup. The third technique entails increasing calcium (Ca2+) levels by overexpressing calcium (Ca2+) binding proteins.

6.3.3 Molecular Breeding in Yield Improvement:

GWAS and GS are valuable tools for understanding the genetic basis of complex traits in soybean. Previous studies have utilized GWAS to identify molecular markers associated with various agronomic traits in soybean (Yao *et al*., 2015). For example, multiple markers related to maturity have been discovered (Zuo *et al*., 2013), with a concentration on chromosome 16. Candidate genes regulating maturity and plant height have also been identified (Contreras-Soto *et al*., 2017). Additionally, numerous molecular markers associated with seed weight have been found in soybean. Genome editing, particularly using CRISPR technology, plays a crucial role in developing environmentally-friendly and resilient agriculture. Researchers have successfully used CRISPR to edit genes such as OsGS3 and OsGL3.1 in rice, resulting in increased grain size and overall yield per plant. Multiplex gene editing has also led to higher grain yield in rice by targeting genes GS3, GW2, and Gn1a (Yuyu *et al.,* 2020). Furthermore, CRISPR-based gene editing has been employed to improve photosynthesis by editing genes like NRP1, resulting in enhanced photosynthetic efficiency, grain yield, and biomass production in rice (Flexas *et al*., 2020).

Scientists are also focusing on enhancing crop photosynthesis by targeting Rubisco, a crucial enzyme in CO2 fixation. Recent research has used CRISPR to disrupt the RbcS multigene family in rice and replace it with RbcS from sorghum, leading to improved photosynthetic rates and increased crop productivity (Matsumura *et al.*, 2020). These advancements demonstrate the potential of genome editing in improving crop traits and overall agricultural productivity. Researchers have employed the CRISPR-Cas system to enhance the photosynthetic system of diploid and polyploid crops. For instance, in one study, multiple rbcS homologues (rbcS_S1a, rbcS_S1b, and rbcS_T1) were targeted and eliminated in tobacco, which is a tetraploid crop. As a result, the mutant plants exhibited a higher photosynthetic rate compared to the wild-type plants (Donovan *et al.*, 2020). This research highlights the potential of CRISPR-based gene editing to improve photosynthesis in both diploid and polyploid plant species.

6.4 Future Challenges and Prospective:

Plant transformation is a crucial technique for gene editing, but it faces challenges in certain plant species with complex genomes like wheat, cotton, and Brassica. Moreover, CRISPR-Cas gene editing often requires time-consuming and labor-intensive tissue culture. To overcome these limitations, scientists are exploring tissue culture-free genome editing methods, such as RNA virus-based systems for delivering gRNA. Despite the popularity of CRISPR-Cas technology, concerns remain regarding off-target effects and regulatory issues. To address these concerns, researchers are developing more precise and well-structured strategies, including biased and unbiased off-target detection methods, modification and engineering of gRNA, improved Cas variants, efficient delivery methods for the CRISPR system, development of antiCRISPR proteins, as well as effective base-editing and prime editing systems. The newly developed base-editing and prime editing tools have demonstrated reduced risks with minimal off-target effects in both plants and animals, presenting opportunities for the safe development of genetically engineered food crops and contributing to the global zero hunger goal.

The use of rapid cycling genomic selection in plant breeding programs has the potential to increase genetic gains, but adoption of these methods has been limited due to the high cost of genotyping, which is still a barrier for smaller breeding programs or public-sector programs with limited resources. To overcome this limitation, it is important to evaluate the feasibility of rapid cycling genomic selection in different crop species and design new breeding programs that integrate this technology more efficiently. Efforts are already underway, such as those of the International Maize and Wheat Improvement Center (CIMMYT) in Africa and Asia, which serve as examples of how public-sector breeding programs can increase genetic gains in important crops.

6.5 Conclusion:

The preceding literature underscores that although there have been recent advancements and successful instances of molecular plant breeding, a significant challenge in plant biology is still the identification of gene combinations that result in substantial enhancements in crops.

The suggestion put forth is that the advancement of molecular plant breeding can be accelerated by enhancing the integration of different research disciplines and activities that are essential to the field. It is also recommended that the corporate sector continues to invest in initiatives that promote this integration and create a favorable training environment for aspiring scientists in molecular breeding. In addition to financial support for graduate training and sponsored research, companies can provide non-monetary assistance to bridge the technological gap between public and private sector research in molecular plant breeding. By uniting the collective efforts of the diverse community of scientists dedicated to plant biology and crop improvement, molecular plant breeding will be able to make even greater contributions to meeting global demands for sustainable increases in agricultural productivity.

6.6 References:

1. Asima Gazal, ZA, Dar AA, Lone I, Abidi AG. Molecular breeding for resilience in maize. Journal of Applied and Natural Science. 2015; **7**(2):1057-1063.
2. Chaves-Silva S, Luís dos Santos A, Chalfun-Júnior A, Zhao J, Peres LEP, Benedito VA. Understanding the genetic regulation of anthocyanin biosynthesis in plants – tools for breeding purple varieties of fruits and vegetables. Phytochemistry. 2018; **153**: 11–27.
3. Contreras-Soto RI, Mora F, de Oliveira MAR, Higashi W, Scapim CA, Schuster I. A genome-wide association study for agronomic traits in soybean using SNP markers and SNP-based haplotype analysis. PloS one. 2017; 12(2): e0171105.
4. DellaPenna D, Pogson B. Vitamin synthesis in plants: tocopherols and carotenoids. Annu. Rev. Plant Biol. 2006; **57**: 711–738
5. Diretto G, Tavazza R, Welsch R, Pizzichini D, Mourgues F, Papacchioli V, Beyer P, Giuliano G (2006) Metabolic engineering of potato tuber carotenoids through tuber-specific silencing of lycopene epsilon cyclase. BMC Plant Biol. 2006; 6-13.
6. Donovan S, Mao Y, Orr DJ, Carmo-Silva E, McCormick AJ, CRISPR-Cas9-Mediated Mutagenesis of the Rubisco Small Subunit Family in *Nicotiana tabacum*. Front. Genome Ed. 2020; 2-28.
7. Flexas J, Carriquí M. Photosynthesis and photosynthetic efficiencies along the terrestrial plant’s phylogeny: lessons for improving crop photosynthesis. Plant Journal. 2020; **101** (4): 964−978.
8. Gasparis S, Kała M, Przyborowski M, Łyżnik LA, Orczyk W, NadolskaOrczyk A. A simple and efficient CRISPR/Cas9 platform for induction of single and multiple, heritable mutations in barley (*Hordeum vulgare* L.). Plant Methods. 2018; **14**: 111.
9. Gordeeva EI, Glagoleva AY, Kukoeva TV, Khlestkina EK, Shoeva OY. Purple-grained barley (*Hordeum vulgare* L.): Marker-assisted development of NILs for investigating peculiarities of the anthocyanin biosynthesis regulatory network. BMC Plant Biol. 2019; 19-52.
10. Hospital F. Marker-assisted breeding. In: HJ Newbury (ed.) Plant molecular breeding. Blackwell Publishing and CRC Press, Oxford and Boca Raton; 2003, pp. 30-59.
11. Joshi RK, and Nayak S. Gene pyramiding-A broad spectrum technique for developing durable stress resistance in crops. Biotechnol. Mol. Biol. Rev. 2010; **5**(3): 51-60.
12. Koes R, Verweij W, Quattrocchio F. Flavonoids: A colorful model for the regulation and evolution of biochemical pathways. Trends Plant Sci. 2005; **10**: 236–242.

13. Kumar A, Dixit S, Ram T, Yadaw RB, Mishra KK, Mandal NP. Breeding high-yielding drought-tolerant rice: genetic variations and conventional and molecular approaches. Journal of experimental botany. 2014; **65**(21): 6265-6278.
14. Li P, Feng D, Yang D, Li X, Sun J, Wang G. Protective effects of anthocyanins on neurodegenerative diseases. Trends Food Sci. Technol. 2021; **117**: 205–217.
15. Matsui, K., Umemura, Y., and Ohme-Takagi, M. AtMYBL2, a protein with a single MYB domain, acts as a negative regulator of anthocyanin biosynthesis in Arabidopsis. Plant Journal. 2008; **55**: 954–967.
16. Matsumura H, Shiomi K, Yamamoto A, Taketani Y, Kobayashi N, Yoshizawa T, Tanaka SI, Yoshikawa H, Endo M, Fukayama H, Hybrid rubisco with complete replacement of rice rubisco small subunits by sorghum counterparts confers C4 plant-like high catalytic activity. Mol. Plant 2020; **13**(11): 1570−1581.
17. Meuwissen TH, Hayes BJ, Goddard ME. Prediction of total genetic value using genome-wide dense marker maps. Genetics. 2001; **157**(4):1819–1829.
18. Mohapatra S, Panda AK, Bastia AK, Mukherjee AK, Sanghamitra P, Meher J, Mohanty SP, Pradhan SK. Development of submergence-tolerant, bacterial blight-resistant and high-yielding near isogenic lines of popular variety, 'Swarna' through marker assisted breeding approach. Frontiers in Plant Sciences. 2021; **12:** 618-635.
19. Pradhan KC, Barik SR, Mohapatra S, Nayak DK, Pandit E, Jena BK, Sangeeta S, Pradhan A, Samal A, Meher J. Incorporation of two bacterial blight resistance genes into the popular rice variety, ranidhan through marker assisted breeding. Agriculture. 2022; 12: 1287.
20. Römer S, Lubeck J, Kauder F, Steiger S, Adomat C, Sandmann G Genetic engineering of a zeaxanthin-rich potato by antisense inactivation and co-suppression of carotenoid epoxidation. Metab. Eng. 2008; 4: 263–272.
21. Simon PW, Goldman IL Carrot. In: Genetic Resources, Chromosome Engineering, and Crop Improvement, Singh RJ (ed), Boca Raton, FL, USA: CRC. 2007; pp 497–516.
22. Singh M, Metwal M, Kumar VA, Kumar A. Identification and molecular characterization of 48 kDa calcium binding protein as calreticulin from finger millet (Eleusine coracana) using peptide mass fingerprinting and transcript profiling. J. Sci. Food Agric. 2016; **96**: 672–679.
23. Singh UM, Pandey D, Kumar A. Determination of calcium responsiveness towards exogenous application in two genotypes of *Eleusine coracana* L. differing in their grain calcium content. Acta Physiol. Plantarum. 2014; **36**: 2521–2529.
24. Srinivasachary, Dida MM, Gale MD, Devos KM. Comparative analyses reveal high levels of conserved colinearity between the finger millet and rice genomes. Theor. Appl. Genet. 2007; **115:** 489–499.
25. Von Wettstein, D. From analysis of mutants to genetic engineering. Annu. Rev. Plant Biol. 2007; **58**: 1–19.
26. Yadav S, Gaur VS, Jaiswal JP, Kumar A. Simple sequence repeat (SSR) analysis in relation to calcium transport and signaling genes reveals transferability among grasses and a conserved behaviour within finger millet genotypes. Plant Syst. Evol. 2014; **300**: 1561–1568.
27. Yao D, Liu Z, Zhang J, Liu S, Qu J, Guan S, *et al*. Analysis of quantitative trait loci for main plant traits in soybean. Genet Mol Res. 2015; **14**(2): 6101–9.
28. Ye G, and Smith KF. Marker-assisted gene pyramiding for inbred line development: basic principles and practical guidelines. International journal of Plant Breeding. 2008; **2**(1): 1-10.

29. Ye X, Al-Babili S, Klöti A, Zhang J, Lucca P, Beyer P, Potrykus I. Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science. 2000; **287**: 303–305.
30. Yuyu C, Aike Z, Pao X, Xiaoxia W, Yongrun C, Beifang W, Yue Z, Liaqat S, Shihua C, Liyong C, Yingxin Z. Effects of GS3 and GL3. 1 for grain size editing by CRISPR/Cas9 in Rice. Rice Sci. 2020; **27**(5): 405−413.
31. Zuo Q, Hou J, Zhou B, Wen Z, Zhang S, Gai J, *et al*. Identification of QTL s for growth period traits in soybean using association analysis and linkage mapping. Plant Breeding. 2013; **132**(3):317–23.

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7. Reverse Breeding: An Accelerated Breeding Approach

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Abstract:

Reverse breeding is a technique that involves the creation of heterozygous plants that can be self-crossed to produce homozygous plants. The process involves the generation of haploid cells by the genetic engineering of the plant cells using a system called "recombinase-mediated cassette exchange" (RMCE). Reverse breeding is a revolutionary genetic approach in which homozygous parental lines are created for each of the two parents of a hybrid plant using genetic engineering techniques. These lines are then crossed to create new hybrid plants that are identical to the original hybrid. In comparison to conventional breeding techniques, this approach has a number of benefits, including the capacity to work with recessive characteristics and the ability to prevent harmful gene combinations. By avoiding several generations of backcrossing, this novel method quickens the breeding process. In times of climate change and other environmental pressures, reverse breeding has the potential to transform plant breeding and assist in addressing the problems of feeding a growing global population. Reverse breeding can assist to boost agricultural yields, improve pest and disease resistance, and improve the nutritional value of crops by hastening the emergence of new crop varieties with desirable features.

7.1 Introduction:

The rapid growth in the world's population and the increasing demand for food, fiber, and energy require the development of more efficient and sustainable plant breeding methods. Reverse breeding is a novel plant breeding technique that can accelerate the process of creating homozygous parental lines for crop breeding. It is a novel strategy that combines genetic engineering and classical breeding to obtain a set of parental lines that can be used for crop breeding. Plant breeding has been practiced for thousands of years, and it is a critical process for developing new crop varieties with desirable traits. Traditionally, plant breeding has been carried out through the selection and crossing of plants with desirable traits, with the goal of creating new varieties that combine the desired traits.

However, this process can be slow and labor-intensive, and it is often difficult to work with recessive traits or avoid deleterious combinations of genes. Reverse breeding (RB) is a novel plant breeding technique designed to achieve one of the most sought goals of plant breeding by directly producing parental lines for any heterozygous plant. RB generates perfectly complementing homozygous parental lines through engineered meiosis (kumari et. al.,2018). This technique offers several advantages over traditional breeding methods, including the ability to work with recessive traits and the ability to avoid deleterious combinations of genes. Reverse breeding as a novel plant breeding technique to directly produce homozygous parental lines from any heterozygous plant was proposed by Dirks et al. in 2009.

7.2 History of Reverse Breeding:

The concept of reverse breeding was first proposed by the Dutch scientist, Dirk Inzé, in 2001. Inzé, a plant biologist at Ghent University in Belgium, and his colleagues were studying the process of meiosis, which is the process of cell division that produces gametes in plants and animals and published paper in the journal Trends in Plant Science in 2003 (Inzé D, *et al.*,2003)

Since then, researchers have made significant progress in developing and refining reverse breeding techniques. A notable advancement came in 2007 when the same group of scientists led by Dirk Inzé demonstrated successful application of reverse breeding in Arabidopsis thaliana, a model plant species (Wijnker, *et al.*, 2007).

Reverse breeding has been applied in several crop species, including wheat, maize, and soybean, to produce homozygous parental lines with desirable traits. The technique has shown great potential in accelerating the development of new crop varieties with improved yield, quality, and resistance to biotic and abiotic stresses.

The development of reverse breeding has revolutionized plant breeding by offering a faster and more efficient way to produce homozygous parental lines, enabling the creation of hybrid varieties with desired traits, and increasing the genetic diversity of crops. While reverse breeding is still a relatively new technique, it holds great promise for the future of sustainable agriculture and food security.

7.3 Reverse Breeding Technique:

Reverse breeding is a technique that involves the creation of heterozygous plants that can be self-crossed to produce homozygous plants. The process involves the generation of haploid cells by the genetic engineering of the plant cells using a system called "recombinase-mediated cassette exchange" (RMCE).

RMCE system, which involves the insertion of a selection marker gene and a gene of interest into a specific location in the genome of the plant. RMCE is a technique used to insert, replace or delete genes in a specific location in the genome of a plant.

The RMCE system is composed of two recombinases: Cre and FLPe. The Cre recombinase is used to excise the selection marker gene, while the FLPe recombinase is used to exchange the gene of interest. The RMCE system is used to generate haploid cells from diploid cells. The haploid cells are then grown into haploid plants that are genetically identical to the parent plant. The haploid plants are then subjected to a process called doubled haploid production to produce homozygous plants.

This is achieved by inducing chromosome doubling in the haploid cells to produce homozygous plants that are genetically identical to the haploid parent. The RMCE system used in reverse breeding is a powerful tool that allows for the precise manipulation of the genome of the plant.

It enables the insertion, replacement, or deletion of genes in a specific location, allowing for the creation of homozygous parental lines with specific traits of interest.

7.4 How Reverse Breeding Works:

Reverse breeding is a powerful tool in plant breeding that allows breeders to generate homozygous parental lines for each of the two parents of a hybrid plant, which can then be used to recreate the original hybrid.

The technique relies on genetic engineering methods such as CRISPR/Cas9 or TALENs to create targeted mutations in the genome of the hybrid plant.

The following is a step-by-step overview of how reverse breeding works:

Step 1: Identify a hybrid plant with desirable traits

The first step in reverse breeding is to identify a hybrid plant with desirable traits that breeders want to preserve in future generations. The hybrid plant should be a cross between two genetically distinct parental lines.

Step 2: Generate haploid plants from the hybrid

The next step is to generate haploid plants from the hybrid plant. Haploid plants have only one set of chromosomes, rather than the two sets found in diploid plants. This can be achieved through a variety of methods, including the use of haploid inducers or in vitro culture techniques.

Step 3: Create targeted mutations in the genome of the haploid plants

Once the haploid plants have been generated, they can be used as a template for creating homozygous parental lines for each of the two parents of the hybrid plant. This is achieved through the use of genetic engineering methods such as CRISPR/Cas9 or TALENs, which are used to create targeted mutations in the genome of the haploid plants.

Step 4: Regenerate diploid plants from the homozygous parental lines

Once the homozygous parental lines have been generated, they can be crossed to produce new hybrid plants that are identical to the original hybrid. This process involves regenerating diploid plants from the homozygous parental lines. The diploid plants can be generated through a variety of methods, including the use of colchicine or in vitro culture techniques.

Step 5: Verify the identity of the regenerated hybrid plants

Finally, breeders must verify the identity of the regenerated hybrid plants to ensure that they are identical to the original hybrid. This can be achieved through a variety of methods, including genetic testing or phenotypic analysis.

In summary, reverse breeding involves using genetic engineering methods to generate homozygous parental lines for each of the two parents of a hybrid plant, which can then be crossed to produce new hybrid plants that are identical to the original hybrid.

This technique offers several advantages over traditional breeding methods, including the ability to work with recessive traits and the ability to avoid deleterious combinations of genes.

7.5 Applications of Reverse Breeding:

Reverse breeding is a powerful tool in plant breeding that has the potential to revolutionize the way we develop new crop varieties. In this chapter, we will explore some of the most promising applications of reverse breeding.

A. Creation of homozygous parental lines: One of the primary applications of reverse breeding is the creation of homozygous parental lines for traditional breeding methods. Homozygous parental lines are essential for creating hybrid varieties with desired traits. With reverse breeding, homozygous parental lines can be created faster and more efficiently than with traditional breeding methods, where several generations of self-pollination are required to produce homozygous plants.

B. creation of hybrid seeds: Another application of reverse breeding is the creation of hybrid seeds without manual hybridization techniques. Hybrid seeds are essential for producing high-yielding crops with desirable traits, but manual hybridization techniques are often time-consuming and labor-intensive. With reverse breeding, homozygous parental lines can be created, and hybrids can be produced through conventional crossing techniques, without the need for manual hybridization.

C. Development of new hybrid varieties: Reverse breeding offers an efficient and reliable method for developing new hybrid varieties with desirable traits. By using targeted mutagenesis to create homozygous parental lines for each of the two parents of a hybrid, breeders can produce new hybrid plants that are identical to the original hybrid. This approach can save time and resources by avoiding the need for repeated crosses and backcrosses.

D. Accelerated breeding for self-pollinating crops: Self-pollinating crops, such as wheat, rice, and soybeans, are typically difficult to breed because they have a low level of genetic diversity. Reverse breeding can help overcome this limitation by creating homozygous parental lines that can be crossed to produce new hybrid plants with increased genetic diversity. This approach can accelerate the breeding process and help develop new crop varieties more quickly.

E. Trait stacking: Trait stacking is the process of combining multiple desirable traits into a single crop variety. This approach can be time-consuming and challenging using traditional breeding methods. Reverse breeding can simplify the process by allowing breeders to create homozygous parental lines for each of the desired traits and then cross these lines to produce a crop variety with all of the desired traits.

F. Conservation of genetic resources: Reverse breeding can be used to conserve genetic resources by generating homozygous parental lines for rare or endangered plant species. This approach can help preserve genetic diversity and ensure the survival of these species.

G. Genetic research: Reverse breeding can also be used for basic genetic research by allowing scientists to study the effects of specific gene mutations on plant development and physiology. This approach can help uncover new insights into plant biology and inform the development of new breeding strategies.

H. In speeding up the breeding process: Reverse breeding can also speed up the breeding process by reducing the number of generations required. Traditional breeding methods require several generations of self-pollination and selection to produce homozygous parental lines. With reverse breeding, homozygous parental lines can be created in a single generation, reducing the time, labor, and resources required for breeding new crop varieties.

In summary, reverse breeding has a wide range of potential applications in plant breeding, from developing new hybrid varieties to conserving genetic resources and advancing basic genetic research.

With continued development and refinement, reverse breeding has the potential to transform the field of plant breeding and help meet the growing demand for sustainable, high-yielding crops.

7.6 Case Studies on Reverse Breeding:

Here are some case studies that illustrate the potential of reverse breeding in plant breeding:

A. Tomato: In 2017, a team of researchers from the University of California, Davis, used reverse breeding to create a new variety of tomato that is resistant to the devastating bacterial disease known as bacterial speck. The researchers used reverse breeding to create homozygous parental lines with resistance to the disease, and then crossed those lines to produce a hybrid variety with the desired trait. The resulting variety was found to be highly resistant to bacterial speck and had a yield comparable to commercial varieties.

B. Wheat: In 2020, a team of researchers from the John Innes Centre in the UK used reverse breeding to develop a new variety of wheat that is resistant to powdery mildew, a common fungal disease that can significantly reduce yields. The researchers used reverse breeding to create homozygous parental lines with resistance to the disease, and then crossed those lines to produce a hybrid variety with the desired trait. The resulting variety was found to be highly resistant to powdery mildew and had a yield comparable to commercial varieties.

C. Maize: In 2018, a team of researchers from the University of Wisconsin-Madison used reverse breeding to create a new variety of maize that is resistant to the western corn rootworm, a major pest that can cause significant yield losses. The researchers used reverse breeding to create homozygous parental lines with resistance to the pest, and then crossed those lines to produce a hybrid variety with the desired trait. The resulting variety was found to be highly resistant to the western corn rootworm and had a yield comparable to commercial varieties.

These case studies illustrate the potential of reverse breeding to create new crop varieties with desirable traits, such as disease resistance and pest resistance. By creating homozygous parental lines with the desired traits and then crossing those lines to produce a hybrid variety, reverse breeding allows breeders to rapidly develop new varieties with targeted improvements. As the technique continues to evolve and improve, it is likely to play an increasingly important role in developing new crop varieties that are adapted to changing environmental conditions and meet the needs of a growing population.

7.7 Advantages of Reverse Breeding:

Reverse breeding has several advantages over traditional breeding methods in plant breeding. Here are some of the advantages of reverse breeding:

A. **Faster and More Efficient:** Reverse breeding is a faster and more efficient method of producing homozygous parental lines compared to traditional breeding methods. With traditional breeding methods, several generations of self-pollination are required to produce homozygous plants. In contrast, reverse breeding can produce homozygous plants in a single generation, reducing the time, labor, and resources required for breeding new crop varieties.
B. **Precise Gene Manipulation:** Reverse breeding allows for the precise manipulation of the genome of the plant, enabling the insertion, replacement, or deletion of genes in a specific location. This precision allows for the creation of homozygous parental lines with specific traits of interest, making it a powerful tool for plant breeding.
C. **Creation of Hybrid Varieties:** Reverse breeding can also create hybrid varieties without the need for manual hybridization techniques. Homozygous parental lines with desirable traits can be crossed conventionally to create new hybrid varieties. This reduces the labor and resources required for manual hybridization techniques, making it a more efficient way to create hybrid varieties.
D. **Enhanced trait expression:** Reverse breeding can also be used to enhance the expression of desirable traits in a crop variety. By creating homozygous parental lines for each parent and crossing these lines, breeders can select for individuals that express the desired trait at a higher level than either parent, resulting in a crop variety with improved performance and yield.
E. **Increased Genetic Diversity:** Reverse breeding can also help increase genetic diversity in self-pollinating crops, which are typically more challenging to breed due to their low levels of genetic diversity. By creating homozygous parental lines for each parent and crossing these lines, breeders can introduce new genetic material into the breeding population, resulting in increased genetic diversity and a broader range of desirable traits.

F. Enhanced trait expression: Reverse breeding can also be used to enhance the expression of desirable traits in a crop variety. By creating homozygous parental lines for each parent and crossing these lines, breeders can select for individuals that express the desired trait at a higher level than either parent, resulting in a crop variety with improved performance and yield.
G. Conservation of genetic resources: Reverse breeding can also be used to conserve genetic resources by generating homozygous parental lines for rare or endangered plant species. This approach can help preserve genetic diversity and ensure the survival of these species.
H. Reduction in undesirable traits: Reverse breeding can be used to eliminate undesirable traits from a crop variety. By creating homozygous parental lines for each parent and crossing these lines, breeders can select for individuals that do not express the undesirable trait, resulting in a crop variety that is free from the undesired trait.
I. More Sustainable: Reverse breeding is a more sustainable method of plant breeding as it reduces the need for chemical inputs, such as pesticides and fertilizers, by improving the inherent resistance and tolerance of crops to pests and environmental stress.

In summary, reverse breeding offers several significant advantages over traditional breeding methods, including increased efficiency, precision, genetic diversity, enhanced trait expression, conservation of genetic resources, and reduction in undesirable traits. With continued development and refinement, reverse breeding has the potential to transform the field of plant breeding and help meet the growing demand for sustainable, high-yielding crops.

7.8 Disadvantages of Reverse Breeding:

While reverse breeding has several advantages, there are also some disadvantages to the technique. Here are some of the disadvantages of reverse breeding:

A. Limited Applicability: Reverse breeding is only applicable to diploid species, which limits its use to certain crops, such as wheat, maize, and soybean. It cannot be used for polyploid species, such as cotton, potatoes, and strawberries, which make up a significant portion of the world's crops.

B. High Cost: Reverse breeding can be a costly technique as it requires sophisticated molecular biology techniques and equipment to manipulate the genome of the plant. The cost of the technique can be a limiting factor for small-scale breeding programs.

C. Limited Genetic Diversity: Reverse breeding relies on the genetic diversity within the original heterozygous plant to produce homozygous parental lines. If the original plant has limited genetic diversity, the homozygous parental lines may also have limited genetic diversity, which can limit the potential for developing new crop varieties with desirable traits.

D. Risk of Unintended Effects: The precise manipulation of the genome in reverse breeding can also have unintended effects, such as the insertion of unwanted genes or the disruption of essential genes, which can affect the overall health and viability of the plant.

E. Limited Availability: Reverse breeding is a relatively new technique, and there are currently limited resources and expertise available for its application in plant breeding. This limits its availability to certain research institutions and breeding programs.

Overall, while reverse breeding has several advantages, its limitations and disadvantages must be carefully considered before its application in plant breeding.

7.9 Future Directions of Reverse Breeding:

Reverse breeding is a relatively new technique in plant breeding, and there is still much potential for its future directions and applications. Here are some possible future directions of reverse breeding:

A. Improving the efficiency of the technique: While reverse breeding is already more efficient than traditional breeding methods, there is still room for improvement. Researchers are exploring ways to optimize the technique, such as improving the regeneration of haploid cells and enhancing the selection of desirable traits.

B. Expanding the applicability of the technique: Currently, reverse breeding is limited to diploid species, which limits its use to certain crops. Researchers are exploring ways to extend the technique to polyploid species, which make up a significant portion of the world's crops.

C. Developing new crop varieties: Reverse breeding has the potential to accelerate the development of new crop varieties with improved yield, quality, and resistance to biotic and abiotic stresses. Researchers are using reverse breeding to develop new crop varieties that are adapted to changing environmental conditions and meet the needs of a growing population.

D. Precision breeding: Reverse breeding allows for precise gene manipulation, which can lead to the development of crops with specific traits, such as increased nutrient content or reduced allergenicity. Researchers are exploring ways to use reverse breeding to produce crops with targeted improvements in nutritional content and health benefits.

E. Integration with other breeding techniques: Reverse breeding can be used in combination with other breeding techniques, such as genome editing and marker-assisted selection, to accelerate the development of new crop varieties with desirable traits. Researchers are exploring ways to integrate reverse breeding with these other techniques to maximize its potential.

Overall, reverse breeding holds great promise for the future of sustainable agriculture and food security.

As the technique continues to evolve and improve, it will likely play an increasingly important role in developing new crop varieties that are adapted to changing environmental conditions and meet the needs of a growing population.

7.10 Conclusion:

Reverse breeding is a novel plant breeding technique that has the potential to accelerate the development of new crop varieties with desirable traits. By creating homozygous parental lines with the desired traits and then crossing those lines to produce a hybrid variety, reverse breeding allows breeders to rapidly develop new varieties with targeted improvements. The technique offers several advantages over traditional breeding methods, including the ability to work with recessive traits and the ability to avoid deleterious combinations of genes.

While reverse breeding is still a relatively new technique, it has already been successfully applied in several crop species, including tomato, wheat, and maize. As the technique continues to evolve and improve, it is likely to play an increasingly important role in developing new crop varieties that are adapted to changing environmental conditions and meet the needs of a growing population.

However, like any new technology, reverse breeding also has some limitations and potential drawbacks. The technique can be time-consuming and labor-intensive, and it is currently limited to diploid species. Additionally, there are concerns about the potential for unintended effects on gene expression or the accumulation of mutations over multiple generations.

Overall, reverse breeding holds great promise for the future of sustainable agriculture and food security. With continued research and development, the technique has the potential to revolutionize plant breeding and help meet the challenges of feeding a growing global population in the face of climate change and other environmental pressures.

7.11 Reverse Breeding in Plant Breeding:

Reverse breeding is a relatively new technique in plant breeding that has the potential to accelerate the development of new crop varieties with desirable traits. The technique involves starting with a hybrid plant and then using genetic engineering to generate a homozygous parental line for each of the two parents. Once the homozygous parental lines have been generated, they can be crossed to produce a new hybrid plant that is identical to the original hybrid.

The technique offers several advantages over traditional breeding methods. For example, reverse breeding allows breeders to work with recessive traits, which are often difficult to select for using traditional breeding methods. In addition, reverse breeding allows breeders to avoid deleterious combinations of genes, which can sometimes occur during traditional breeding methods.

Reverse breeding has been successfully applied in several crop species, including tomato, wheat, and maize. For example, researchers at the University of California, Davis used reverse breeding to create a new variety of tomato that is resistant to bacterial speck, a devastating bacterial disease. The researchers used reverse breeding to create homozygous parental lines with resistance to the disease, and then crossed those lines to produce a hybrid variety with the desired trait.

Reverse breeding has the potential to revolutionize plant breeding and help meet the challenges of feeding a growing global population in the face of climate change and other environmental pressures. By accelerating the development of new crop varieties with desirable traits, reverse breeding can help to increase crop yields, improve resistance to pests and diseases, and enhance the nutritional quality of crops. However, like any new technology, reverse breeding also has some limitations and potential drawbacks, such as the need for genetic engineering and the potential for unintended effects on gene expression or the accumulation of mutations over multiple generations.

7.12 References:

1. Dirks, R., Dun1, K.V., Snoo, C.B, Berg1, M.V., Cilia, L.C., and Woudenberg1, L. (2009). Reverse breeding: a novel breeding approach based on engineered meiosis. *Plant Biotechnology Journal*. 7:837-845.
2. Inzé, D., De Veylder, L., & Joubes, J. (2003). Reverse breeding: a novel breeding approach based on engineered meiosis. Trends in Plant Science, 8(6), 291-295. doi: 10.1016/s1360-1385(03)00110-1.
3. Kumari,P. Nilanjaya and Singh,N.K.(2018). Reverse breeding: Accelerating innovation in Plant breeding. *Journal of Pharmacognosy and Phytochemistry*. 1811-1813.
4. Wijnker, E., van Dun, K., de Snoo, CB., et al. (2007). Reverse breeding in Arabidopsis thaliana generates homozygous parental lines from a heterozygous plant. Nature Genetics, 39(6), 705-706.

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8. Impact of Climate Change on Insect Pollinators

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Abstract:

The weather on Earth has significantly changed as a result of climate change. The weather's natural cycles, animal behaviours, and flower blooming have all been altered by climate change. Pollinators, who are already struggling to survive, are one of the most severely damaged populations by climate change.

Due to climate change, the physiology of flowering plants gets impacted, decision of the flowering time gets hampered, flower size changes, timing of anthesis get disturbed, the scent, pollen and nectar production starts to decline, height of the plant becomes less attractive to the pollinator as a result of which pollinator's foragers activity, size of their body at maturity stage and life span starts to hinder. Thus, it is very important to conserve pollinators for maintaining healthy ecosystem.

Keywords:

Climate, Plant, Pollinators, Interaction, Flower, Phenology

8.1 Introduction:

Insect pollinators are being significantly impacted by global change. The range, phenology, abundance, physiology, and morphology of those insects pollinating plants in both wild and agricultural ecosystems are changing as a repercussion of changing climate, the introduction of species which are exotic, and loss of habitat. These impacts have complicated after effects in interactions of plant and pollinator in subtle but significant ways, sometimes leading to local extinction. Understanding these implications is crucial despite their complexity since we rely heavily on the insect population to croosbreed our plants, a crucial ecological service, just as the majority of flowering plants do. The pollinator insect species which have been studied the most in relation to climate change among the many insect taxa are Bees, flies, butterflies and moths. Bees are dominant pollinators of not only crop plants but also wild species within these groupings, and research on bees has dominated the body of knowledge on interaction of plant and pollinator under changing climate. Since bees laboriously reckon on resources of flower for their own nourishment and that of their young ones, the fitness of bees is substantially influenced not only by the direct reactions of global change but also by the affected global change operators on flower producing plants. I take into account both impacts that have a direct impact on pollinators as well as ones which are arbitrated via plant crops and other interspecific interactions throughout. To better conservation and management of pollination services, it is necessary to know about how global change affects species relationships more thoroughly because biotic pollination is a multitrophic interaction.

Climate Change refers to short-term observations of the local climate spanning hours and weeks, climate refers to long-term weather averages. Given that climate data is compiled over decades, centuries, and even millennia, it is far more challenging for humans to comprehend climate. Therefore, over a long period of time, severe deviations from the usual in the global weather patterns have been recorded as a result of climate change. Scientists can tell whether a summer was drier or wetter than average by comparing it to a summer that occurred decades before in the same region. More severe effects of climate change can be seen right away; For instance, storms like Hurricane Harvey, which struck in late summer 2017, were intensified by warmer ocean waters and caused greater damage than in the past. Climate change has had a significant negative influence on people all around the world since the seasons' weather is now more intense than it used to be. While winter is lasting longer with more storms and blizzards in certain places, summer has gotten drier and hotter in others. As the severe, unpredictable weather has grown more frequent than it once was, humans have had a difficult time adapting to these changes. It becomes much more obvious why a more delicate group, such as pollinators, are having enormous difficulties coping and surviving, as a more flexible and hardy species like humans are having difficulty in adapting to climate change. Numerous species are being impacted by climate change in different ways (Walther et al., 2002; Parmesan, 2006). For many species, the timing of life history events is changing as a result of global warming (Root et al., 2003). Many plants are blooming earlier, the larvae of insects are moulting into adults earlier, and certain the species of bird are laying their eggs untimely (Hughes, 2000). The dispensation of both animal and plant species are changing as a result of global warming, which also advances numerous phenological phenomena. For instance, butterfly ranges are moving northward and treelines are gradually getting higher (Hughes, 2000).

While studies on how climate warming affects species' ranges and phenologies have increased recently (Cleland *et al*., 2012), research on how warming directly affects an organism's physiological processes has lagged (Forrest and Miller-Rushing, 2010). The studies which have been performed recently on plants which produce flowers and pollinating insects show this deviation.

Most part of this study has been on changes which occur in time of flowering and emergence of insect and potential temporal mismatches between the two. (Memmott *et al*., 2007). Direct physiological effects, in contrast, have received very little attention in the literature despite the fact that they are expected to have significant influence on the interactions between plants and pollinators.

Pollinator interactions with flowering plants are both ecologically significant and economically valuable. According to Ollerton *et al*. (2011), angiosperms (88%) contingent on animals for favour of pollination.

If this relationship will not occur, seed distribution, and plant recruitment may all be negatively impacted (Kearns and Inouye, 1997). According to Gallai *et al*. (2009), the profit that pollinators provide is estimated at $220 billion per annum globally. According to Potts *et al*. (2010), a number of interrelated reasons have likely contributed to the global loss of some insect pollinators, and corresponding lessens in insect-pollinated plants have also been perceived (Biesmeijer *et al*., 2006). Therefore, it is crucial to comprehend how physiological changes in the environment affect pollinators, their floral supplies, and their mutualistic relationships.

According to several studies, elevated temperatures have a variety of effects on the physiology of flowering plants, resulting in altered production of flowers, nectar, and pollen. Warming can affect an insect pollinator's foraging behaviour, body size, and lifespan (Bosch *et al*., 2000).

Individual flowering plants or insect pollinators may not directly suffer from the physiological effects of climatic warming; in some cases, they may even benefit. However, these physiological reactions may in turn have conflicting implications on how pollinators and plants interact. There hasn't been a synthesis of these physiological reactions or their possible effects on interactions between plants and pollinators as of yet.

Here, we provide a summary of the current understanding of how high temperatures affect the biology of plants produces flowers and pollinating insects. Physiology of plants and insects can be impacted by other components of intercontinental changing in climate, like inflated levels of carbon dioxide and changed patterns of precipitation (Minckley *et al*., 2013), either directly or indirectly (Hoover *et al*., 2012). We first consider how plant physiological responses to warming may impact insect pollinators, then we consider how insect reactions to warming may impact flowering plants, and finally we consider how these responses may impact networks of interactions between plants and pollinators. Our objective is to both summarise what is currently known about the biological repurcussions of warming on every partner which are giving benefits to each other and to suggest fruitful lines of inquiry for further study in this area.

8.2 Physiological Impacts on Cross Breeding Plants and Plausible Repucussions on Pollinating Insects:

The physiology of flowering plants can be impacted by increased temperatures in a number of different ways. Here, we concentrate on physiological factors that could affect how plants interact with pollinating insects. Many insect taxa reckon on flower resources, mainly pollen, to cater for their eggs and developing offspring as well as in sometimes, to keep themselves alive during overwintering. According to Kevan and Baker, 1983, the numerous insect taxa that consume nectar out of flowers to propellant their flight and/or metabolic activity

8.2.1 Decision to Flower and Flower Production:

It has been discovered that elevated temperatures have a variety of consequences on flower output. Some plants may flower less frequently or produce fewer flowers when grown in hotter temperatures. In an investigation on *Delphinium nuttallianum,* Nuttall's larkspur, it was discovered that the experimentally heated plots had less flower reproducing plants unheated plots under control. According to the same investigation (3.94 vs. 4.53 flowers/plant; Saavedra *et al.*, 2003), plants in warm plots had on average fewer flowers than plants in control plots. Similar to this, numerous species' flower production declined as a result of a research trial that replicated winter warming of plant species by 1.5 °C on the Tibetan plateau (Liu *et al*., 2012).

According to Menzel and Simpson (1995), lychee (*Litchi chinensis*) plants that were revealed to temperatures above 20 °C for at least eight hours a day failed to blossom. On the other hand, research on alpine tundra and arctic dwelling plants revealed that, following a few years of investigation warming, the plants' blooming productivity rose (Arft *et al.*, 1999). Many New Zealand species experienced an increase in mass flowering as an outcome of inflating temperatures (Schauber *et al.*, 2002). The conflicting results of climate change on flower growth imply that certain breeds are impacted by inflated temperatures, where others are not. Species those reckon on temperature cues to command flowering, in general, had greater potential to adjust in high temperatures. (Cleland *et al*., 2012).

The reason of this may be a transcription factor ehich activates flowering at warmer temperatures (Kumar *et al*., 2012), and warming may also be beneficial for species whose growth is more dependent on the availability of nitrogen than water (De Valpine and Harte, 2001). Species' ability to produce floral resources for insect visitors and the level of pollinator attraction to those plants will depend on whether and how intensely they blossom. Reduced food availability due to increased temperatures would almost likely result in decreased flower production, which might then lead to decreased insect pollinator reproductive output (Minckley *et al.*, 1994) and density of pollination (Westphal *et al*., 2003). As an alternative, if floral resources are limited, the pollinators of those plants that produce more flowers in response to warming may have access to more food and experience population growth. Regardless of substitute in absolute abundance, the species mix of plants in flower will probably alter, which may have an impact on pasturing distances (Jha and Kremen, 2013) and growth of larvae (Génissel *et al*., 2002).

8.2.2 Flower Size and Timing of Anthesis:

When plants give production to flowers in hot conditions, it's likely that those blossoms will vary in a number of crucial characteristics that could alter how appealing, reachable, and beneficial their rewards would be for insect visitors. The results of all the investigations done up to this point indicate a wide range of biological repurcussions of temperature on flower features, the process for which probably reckon on part on whether and at what developmental stages plants encounter heat stress (Wahid *et al*., 2007) which means temperature has an impact on the size of each individual bloom. Pumpkin plants, *Cucurbita maxima* that were experimentally warmed (to 23 °C) produced blooms that reduced in diameter (Hoover *et al*., 2012). The length of corolla tubes from the shore flowers of *Ipomoea trichocarpa* produced during cooler time were several millimetres shorter than flowers produced during a warmer period. The timing of anthesis was similarly influenced by temperature, with the opening of flowers 2-3 hours earlier on warmer mornings (Murcia, 1990). The ability of pollinators to access floral resources from a particular species may be impacted by these temperature-related alterations in flower size and timing of anthesis. According to morphological correlations between the extent of proboscides and nectar spurs (Nilsson, 1988), it is known that floral dimensions specifically affect those pollinators which are physically able to access floral rewards.

Changes in floral dimensions may have an impact on pollinator's foraging effectiveness even if rewards are still available. Pollinator species that are working earlier may gain from access to those incentives if the anthesis process occurs more quickly as a result of warmer morning temperatures, but this could change the accessibility of resources for pollinator taxa operating at the end of the day. (Murcia, 1990). It is also important to remember that the size of flower can influence the pollinator appeal (Totland, 2001).

8.2.3 Floral Scent, Nectar, and Pollen Production:

Temperature can also have an impact on floral smell, nectar, and pollen production. Although some investigations have suggested that endogenous floral smell production diminishes with increasing temperature (Sagae *et al*., 2008), hot temperatures may intensify emissions and/or fickleness of organic chemicals manufactured by flowers (Yuan *et al*., 2009). Despite the fact that Pacini *et al*. (2003) demonstrated that nectar production, composition, and concentration of flower, all are affected by temperature, it appears that not many research have looked upon these issues in the context of global warming. In a Mediterranean plant, *Thymus capitatus*, nectar volume and sugar concentration rose with temperature (38°C) (Petanidou and Smets, 1996), even though the proportion of glucose to fructose in the nectar of plants of pumpkin was negatively altered by temperature (23 °C vs. 19 °C), (Hoover *et al.*, 2012).

Compared to plants grown at a constant temperature of 25 °C. The plants of Medicago sativa revealed to temperature fluctuations (18 to 32 °C) bring out less nectar (57.1 vs. 68.4 l/100 florets; Walker *et al*., 1974). The performance and chemical makeup of pollen can also be impacted by temperature (Delph *et al.*, 1997). Glycine max soybean flowers generated 30-50% less pollen which was less likely to germinate when grown at high temperatures (38 °C Day, 30 °C night) (Koti *et al.*, 2005). Similar to this, when exposed to high temperature, *Arachis hypogaea* plants generated fewer viable pollen (up to 44 °C) (Prasad *et al*., 2003). These swap in floral fragrance and benefits may have an impact on the likelihood that insects will visit particular flowers and the rewards they receive. The detectability of flowers may be impacted by substituted odour of flower outpouring or volatilization at temperatures at higher rate (Kevan and Baker, 1983), especially for crossbreeding insects, eg. moths that reckon on long distance cues to collect flower resources (Yuan *et al*., 2009).

Without a doubt, substitutes in production and composition of nectar could have an instant bump on activity of pollinators and energetics as well as longer-term allusions on pollinator fitness (Burkle and Irwin, 2009) for insects those depend on nectar for both carbohydrates and amino acids, such as some lepidopterans and wasps (Kevan and Baker, 1983).

The reproductive success of many bees is also likely to be impacted by decreasing pollen production, as these insects may need to collect pollen from numerous plants in order to effectively nurture their young-ones. (Muller *et al*., 2006).

In spite of the fact that, there has not been much cessation research on whether less viable pollen is fewer or many appealing to pollinators. Bumblebees favoured potato *Solanum tuberosum* flowers with viable pollen grains over those with inviable or shrunken pollen grains, showing the former are more nutrient-rich (Batra, 1993).

8.2.4 Plant Height:

Elevated temperatures can change various plant properties that could affect insect pollinators' visits and floral attributes. For instance, plant communities subjected to 1.5 °C of winter warming via open top chambers grew to a greater height than communities in control chambers (Liu *et al*., 2012). With contradiction to this, *Silene noctiflora* plants get taller at higher temperatures (28°C Day, 24°C night) were several cm minuscule (Qaderi and Reid, 2008) similarly, *Hypericum perforatum* plants uncovered to 3°C winter warming was shorter (Fox *et al*., 1999); showing that species-specific effects of temperature on plant height may reckon on the accessibility of water and other resources.

The likelihood that insects may come across and visit flowers may change as a result of changes in plant stature. Indeed, plants having tall height are generally anticipated to draw more visits of pollinator, and some pollinating insects are known to evinced height-specific habits of feeding (Levin and Kerster, 1973). As a result, shorter plants may be harder for pollinators to spot (Aspi *et al*., 2003), which could alter how much time and effort they need to spend finding these floral resources.

8.3 Pollinating Insects' Physiological Reactions and Possible Implications for Blossoming Plants:

As a direct result of climate change, pollinators are also subjected to several alterations. The impact of changing temperatures on the physiology of several important pollinators has comparatively less studied. Instead, we focus on what we already know about the ecology of temperature of insect pollinators and in what way this can have an impact on how successfully flowering plants are pollinated.

8.3.1 Foraging Activity:

The pollinators which can be active when the temperature is high is determined by thermoregulatory constraints (Willmer and Stone, 2004). Pollinating insects of varying sizes are likely to be affected by warming in a different way as bigger insects are effectively having potential to maintain their temperatures of body in comparison to the ones having smaller size. The likelihood of overheating is inflated because big-bodied insects may engross more heat and do not liberate it rapidly (Heinrich, 1993). In fact, Asian honey bees overall body size was inversely associated with passive convective heat loss through the thorax. (Dyer and Seeley, 1987). Insects' ability to regulate their body temperature can also be influenced by colour and pile or fur thickness (Willmer, 1983). Under hotter conditions, daily activity patterns and timing of insect pollinators can change due to the thermal restrictions. Eg. Honey bees, *A. mellifera* found in Sonoran Desert ceasing to browse at temperatures which exceeds 40 °C for collecting pollen (Cooper *et al.*, 1985), while larger insects, such as *Bombus* spp., be liabled to feed either very early in the morning or at the end of the day, circumvent the warmest time of the day. (Willmer, 1983).

Pollination success is likely to be impacted if climate change obtruded new physiological restraints on the discernible patterns of diurnal pollinating insects that change the time of day, they select to browse flowers. These changes are likely to have an impact on pollen flow patterns, that pollen will be received, and pollination will be successful if pollinators only visit flowers that open earlier in the day, plants with later-opening blooms would receive fewer visits, which would lead to a reduction in seed and fruit production (Wilcock and Neiland, 2002).

Pollen flow patterns may change as a result of when pollinators have to restrain their foraging browsing to shorter distances to prevent overheating during flight on extremely hot days. Reduced outcross pollen from more distant conspecifics could occur as a result of shorter flight distances, which could impair seed germination and seedling survival (Price and Waser, 1979). Similar to this, plants might be pollinated more- or less-effectively, if everyday’s temperature analyse the constituents of sternous floral visitors on the basis of intra- or inter-specific differences in body size (Herrera, 1997).

8.3.2 Body Size at Maturity:

The tendency of ectotherms, which include insects, to generate adults that are smaller in size as they develop at higher temperatures is a well-known phenomenon (King-solver and Huey, 2008). This phenomenon may be due to the acceleration of development. According to several research, higher temperatures (both constant and changing) cause solitary bee larvae or pupae to weigh less, developing into adults of small size (Radmacher and Strohm, 2010; 2011). With increased temperatures of 20, 25, and 30 °C, the size of larval stage of tobacco hornworm, *Manduca sexta* shrank (Davidowitz *et al*., 2004), which would produce smaller adult hawkmoths. (Kingsolver *et al*., 2012).

The efficiency of pollinators can differ with their body size (Sahli and Conner, 2007), so warming persuaded changes in developmental physiology that produces smaller adult pollinators could ameliorate or reduce pollen impregnation to female flowers and there upon hampered per-visit setting of seed, capably altering the expense and well-being of pollinator visits. According to the results showed by Greenleaf *et al*. (2007), bee body size has also been connected to foraging distance, with larger bees covering longer distances. Smaller pollinators may carry pollen farther if the similar relationship exists within the species.

8.3.3 Life Span:

Increasing temperature may shorten the life span of pollinating insects. For instance, the average number of days that male orange sulphur butterflies, *Colias eurytheme* life span decreased by about 40% when they were exposed to 4°C "warming" episode in the half of their "normal" temperature cycle of 20 to 32°C (Kingsolver and Watt, 1983). Bees that had overwintered lived shorter lives, as a result of imitated prolonged summers and sizeable degree-day cimulations encountered by the solitary bee, *Osmia lignaria* (Sgolastra *et al*., 2011). Similar to this, this species' adult life span was shortened by up to several days when exposed to persistently high pre-winter temperatures (Bosch *et al.*, 2000).

The window of time during which certain pollinators may collect pollen and remove it from plants is fundamentally decreased due to their shorter life spans. For plants, those are non-autogamous and reckon on just some breeds of pollinators during a small period of flowering could produce harmful effect. The majority of plants, however, do not fit into this group because they possess compensating characteristics that can guarantee reproduction even in the absence of pollinator visitation. Discrete plants those produces flower outside of the window of overlap with efficacious pollinators may have lower reproductive output.

8.4 Consequences for Plant-Pollinator Networks:

Both, the pair wise relationships and their overall interaction networks will change as a result of the integrated effects of heat on flowering plants and insect pollinators. Many researchers have studied the anatomy and passage of networks of plant-pollinators (Olesen *et al*., 2008), and some have looked into how these networks may react to disruptions like phenological shifts brought by climate change (Memmott *et al*., 2007) and shifts in the ranges (Devoto *et al*., 2007). Latest empirical work demonstrates that when generalization and the emergence of new interactions can act as some buffers, species extinction and phenological incompatibilities can eventually damage networks. (Burkle *et al*., 2013).

Even without alterations to the species composition or phenological overlap, physiological reactions to warming may be able to affect the networks of plants and pollinators. Network structure and dynamics may be considerably impacted by the additional unpretentious changes in contact strength that could make an appearance from changed floral reward quality or shorter pollinator life spans. Positive assessment between effects on pollinator and plant populations are also likely, even though we have briefly explored them. For example, direct plant physiological responses that decreased pollinator reproductive success may in turn reduce pollination success. On the other hand, if plant and pollinator responses are complementary, both anthesis and foraging occur promt in the day or both flower size and body size are smaller, then there may not be much of an overall impact on interactions. Even if a brred reactions are not so much directed and more changeable, new interactions might develop, preventing the network as a whole from becoming too unstable.

Ultimately, though, physiological reactions to climate warming may have an impact on networks in a lot of the same ways that more pronounced phenological shifts with some plant species being visited by fewer pollinator species and reduced diet breadths for some pollinators.

8.5 Impact of Different Climate Factors on Bee Populations:

Colony collapse disorder (CCD) is a phenomenan that poses a risk to bees in particular. An article from Oregon State University describes CCD: "CCD is most likely caused by a number of issues related to agricultural beekeeping, including as infections, nutritional inadequacies and a lack of variety in diet, exposure to pesticides and neonicotinoid insecticides, a lack of genetic diversity, habitat degradation, and transportation stress. In fact, pesticides, stress, and a lack of diversity can make bees more susceptible to infections. Habitat loss, nutritional inadequacies, and a lack of variety in diet are all closely linked to climate change due to which the irregular weather affects plant and flower growth. Flowers are blossoming half a day earlier each year due to climate change, which means that plants are currently in full bloom one month earlier than they were 45 years ago. Early blooming plants ultimately result in less pollination, which leaves bees hungry.

Humans will continue to notice the effects of CCD on their plants and crops as long as bee colonies are suffering from it. Green Living Ideas, the website showed the importance of pollination in NEFT reports by stating that all the billions of humans living on earth heavily rely on food and products for their survival, thus those 1,000 plants which helps us to achieve that survival has to be inseminated by animals, which counts coffee, almonds, some delicious snacks like melon, and also tequila. Bees are responsible for over 75% of the pollination of the plants in our yards. Humans would experience severe food shortages, serious economic ramifications, and the tragic fallout of bee extinction if this dreadful trend of CCD persists.

8.6 How Can We Conserve Pollinators:

Plant a wide range of native flowers and plants to your environment that are good for pollinators. Pesticides are dangerous to pollinators, so stop using them on your property or use them sparingly. Establish a bee-friendly environment. This entails either putting beehives on your property, leaving dead logs lying around that bees may nest in, or simply making sure that your yard is filled with plenty of flora that are beneficial to bees. Plant milkweed plants so that monarch butterflies can feast on the nectar of the blooms and lay their eggs on the leaves.

8.7 Conclusions:

A challenging and crucial conservation objective for the coming decades is the preservation of of interaction between plant and pollinator because of continuous climate change. Although scientists have made progress in documenting how warming affects various plant and pollinator species physiologically, there is still a lot of space for advancement in this area of study. Studies that more truly account for the effects of warming might provide useful insights as investigation on the repercussions of changing climate on plant and pollinator physiology advances. Simulations that take into cogitation, thermal variability in landscapes and microclimatic change at scales relevant for focal organisms, are likely to more effectively predict the impacts of climate warming (Sears *et al*., 2011). Our understanding of the overall effects of global change on plant-pollinator interactions should also be improved by research that combine physiological, behavioural, and phenological responses as well as interactions among different drivers (Hoover *et al.*, 2012).

Studies at the network level in some ways inherently achieve this goal, mainly if networks are sampled throughout space and time. Greater cogitation of species attributes and abiotic factors in network research would be particularly beneficial in assisting with the solution to this topic. The only way to put the unique physiological reactions of each benifitting partner to each other into a broader ecological framework and comprehend the overall impact on focal species is to study interactions.

8.8 References:

1. Aarssen LW. Hypotheses for the evolution of apical dominance in plants: implications for the interpretation of over-compensation. *Oikos*. 1995; 74:149–156.
2. Arft AM, Walker MD, Gurevitch J, Alatalo JM, Bret-Harte MS, Responses of tundra plants to experimental warming: Meta-analysis of the international tundra experiment. *Ecol. Monogr*. 1999; 69:491–511.
3. Aspi J, Jäkäläniemi A, Tuomi J, Siikamäki P. Multilevel phenotypic selection on morphological characters in a meta-population of Silene tatarica. *Evolution.* 2003; 57:509–517.
4. Batra SWT. Male-fertile potato flowers are selectively buzz-pollinated only by Bombus terricola Kirby in upstate New York. J. Kansas Entomol. Soc. 1993; 66:252–254.
5. Biesmeijer JC, Roberts SPM, Reemer M, Ohlemuller R, Edwards M, et al. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*. 2006; 313:351–354.
6. Bosch J, Kemp WP, Peterson SS. Management of *Osmia lignaria* (Hymenoptera: Megachilidae) populations for almond pollination: methods to advance bee emergence. *Environ. Entomol*. 2000; 29:874–883.
7. Burkle L, Irwin R. Nectar sugar limits larval growth of solitary bees (Hymenoptera: Megachilidae) *Environ. Entomol*. 2009; 38:1293–1300.
8. Burkle LA, Marlin JC, Knight TM. Plant-pollinator interactions over 120 years: Loss of species, co-occurrences, and function. *Science*.
9. Cleland EE, Allen JM, Crimmins TM, Dunne JA, Pau S, et al. Phenological tracking enables positive species responses to climate change. *Ecology*. 2012; 93:1765–1771.
10. Cooper PD, Schaffer WM, Buchmann SL. Temperature regulation of honey bees Apis mellifera foraging in the Sonoran Desert. *J. Exp. Biol*. 1985; 114:1–15.
11. Davidowitz G, D'Amico LJ, Nijhout HF. The effects of environmental variation on a mechanism that controls insect body size. *Evol. Ecol. Research*. 2004; 6:49–62.
12. Delph LF, Johannsson MH, Stephenson AG. How environmental factors affect pollen performance: Ecological and evolutionary perspectives. *Ecology*. 1997; 78:1632–1639.
13. Devoto M, Zimmermann M, Medan D. Robustness of plant-flower visitor webs to simulated climate change. *Ecol. Austral*. 2007; 17:37–50.
14. Dyer FC, Seeley TD. Interspecific comparisons of endothermy in honey-bees (Apis): Deviations from the expected size-related patterns. *J. Exp. Biol*. 1987; 127:1–26.

15. Forrest J, Miller-Rushing AJ. Toward a synthetic understanding of the role of phenology in ecology and evolution. *Phil. Trans. R. Soc. B.* 2010; 365:3101–3112.
16. Fox LR, Ribeiro SP, Brown VK, Masters GJ, Clarke IP. Direct and indirect effects of climate change on St John's wort Hypericum perforatum L. (Hypericaceae) Oecologia. 1999; 120:113–122.
17. Erhardt A, Rusterholz H-P. Effects of elevated CO2 on flowering phenology and nectar production. *Acta Oecologica*. 1997; 18:249–253. [Google Scholar]
18. Gallai N, Salles J-M, Settele J, Vaissiere BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ*. 2009; 68:810–821.
19. Génissel A, Aupinel P, Bressac C, Tasei J-N, Chevrier C. Influence of pollen origin on performance of Bombus terrestris micro-colonies. *Entomol. Exp. Appl*. 2002; 104:329–336.
20. Greenleaf SS, Williams NM, Winfree R, Kremen C. Bee foraging ranges and their relationship to body size. *Oecologia.* 2007; 153:589–596.
21. Heinrich B. The Hot-blooded Insects: Strategies and Mechanisms of Thermoregulation. Harvard Univ. Press; Cambridge, MA: 1993.
22. Herrera CM. Components of pollinator "quality": Comparative analysis of a diverse insect assemblage. *Oikos*. 1987; 50:79–90.
23. Herrera CM. Thermal biology and foraging responses of insect pollinators to the forest floor irradiance mosaic. *Oikos*. 1997; 78:601–611.
24. Hoover SER, Ladley JJ, Shchepetkina AA, Tisch M, Gieseg SP, et al. Warming, CO2, and nitrogen deposition interactively affect a plant-pollinator mutualism. *Ecol. Lett*. 2012; 15:227–234.
25. Hughes L. Biological consequences of global warming: Is the signal already apparent? *Trends Ecol. Evol.* 2000; 15:56–61.
26. Jha S, Kremen C. Resource diversity and landscape-level homogeneity drive native bee foraging. Proc. Natl. Acad. Sci. U.S.A. 2013; 110:555–558.
27. Kearns CA, Inouye DW. Pollinators, flowering plants, and conservation biology. Bioscience. 1997; 47:297–307.
28. Kevan PG, Baker HG. Insects as flower visitors and pollinators. *Annu. Rev. Entomol*. 1983; 28:407–453.
29. Kingsolver JG, Watt WB. Thermoregulatory strategies in Colias butterflies: Thermal stress and the limits to adaptation in temporally varying environments. *Am. Nat.* 1983; 121:32–55.
30. Kingsolver JG, Huey RB. Size, temperature, and fitness: Three rules. *Evol. Ecol. Research*. 2008; 10:251–268.
31. Kingsolver JG, Diamond SE, Seiter SA, Higgins JK. Direct and indirect phenotypic selection on developmental trajectories in Manduca sexta. *Funct. Ecol*. 2012; 26:598–607.
32. Kumar SV, Lucyshyn D, Jaeger KE, Alós E, Alvey E, et al. Transcription factor PIF4 controls the thermosensory activation of flowering. *Nature*. 2012; 484:242–245.
33. Levin DA, Kerster HW. Assortative pollination for stature in *Lythrum salicaria*. Evolution. 1973; 27:144–152.
34. Liu Y, Mu J, Niklas KJ, Li G, Sun S. Global warming reduces plant reproductive output for temperate multi-inflorescence species on the Tibetan plateau. *New Phytol*. 2012; 195:427–436.
35. Memmott J, Craze PG, Waser NM, Price MV. Global warming and the disruption of plant-pollinator interactions. *Ecol. Lett*. 2007; 10:710–717.

36. Menzel CM, Simpson DR. Temperatures above 20 °C reduce flowering in lychee (*Litchi chinensis* Sonn.) J. *Hortic. Sci*. 1995; 70:981–987.
37. Minckley RL, Wcislo WT, Yanega D, Buchmann SL. Behavior and phenology of a specialist bee (Dieunomia) and sunflower (Helianthus) pollen availability. *Ecology*. 1994; 75:1406–1419.
38. Minckley RL, Roulston TH, Williams NM. Resource assurance predicts specialist and generalist bee activity in drought. *Proc. R. Soc. B*. 2013; 280:20122703.
39. Muller A, Diener S, Schnyder S, Stutz K, Sedivy C, Quantitative pollen requirements of solitary bees: Implications for bee conservation and the evolution of bee-flower relationships. *Biol. Conserv*. 2006; 130:604–615.
40. Murcia C. Effect of floral morphology and temperature on pollen receipt and removal in Ipomoea trichocarpa. Ecology. 1990; 71:1098–1109.
41. Nilsson LA. The evolution of flowers with deep corolla tubes. *Nature*. 1988; 334:147–149.
42. Olesen JM, Bascompte J, Elberling H, Jordano P. Temporal dynamics in a pollination network. *Ecology*. 2008; 89:1573–1582.
43. Ollerton J, Winfree R, Tarrant S. How many flowering plants are pollinated by animals. Oikos. 2011; 120:321–326.
44. Pacini E, Nepi M, Vesprini JL. Nectar biodiversity: A short review. *Plant Syst. Evol*. 2003; 238:7–21.
45. Parmesan C. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst*. 2006; 37:637–69.
46. Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, et al. Global pollinator declines: Trends, impacts and drivers. Trends Ecol. *Evol*. 2010; 25:345–353.
47. Price MV, Waser NM. Pollen dispersal and optimal out-crossing in Delphinium nelson. *Nature.* 1979; 277:294–297.
48. Qaderi MM, Reid DM. Combined effects of temperature and carbon dioxide on plant growth and subsequent seed germinability of Silene noctiflora. *Int. J. Plant Sci*. 2008; 169:1200–1209.
49. Radmacher S, Strohm E. Factors affecting offspring body size in the solitary bee. *Osmia bicornis* (Hymenoptera, Megachilidae) Apidologie. 2010; 41:169–177.
50. Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Fingerprints of global warming on wild animals and plants. *Nature*. 2003; 421:57–60.
51. Sagae M, Oyama-Okubo N, Ando T, Marchesi E, Nakayama M. Effect of temperature on the scent emission and endogenous volatile profile of Petunia axillaris. *Biosci. Biotechnol. Biochem*. 2008; 72:110–115.
52. Sears MW, Raskin E, Angilletta MJ. The world is not flat: Defining relevant thermal landscapes in the context of climate change. *Integr. Comp. Biol*. 2011; 51:666–675.
53. Sgolastra F, Kemp WP, Buckner JS, Pitts-Singer TL, Maini S, et al. The long summer: Pre-wintering temperatures affect metabolic expenditure and winter survival in a solitary bee. *J. Insect Physiol.* 2011; 57:1651–1659.
54. Totland O. Environment-dependent pollen limitation and selection on floral traits in an alpine species. *Ecology*. 2001; 82:2233–2244.
55. De Valpine P, Harte J. Plant responses to experimental warming in an montane meadow. *Ecology*. 2001; 82:637–648.
56. Wahid A, Gelani S, Ashraf M, Foolad MR. Heat tolerance in plants: An overview. *Environ. Exp. Bot*. 2007; 61:199–223.

57. Walker AK, Barnes DK, Furgala B. Genetic and environmental effects on quantity and quality of alfalfa nectar. *Crop Sci*. 1974; 14:235–238.
58. Walther G-R, Post E, Convey P, Menzel A, Parmesan C, et al. Ecological responses to recent climate change. *Nature.* 2002; 416:389–395.
59. Westphal C, Steffan-Dewenter I, Tscharntke T. Mass flowering crops enhance pollinator densities at a landscape scale. *Ecol. Lett*. 2003; 6:961–965.
60. Wilcock C, Neiland R. Pollination failure in plants: Why it happens and when it matters. Trends Plant Sci. 2002; 7:270–277.
61. Willmer PG. Thermal constraints on activity patterns in nectar-feeding insects. *Ecol. Entomol*. 1983; 8:455–469.
62. Willmer PG, Stone GN. Behavioral, ecological, and physiological determinants of the activity patterns of bees. *Adv. Stud. Behav*. 2004; 34:347–466.
63. Yuan JS, Himanen SJ, Holopainen JK, Chen F, Stewart CN. Smelling global climate change: Mitigation of function for plant volatile organic compounds. *Trends Ecol. Evol*. 2009; 24:323–331.

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9. Insect Resistance to BT Toxins and Its Management

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Abstract:

Bacillus thuringiensis (Bt) a spore producing, gram-positive, facultative anaerobic bacteria persist in soil. The synthesis endotoxins or Cry proteins, during sporulation is its main hallmark. These proteins toxic to certain group of insects. Bt is the most frequently used bio pesticide in the world due to the enormous variety of these poisons, their effectiveness, and their comparatively low cost of manufacture. Most commonly lepidopteran and coleopteran larvae are the targets in the control of agricultural crop pests, and it is particularly useful in the development of new plant varieties carrying Bt cry genes. Even Bt can be used to successfully control populations of a number of dipteran disease vectors, which benefits human health. This book chapter objectives are to give a general overview of Bt application in the crop protection and to address the issue of the appearance of insects that are resistant to this bio pesticide. Following a discussion of the biology of this entomopathogenic microorganism, several examples of the use of commercially available Bt products as sprays or in transgenic plants will be provided. The main method for using Bt transgenic plants to stop or postpone the development of resistance in target insect populations was detailed in the last section.

Keywords:

Bacillus thuringiensis, Toxins, Resistance, IRM.

9.1 Introduction:

The bacterium *Bacillus thurengensis* which is extensively distributed, rod-shaped, sporulating, and gram-positive, has been isolated from a variety of ecosystems, including soil, water, dead insects, silo dust, deciduous tree leaves, various conifers, insectivorous mammals, and human tissues with severe necrosis. The bacteriologist from Japan S. Ishiwata initially isolated Bt in 1901 from infected silk worms, *Bombyx mori* (L.). Then, in 1911, it was once again found by the German scientist Berliner, who isolated it from infected chrysalids of the Mediterranean flour moth *Ephestia kuehniella* (Zell.), which were gathered at a mill in the Thuringe province (Berliner, 1915), he gave the organism the name *Bacillus thuringiensis*. Because of Bt preparations could quickly kill insect larvae in modest quantities, agronomists became intrigued by their entomopathogenic capabilities. The vast array of insecticidal proteins that Bt strains produce are effective against the larvae of a wide range of insect orders as well as, in certain circumstances, against species from different phyla. The genes producing insecticidal proteins have been effectively employed in novel insecticidal formulations and in the development of transgenic crops, making Bt-based products the best-selling biological insecticides to date. The first formulation based on Bt was developed in France in 1938, under the name “Sporéine”, but the first well-documented industrial procedure for producing a Bt-based product dates from 1959, with the manufacture of “Bactospéine” under the first French patent for a biopesticide formulation. The first Bt-based formulation, known as "Sporéine," was created in France in 1938, but the production of "Bactospéine," the product covered by the country's first biopesticide formulation patent, did not follow a well-documented industrial process until 1959. Spore/crystal preparations derived from cultures in fermentors make up commercial Bt formulations. The preparations are dried and utilised in granulated form or as a wettable powder for spraying. δ endotoxins are extremely diverse, resulting in a relatively constrained action spectrum for each specific toxin, and are safe for plants, animals, and practically all non-target insects to consume (Marvier *et al.*, 2007).

More than 700 cry gene sequences that produce crystal (Cry) proteins have been discovered in long before decades, and big plasmids seem to be where these genes are typically found. While many Cry proteins have beneficial pesticidal qualities that can be used to control insect pests in agriculture, other proteins generated by Bt strains as parasporal crystals have no known invertebrate target and have been referred to as parasporins (Palma *et al*., 2014). Additionally, during the vegetative development phase, Bt isolates produce additional insecticidal proteins that are subsequently secreted into the culture media and are known as vegetative insecticidal proteins (Vip). In addition, Vip proteins are divided into four families—Vip1, Vip2, Vip3, and Vip4—based on how similar their amino acid sequences are (Warren *et al.*, 1988). As an alternative to conventional pesticides, Bt crystal and released soluble toxins have grown in importance due to their excellent host specificity. In order to discover and characterise new insecticidal proteins with various specificities, the utility of these insecticidal proteins has also prompted the quest for new Bt isolates from the most varied ecosystems. A pluripotent nature of some toxins is suggested by the fact that some of these isolates demonstrate novel and unexpected toxic actions against species other than insects.

At the end of the 19th century, various trailblazing scientists, notably Louis Pasteur, first suggested the use of entomopathogenic microorganisms for controlling the populations of insect pests. Since then, a wide variety of microbes, including bacteria, viruses, fungi, and protozoans, have been identified as prospective candidates for use in biocontrol techniques against insect pests (Riba and Silvy, 1989). These bio pesticides, which also provide the advantage of having just a little influence on the environment, have come to occupy a stable, although modest position in the insecticide market in light of the unfavourable impacts of chemical insecticides and the public health issues in tropical nations. Currently, the biopesticide market represents 2% of the approximately 600 million US dollar global crop protection business. Bacillus thuringiensis (Bt)-based products account for 90% of all biopesticide sales. This achievement is due to a variety of factors: The larvicidal action of Bt is rapid but sustained, Bt can be administered using ordinary equipment, and its impacts on beneficial insects and non-target organisms are minimal, among other factors, all contribute to its achievement. Biotech corporations, who started putting Bt genes into numerous crop plants, including cotton and maize, towards the end of the 1980s, have not been able to ignore the benefits of Bt.

By producing Bt toxins in diverse tissues as a result of the insertion of these genes, the plant is defended against attacks from numerous seriously harmful pests. How Bacillus thuringiensis is made up of bacteria from the Bacillus cereus sensu lato group that are able to produce a protein crystal during sporulation that contains δ-endotoxins that have insecticidal activity. The crystalline inclusion may account for around 25% of the dry weight of the bacterium (Figure 9.1).

The bacterium Bacillus thurengensis which is considerably distributed, rod- shaped, sporulating, and gram-positive, has been insulated from a variety of ecosystems, including soil, water, dead insects, silo dust, evanescent tree leaves, colorful conifers, insectivorous mammals, and mortal apkins with flinty necrosis. The bacteriologist from JapanS. Ishiwata firstly isolated Bt in 1901 from infected silk worms, Bombyx mori (L.). Similarly, in 1911, it was onetime over set up by the German scientist Berliner, who isolated it from infected chrysalids of the Mediterranean flour moth *Ephestia kuehniella* (Zell.), which were gathered at a plant in the Thuringe fiefdom (Berliner, 1915), he gave the organism the name Bacillus thuringiensis. Because of Bt medications could snappily kill nonentity naiads in modest amounts, agriculturists came intrigued by their entomopathogenic capabilities. The vast array of insecticidal proteins that Bt strains produce are effective against the naiads of a wide range of nonentity orders as well as, in certain circumstances, against species from different phyla. The genes producing insecticidal proteins have been effectively employed in new insecticidal phrasings and in the development of transgenic crops, making Bt-grounded products the best- dealing natural germicides to date. The first expression grounded on Bt was developed in France in 1938, under the name " Sporéine ", but the first well- proved artificial procedure for producing a Bt- grounded product dates from 1959, with the manufacture of " Bactospéine " under the first French patent for a biopesticide expression. The first Bt- grounded expression, known as" Sporéine," was created in France in 1938, but the product of" Bactospéine," the product covered by the country's first biopesticide expression patent, didn't follow a well- proved artificial process until 1959. Spore/ demitasse medications deduced from societies in fermentors make up marketable Bt phrasings. The medications are dried and utilised in grained form or as a wettable greasepaint for scattering. δ endotoxins are extremely different, performing in a fairly constrained action diapason for each specific poison, and are safe for plants, creatures, and virtually all non-target insects to consume (Marvier *et al*., 2007).

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A pluripotent nature of some poisons is suggested by the fact that some of these isolates demonstrate new and unanticipated poisonous conduct against species other than insects. At the end of the 19th century, colorful trailblazing scientists, especially Louis Pasteur, first suggested the use of entomopathogenic microorganisms for controlling the populations of nonentity pests. Since also, a wide variety of microbes, including bacteria, contagions, fungi, and protozoans, have been linked as prospective campaigners for use in biocontrol ways against nonentity pests (Riba and Silvy, 1989). These bio fungicides, which also give the advantage of having just a little influence on the terrain, have come to enthrall a stable, although modest position in the germicide request in light of the unfavourable impacts of chemical germicides and the public health issues in tropical nations. Presently, the biopesticide request represents 2 of the roughly 600 million US bone

Global crop protection business. Bacillus thuringiensis (Bt)- grounded products regard for 90 of all biopesticide deals. This achievement is due to a variety of factors The larvicidal action of Bt is rapid-fire but sustained, Bt can be administered using ordinary outfit, and its impacts on salutary insects andnon-target organisms are minimum, among other factors, all contribute to its achievement. Biotech pots, who started putting Bt genes into multitudinous crop plants, including cotton and sludge, towards the end of the 1980s, haven't been suitable to ignore the benefits of Bt. By producing Bt poisons in different apkins as a result of the insertion of these genes, the factory is defended against attacks from multitudinous seriously dangerous pests. How Bacillus thuringiensis is made up of bacteria from the Bacillus cereus sensu lato group that are suitable to produce a protein demitasse during sporulation that contains δ- endotoxins that have insecticidal exertion. The crystalline addition may regard for around 25 of the dry weight of the bacterium (Figure 9.1).

9.2 Structure of Bt Toxin:

A variety of Cry toxins, including Cry3Aa, Cry1Aa, Cry1Ac, Cry2Aa, Cry3Bb, Cry4Ba, Cry4Aa, and Cry8Ea1, have published three-dimensional structures. All Cry toxins have three structural domains (Figure 10.1) and are topologically quite similar (Donovan *et al*., 2006; Crickmore *et al*., 1988). Seven -helices are bundled together and joined by loops to form Domain I. The central amphipathic helix of the -helical bundle is largely preserved across all the toxins mentioned. Different Domain I mutations seem to eliminate toxicity but not binding to cellular receptors. It is unknown if these changes change the toxin molecule's overall shape, reducing its toxicity. Domain II consists of three sets of antiparallel βsheets, each terminating with a loop. The beta sheets form a beta-prism structure, which is centred on a hydrophobic core. Two antiparallel -sheets sandwiched together to form Domain III have a "jelly-roll" structure. Strong support for Domains II and III's participation in receptor binding and insecticidal activity is provided by the results of site-directed mutagenesis and truncation studies (Crickmore *et al*., 1988). The hydrophobic patterns found in domain I, which are thought to generate ion channels in the cell membrane, affect toxicity. As with other bacterial toxins, the domain undergoes refolding when it comes into contact with the cell membrane which helps in toxin insertion. According to several articles, toxicity is caused by the orientation of hydrophobic -4 and -5 helices that intrude into the membrane. However, these statements are not supported by in situ or in vivo research. The Cry toxins' most divergent domain, Domain II, can have an impact on host specificity if it is switched out for domains II or III of other toxins. The antiparallel -sheet loops, which connect the strands, are visible at the top of the domain and are the least conserved among the Cry toxins. It's interesting to note that the length of the apical loops in the Cry1A, Cry2A, Cry3A, Cry4A, and Cry5A toxins varies greatly. The longest loop is found in the Cry5Aa toxin, whereas the smallest is found in Cry3Aa. It is unknown how loop length affects domain organisation and function. The length of the loops unquestionably affects Domain II's configuration and, most likely, the three domains' interactions as well as the specific poisons' ability to attach to their appropriate receptors. Numerous researchers have hypothesised that shorter loops are more likely to disrupt the Domain II core -sheets' structure and, as a result, prevent Domains I and II from interacting (Ibrahim *et al*., 2010). The loops appear to be crucial components in receptor recognition, binding, and specificity, regardless of their structural or functional significance. Figure 9.1: Toxin's three-dimensional structures (Crickmore *et al*., 1988).

The development of channels in the cell membrane and the binding of receptors have both been linked to domain III. The insect specificity of some Cry1 toxins has changed as a result of in vitro Domain III switching. It has been proposed that domain III swapping is a mechanism of evolution and that this activity may be in charge of the creation of poisons with various specificities. Toxins having dual specificity, particularly to moths and beetles, such as Cry1I, are examples of substances that may have naturally undergone domain shifting (Demaagd *et al*., 2010).

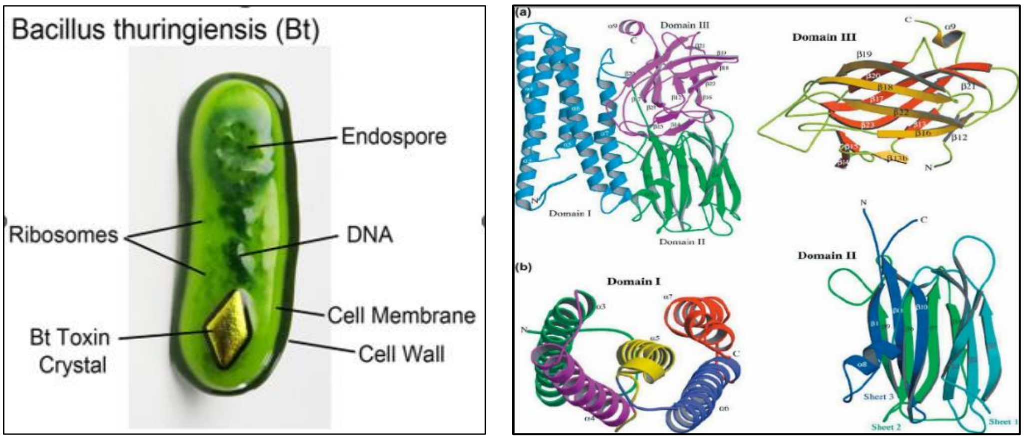

Figure 9.1: General structure of Bt and three-dimensional structures of toxin [5]

9.3 Mode of Action:

There are several models reviewed in the literature that essay to explain how cry poisons put out their clean up capacity, but only two are extensively accepted. The first one presupposition that cry poison binds to midgut receptors, oligomerizes, and inserts into the membrane to form lytic pores (Figure 9.2). The discovery of ion fluxing in encounter border membrane vesicles and synthetic lipid bilayers treated with Cry poisons is the base for the proposition that Cry poisons assemble lytic pores in the tube membrane by forming oligomers. Still, no direct substantiation has been presented for such a medium in either living cells or a nonentity. In reality, it has been demonstrated that poisons integrated into living cells' tube membranes don't produce lytic holes and aren't dangerous. Likewise, exploration on mutant Cry poisons shows that neither poison oligomers nor original variations in the permeability of membrane vesicles are directly identified with toxin. Figure 9.2 Depicting medium of mode of action (6) Advanced alternate model (Figure 9.3) challenges the notion that Cry poison kills cells simply by bibulous lysis (Grochulski *et al*., 1995). poison monomer rather attaches to the cadherin receptor BT- R1 and triggers the Mg2 dependent signal- transduction pathway, causing cell death. The model shows that Cry1Ab oligomers incorporated into cell membranes don't relate with cytotoxicity in living cells. Contrary to what has been suggested, poison exertion is significantly more complex than poison- convinced bibulous lysis. The largely conserved structural motif in the cadherin receptor BT- R1 is where the univalent list of the cry poison occurs to begin the complicated, dynamic process of cry poison action. In turn, a waterfall of events is touched off that leads to a form of programmed cell death appertained to as oncosis. When the Cry1Ab poison binds to the BT- R1 receptor, it triggers a chemical signal that stimulates the heterotrimeric G protein and adenylyl cyclase, along with a significant boost in cAMP conflation. Protein kinase A is actuated by cAMP, which results in a variety of cellular changes similar as cytoskel et al reorganisation and ion fluxing. Acceleration of this alternate runner pathway causes cell death by changing the chemistry of the cell. also, the poison promotes the exocytotic translocation of BT- R1 from intracellular membrane vesicles to the cell membrane as part of the payoff medium. poison- convinced signal-transduction controls the movement of the receptor, and the prosecution of cell death is directly connected with the breadth of this signalling(Zhang *et al*., 2005).

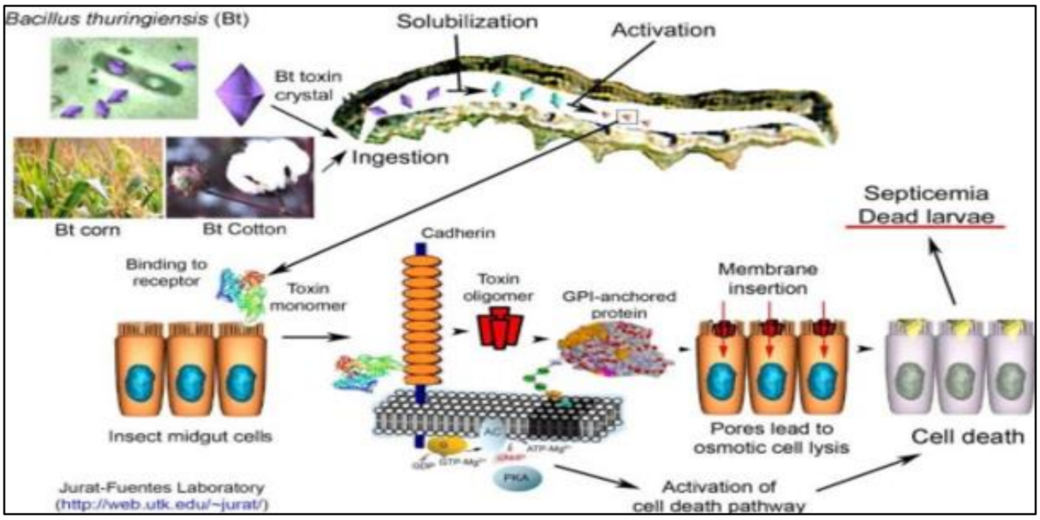

Figure 9.2: Showing Mechanism of Mode of Action (Zhang *et al*., 2005).

9.4 Global Area Under Biotech Crops:

Biotech crops are grown globally over an area of 181.5 million hectares at an annual growth rate of 3-4% from 175.2 million hectares in 2013 to 181.5 million hectares. From 1.7 million hectares in 1996 to 181.5 million hectares in 2014, the global area of biotech crops has expanded 100-fold, making them the fastest-adopted crop technology in recent years. Regarding sustainability, resilience, and the substantial advantages it offers to both small and large farmers as well as consumers, this excellent adoption rate speaks for itself.

Twenty years after its debut, just a small number of nations still contain the vast majority of the acreage planted to GM crops. In 2014, the US cultivated 40.3% (73.1 million hectares) of the world's GM crop acreage, making it the largest cultivator and the first country to adopt GM crops (Table 9.1).

Table 9.1: Bt Transgenic Crops Area and Its Distribution in World (Bravo *Et Al*., 2007)

Rank	Country	Area (mha)	Biotech crops
1	USA	73.1	Maize, soybean, cotton, canola, sugarbeet, alfalfa, papaya, squash
2	Brazil	42.2	Maize, soybean,cotton
3	Argentina	24.3	Maize, soybean,cotton
4	Canada	11.6	Canola, Maize,soybean, sugarbeet
5	India	11.6	Cotton
6	China	3.9	Cotton, papaya
7	Paraguay	3.9	Soybean, maize,cotton
8	South Africa	2.9	Soybean, maize,cotton
9	Pakistan	2.8	Cotton
10	Uruguay	1.4	Soybean, maize,
11	Bolivia	1.0	soybean
12	Philippines	0.8	Maize
13	Australia	0.7	Cotton, canola
14	Myanmar	0.3	Cotton
15	Others	<0.1	Maize, cotton, soybean, canola
		181.48m ha	

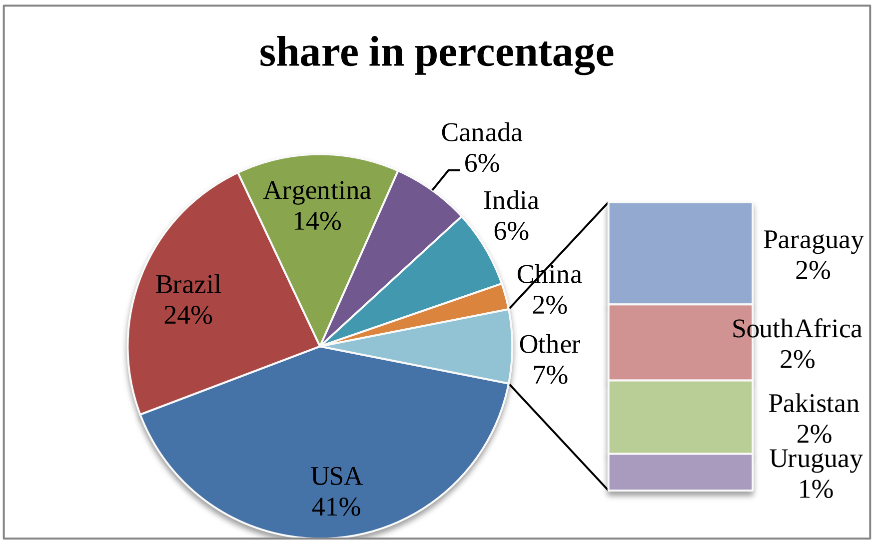

Figure 9.3: Bt Transgenic Crops Area and Its Distribution in World (Bravo *Et Al*., 2007)

9.4.1 Major Transgenic Crops:

Ninety-nine per cent of the acreage used for GM crops globally is made up of four crops. These include canola, soy, maize and cotton. GM soybeans are grown on half of the world's GM hectares. 30% of the total global GM area is made up of GM maize, and another 14% is made up of GM cotton. 5% of the global GM hectares are made up of GM canola (Table 9.2). The development of new constructions of Bt toxin genes with promoters to be expressed in monocots or dicots in diverse tissues of the plant, including the integration of a native Bt gene into the chloroplast genome of tobacco, was made possible by advancements in biotechnological techniques. Since the toxin gene does not need to be altered for increased production because the chloroplast genome is bacterial in origin. This method offers fresh opportunities for Bt plant breeding in the future, even though it is not yet commercially available (James, 2015).

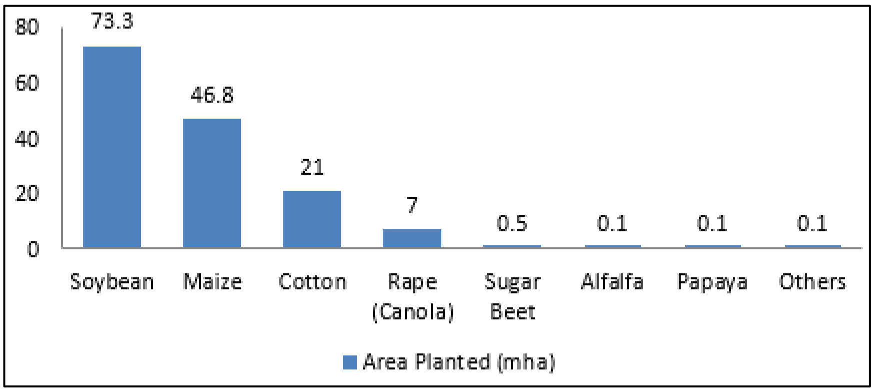

Figure 9.4: Major Transgenic Crops

9.4.2 GM Transgenic Crops Expressing Bt Toxins

Crop plants have been treated with Bt toxins to protect them against several types of insect pests. By the number of employees, a succinct summary was provided (MacBride eta al., 1995) in Table 9.3. Bt toxins are currently being used to modify a variety of crops, including vegetables, forage crops, root crops, cereals, and trees, to provide protection against insects (Jouanin *et al*., 1998).

Table 9.3: Transgenic Plants Expressing Bt Toxins in different important crops (Shelton *et al.*, 2000)

Crop	Gene	Target pest
Cotton	*cry1Ab/cry1Ac*	Bollworms
Corn	*cry1Ab*	European corn borer
Potato	*cry3a*	Colorado potato beetle
Rice	*cry1Ab/cry1Ac*	Stem borers and leaf folders
Tomato	Cry1 Ac	Fruit borer

Crop	Gene	Target pest
Brinjal	*cry1Ab/cry1B*	Shoot and fruit borer
Canola	*cry1Ac*	Diamondback moth
Soybean	*cry1Ac*	Soybean looper
Corn	*cry1Ab/cry1A*	European corn borer
Potato	*cry1Ab*	Tuber moth

9.5 Insects Resistance Against Bt Crops:

Resistance is a heritable alteration in a pest population's sensitivity that is reflected in a product's repeated inability to provide the desired level of control (Fontes *et al.*, 2002). Due to the intense temporal and geographical selection pressure of Bt toxins regulated by a single gene, the potential for rapid evolution of insect resistance is the most urgent concern relating to the practical application of transgenic plants in agricultural systems (Groot *et al*., 2001). In the lab, roughly 17 insect species have already developed resistance to Bt, but only one has demonstrated broad resistance in the field. It is widely believed that resistance will eventually appear in Bt-plants (Ferre and Van, 2002).

The development of resistance will put the use of related Bt bio-pesticides at risk for all users, including those not using transgenic technologies, in addition to the costs associated with the loss of the product and the development of alternative control strategies [either transgenic or conventional] (Andow,2002).

Many researchers came to the conclusion that field-evolved resistance in some populations of 5 of 13 species of important pests by 2010 compared with only one such species in 2005 (McGaughey *et al*., 1998) in Table 9.4 after conducting 77 studies in eight countries. Increases in the area planted to Bt crops, the number of pest populations exposed to Bt crops, and the cumulative duration of exposure are among the factors causing this rise in recorded occurrences of resistance.

The United States, which accounts for over half of the global Bt crop area each year, is home to three of the five resistant pests. The other two resistant pests originate from South Africa and India. Four of the five resistant pests are caterpillars; the fifth is an insidious beetle called western corn rootworm (*Diabrotica virgifera virgifera*).

Table 9.4: Present status of resistance to Bt plants (McGaughey *et al.*,1998)

Pest	Country	Gene	Crop	Year(i)	Year(r)	period
Helicoverpazea	USA	Cry1Ac	cotton	1996	2002	6 years
Spodopterafrugiperda	Puerto Rico	Cry1F	maize	2003	2007	4 years
Busseolafusca	South Africa	Cry1Ab	maize	1998	2004	6 years
Pectinophoragossypiella	India	Cry1Ac	cotton	2002	2009	7 years
Dibarotica virgifera virgifera	USA	Cry3Bb1	maize	2010	2013	3 years

9.6 Risk of Resistance for Bt:

Insects can adapt to Bt proteins, just like they can to most insecticides. This risk may be increased in Bt by the following factors:

- Bt proteins are expressed at high levels in most or all plant tissues;
- The proteins are produced by the plant continually during the growing season
- Some of the major target pests, such as European corn borer, corn rootworm, and pink bollworm, feed almost exclusively on corn or cotton.

These factors can increase insect exposure to the controlling toxins (Bt protein) and hence, increase selection pressure for resistance. That means that if the toxin kills susceptible insects, those that survive and reproduce are more likely to be resistant to the toxin.

9.7 Insect Resistance Management:

The commercialization of Bt crops—transgenic plants that express Bt proteins—for the management of insect pests is widespread. The threat that insect resistance poses to the continued use of Bt plant protectants has resulted in the development of the idea of managing insect resistance. IRM has acquired prominence since it is thought to be crucial to the sustainable use of Bt crops, which are genetically modified. It might be described as a strategy that delays the emergence of insect resistance to pesticides in the target pest populations. Insect resistance management (IRM) is an important part of stewarding this valuable technology. IRM requirements for Bt crops, however, fluctuate between nations because to variations in insect biology, farming methods, and experience.

The size and diversity of the agricultural systems in nations with small-scale farming systems present both potential and considerable obstacles for IRM. IRM initiatives in these nations should, to the greatest extent possible, be implemented through the technology suppliers rather than by pushing individual farmers to use revolutionary techniques. Alternative crop and non-crop hosts should be taken into account in appropriate IRM methods as sources of unstructured refuge, especially for highly polyphagous pests like the cotton bollworm *H. armigera*.

9.7.1 Refuges:

Refuges are host plants that do not have the particular insect protective trait, allowing some of the target pest population to avoid exposure and preserve the population's vulnerability to the trait. Recessive Bt resistance requires both copies of the receptor gene to be lost or altered in order to develop resistance. Because the RS genotypes don't do well under survival conditions, refuge is more effective the less prevalent Bt resistance is.

The initially extremely uncommon RR genotypes are what promote the development of resistance, but for a very long time, they can only mate with the RS kinds. Planting refuges reduces the fitness difference between genotypes that are more and less resistant, which ultimately slows the evolution of resistance.

A. Refuge Approaches:

- **Structured refuges** are an area of the farm that is solely used to grow non-Bt crops. These refuges are sown as separate fields (blocks), rows along the perimeter of Bt fields, or rows inside Bt fields. The size (as a proportion of the related Bt crop) and closeness to the Bt field(s) are the two most important factors for a structured refuge. In order for vulnerable insects from the refuge and resistant insects from the Bt fields to interact and reproduce, refuges must be able to produce a significant quantity of susceptible insects and present close enough to the Bt field.
- **Seed blends** (refuge-in-the-bag) seed mixtures combine Bt seed with non-Bt seed (refuge) in a single seed bag. The benefit of seed mixtures is that growers don't have to plan the planting of a separate refuge, guaranteeing refuge compliance. To present, some Bt maize PIP products have received approval for seed mixtures. For more information on the FIFRA Scientific Advisory Panel (SAP) sessions that the EPA has held on seed blends, check the links provided below under "Information Sources."
- **Natural refuge** refers to uncultivated plants, weeds, or natural hosts that might act as a supply of vulnerable insects. Such a refuge may be successful if the targeted pest(s) feed on a variety of plant hosts and are not restricted to the Bt crop. Only as an IRM technique for Bt cotton in the Southeast of the United States has natural refuge been approved. For more information, see the SAP links mentioned below under "Information Sources." The EPA sponsored a SAP meeting on natural refuge in 2006.

9.7.2 Multigene Strategy (Pyramided Plants):

Pyramiding A specific example of gene stacking in which two or more genes combined in a single genotype give at least two mechanisms of action against the same target pest(s). to create crops that express a minimum of two poisonous chemicals that act separately, preventing the spread of resistance from one to the other.

With the release of Bollgard II, this strategy, known as gene pyramiding, was made commercially viable. a transgenic cotton plant that expresses both the Cry1Ac and Cry2Ab variants of the Bt protein.In that they bind to various midgut receptors in the insect, the two proteins function independently of one another.

Insects that are homozygous for numerous resistance genes are much more uncommon (Table 10.5) than those that are homozygous for only one resistance gene.

A species cannot easily evolve resistance to both toxins because that would require two simultaneous, independent mutations in genes encoding the receptors (Shelton *et al.*, 2000).

Successful resistance management is demonstrated by the low percentage of resistant people even after prolonged exposure to Bt cotton over many years (Jackson *et al*., 2003).

Two Bt proteins, Cry1Ac and Cry2Ab2, are used in products like Bollgard II cotton to suppress lepidopteran pests. Since their modes of action are different, both proteins are more efficient than single-Bt products against the pests they are intended to control (Figure 9.4).

Table 9.5: Bt toxin pyramids used proactively and separately from one-toxin plants or remedially and concurrent with one-toxin plants (Jackson *et al.*, 2003)

Pest	Crop	Country	Toxins in pyramid	Resistance detected
Proactive and separate from one-toxin plants				
H. armigera	Cotton	Australia	Cry1Ac, Cry2Ab	None
H. punctigera	Cotton	Australia	Cry1Ac, Cry2Ab	None
Remedial and concurrent with one-toxin plants				
D. virgifera	Corn	USA	Cry3Bb, Cry34/35Ab	Cry3Bb
H. zea	Cotton	USA	Cry1Ac, Cry2Ab	Cry1Ac
H. zea	Cotton	USA	Cry1Ac, Cry1F	Cry1Ac
P. gossypiella	Cotton	India	Cry1Ac, Cry2Ab	Cry1Ac
S. frugiperda	Corn	USA	Cry1F, Cry1A.105b, Cry2Ab	Cry1F

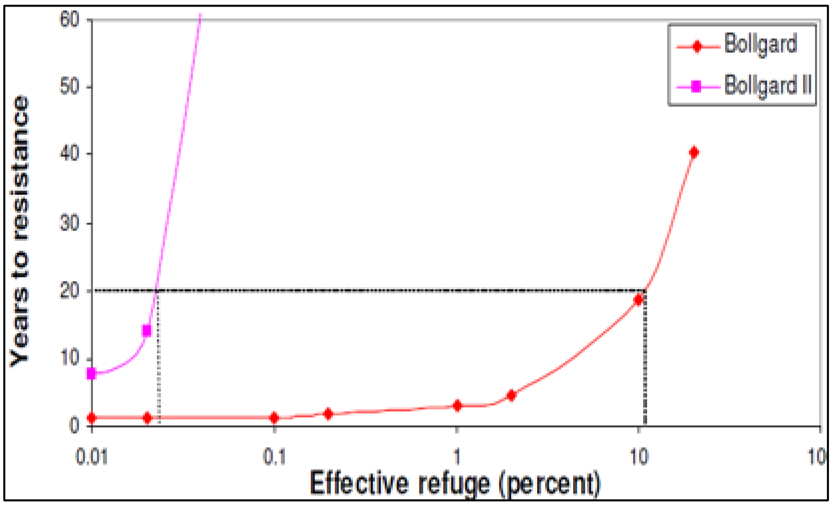

Figure 9.4: Effect of Products with Two Bt Proteins on rate of resistance (Tabashnik *et al.*, 2013)

9.7.3 High Dose Strategy:

A suitable resistance operation strategy is needed, according to the EPA and the 1998 Science Advisory Panel Subpanel, to help the emergence of insect resistance to the Bt proteins generated in transgenic crop plants. The 1998 Subpanel agreed that programmes for managing resistance should be grounded on the employment of both a high dose of Bt and structured refuges made to offer an acceptable number of adult insects that are susceptible to the substance. According to the high dose/ refuge method, there are three genotypes of Bt- resistant organisms' susceptible homozygotes (SS), heterozygotes (RS), and resistant homozygotes (RR). This is grounded on the supposition that Bt resistance is sheepish and is handed by a single locus with two alleles. also, it's assumed that resistant and susceptible grown-ups would constantly copulate at arbitrary and that there will be a low original resistance allele frequency.

Only a many extremely uncommon RR individualities would immaculately tolerate a big dose of Bt crop. The Bt toxin will affect those with both SS and RS. A structured refuge is a non-Bt area in a farmer's field or group of fields that supports the generation of susceptible (SS) insects that may aimlessly copulate with uncommon resistant (RR) insects who survive the Bt crop to induce susceptible RS heterozygotes that will be destroyed by the Bt crop. Insect populations will no longer contain resistant (R) alleles as a result, which will stop the evolution of resistance (Figure 9.5).

It has been discovered that a strategy to bring transgenic plants that synthesise extremely high degrees of insecticidal proteins is particularly efficacious in arresting or delaying the development of resistant insects.

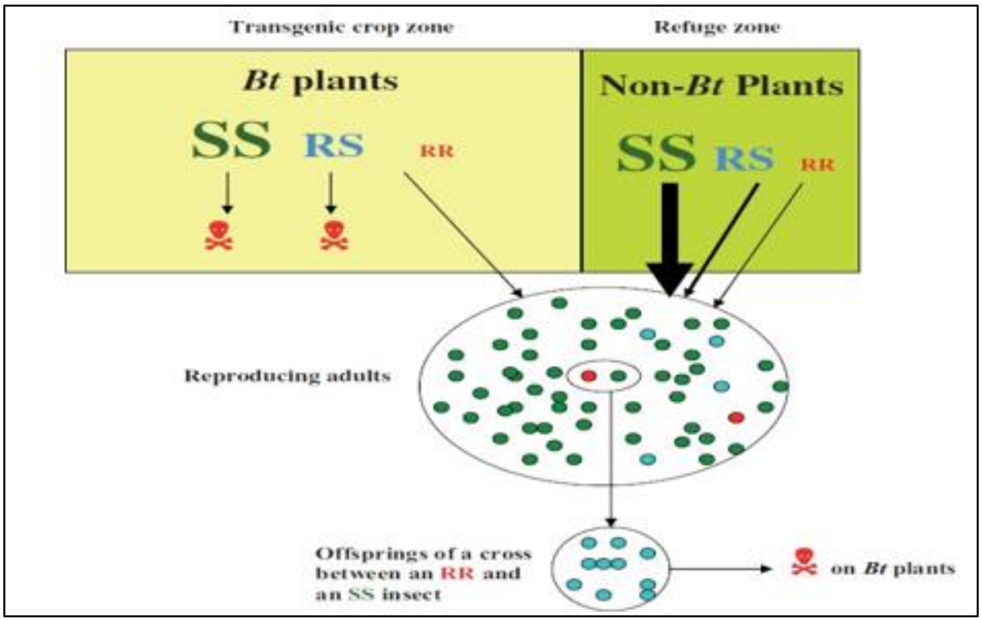

Figure 9.5: Schematic representation of the “high dose- refuge” (HDR) strategy. The success of the HDR program depends on resistance subsisting a exquisite and modest attribute and the genetically modified plants producing a dosage of poison sufficient to kill all homozygous susceptible entities (SS-green) and all heterozygous entities with for both resistance and vulnerability alleles (RS-blue) (Graham, 2010).

9.8 Why IRM For Bt?

The effectiveness of Bt PIPs (Plant Incorporated Proteins) and the preservation of their substantial agricultural and environmental benefits are highly valued by EPA. In order to prevent the development of resistance in the target pests, the Agency is dedicated to maintaining adequate oversight of these products. The EPA has enforced the implementation of an Insect Resistance Management (IRM) strategy for each commercially registered Bt PIP in order to combat the threat of resistance. IRM aims to postpone the emergence of resistance for as long as possible, but it's vital to remember that resistance may not be completely prevented from developing.

9.9 Conclusion:

In addition to reducing the need for pesticides and their expense, bt crops have provided a powerful tool for farmers and the environment in the fight against plant pests. Additionally, increased usage of transgenic crops for insect control is likely to involve additional cultivars with blends of two or more Bt toxins, including novel Bt toxins as VIP. However, modified Bt toxins that have undergone genetic engineering can kill insects that are resistant to traditional Bt toxins. With a wider variety of genetically modified crops and pest-targeting insect species, there is a likelihood that the adoption of transgenic crops will rise in developing countries.

Additionally, by integrating more effectively noticed patterns of field evolved resistance into future resistance management tactics, it may be possible to reduce the negative effects of present and upcoming generations of transgenic crops while maximising their advantages. To grow more crops, it is vital to utilise all possibility with the least amount of sacrifice. Bt insect resistance technology can benefit crops, farmers, and consumers alike when used in conjunction with good agricultural practises.

9.10 References:

1. Andow DA. Resisting resistance to Bt-corn. In: Letourneau, D.K.; Burrows, B.E. ed. Genetically modified organisms. Assessing environmental and human health effects. CRC Press, Boca Raton, 2002, 99-124.
2. Bravo A, Gill SS, Soberón M. Mode of action of Bacillus thuringiensis Cry and Cyt toxins and their potential for insect control. Toxicon. 2007; 49:423-435
3. Crickmore N, Zeigler DR, Feitelson J, Schnepf E, Van RJ, Lereclus D. Revision of the nomenclature for the Bacillus thuringiensis pesticidal crystal proteins. Microbiol Mol Biol Rev. 1998; 62:807-813
4. Demaagd RA, Weemen-Hendriks M, Stiekema W, Bosch D. Bacillus thuringiensis delta-endotoxin Cry1C domain III can function as a specificity determinant for Spodoptera exigua in different, but not all, Cry1- Cry1C hybrids. Appl Environ Microbiol. 2000; 66:1559- 1563.
5. Donovan WP, Engleman JT, Donovan JC, Baum JA, Bunkers GJ, Chi DJ *et al.* Discovery and characterization of Sip1A: A novel secreted protein from Bacillus thuringiensis with activity against coleopteran larvae. Appl. Microbiol. Biotechnol. 2006; 72:713-719.
6. Ferre J, Van RJ. Biochemistry and Genetics of Insect Resistance to Bacillus thuringiensis. Annual Review Entomology. 2002; 47:501-533.
7. Fontes EMG, Carmen SS, Sujii PER, Panizzi AR. The Environmental Effects of Genetically Modified Crops Resistant to Insects. Neotropical Entomology. 2002; 31:497-513
8. Graham M. Insect Resistance Management Strategies for Bt Crops in Small Scale Farming Systems Head, Monsanto Company, St. Louis, USA, 2010, 1-34.
9. Grochulski P, Masson L, Borisova S, Pusztai-Carey M, Schwartz JL, Brousseau R. Bacillus thuringiensis CryIA (a) insecticidal toxin: crystal structure and channel formation. J Mol Biol. 1995; 254:447-464.
10. Groot AT, Dicke M. Transgenic crops in an agroecological context: Multitrophic effects

of insect-resistant plants. Wageningen University Press, the Netherlands. 2001, 76.

11. Ibrahim MA, Griko N, Junker M, Bulla LA, Bacillus thuringiensis A genomics and proteomics perspective., Bioeng Bugs. 2010; 1(1):31-50.
12. Ishiwata S. (1901) On a kind of severe flacherie (sotto disease), Dainihon Sanshi Kaiho 114, 1–5.
13. Jackson RE, Bradley JR, Van Duyn JW. Performance of feral and Cry1Ac-selected Helicoverpa zea (Lepidoptera: Noctuidae) strains on transgenic cottons expressing one or two Bacillus thuringiensis spp. Kurstaki proteins under greenhouse conditions. J Entomol. Sci. 2003; 39:46-55.
14. James C. Global status of commercialized biotech/GM crops: lessons from the laboratory and field. Journal of Economic Entomology. 2015; 96:1031-1038
15. Jouanin L, Bonade M, Girard C, Morrot G, Gibaud M, The design and implementation of insect resistance management programs for Bt crops. Plant Sci. 1998; 131(1):1-11.
16. MacBride GB, Loftis JC, Adkins NC. What do significance tests really tell us about the environment? Environ. Manage. 1995; 17:423-432
17. Marvier M., McCreedy C., Regetz J., Kareiva P. (2007) Meta-analysis of effects of Bt cotton and maize on nontarget invertebrates, Science 316, 1475–1477.
18. McGaughey WH, Gould F, Gelernter W. Bt resistance management. Nature Biotechnology. 1998; 16:144-146
19. Palma L, Munoz D, Berry C, Murillo J, Caballero P. Bacillus thuringiensis Toxins: An Overview of Their Biocidal Activity. Toxins. 2014; 6:3296-3325
20. Riba G., Silvy C. (1989) Combattre les ravageurs des cultures enjeux et perspectives, INRA, Paris.
21. Shelton AM, Tang JD, Rousch RT, Metz TD, Earle ED. Field tests on managing resistacne to Bt-engineered plants. Nature Biotechnol. 2000; 18:339-342.
22. Shelton AM, Tang JD, Rousch RT, Metz TD, Earle ED. Field tests on managing resistance to Bt-engineered plants. Nature Biotechnol. 2000; 18:339-342
23. Tabashnik BE, Brevault T, Carriere Y. Insect resistance to Bt crops: Lessons from the first billion acres. Nature Biotechnology. 2013; 31:510-521.
24. Warren GW, Koziel MG, Mullins MA, Nye GJ, Carr B, Desai NM *et al*. Auxiliary Proteins for Enhancing the Insecticidal Activity of Pesticidal Proteins. U.S. Patent. 1998; 5:770-696
25. Zhang X, Candas M, Griko NB, Rose-Young L, Bulla LA. Cytotoxicity of Bacillus thuringiensis Cry1Ab toxin depends on specific binding of the toxin to the cadherin receptor BT-R1 expressed in insect cells. Cell Death Differ. 2005; 12:1407-1416.

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10. Bioremediation: A Remedy for Contaminated Soil for Sustainability and Environmental Stability

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Abstract:

An increasing trend has been seen in environmental pollution due to developing human activity on energy resources, intensive farming practices, and rapid industrialization during last few years. The release of contaminants such as pesticides, nuclear wastes, heavy metals, hydrocarbons, and greenhouse gases by different process in the environment causing toxic effect on human and environment health. Bioremediation has proven to be an efficient and widely used solution for removing pollutants from soil and water. Bioremediation is sustainable and cost-effective approach for soil decontamination by degrading or transforming contaminants, thereby restoring soil quality. Bioremediation process uses plant and microbes to degrade or convert harmful contaminants to fewer toxic contaminants using different mechanism and method. There are different in-situ and ex-situ techniques based on the location and appropriate method of treatment for the decontamination of soil. This chapter includes various bioremediation techniques and elaborates on phytoremediation and microorganism remediation technique for contaminated soil.

Keywords:

Bioremediation, contaminated soil, heavy metal, phytoremediation

10.1 Introduction:

Soil contamination caused by industrial activity, intensive cultivation, and inadequate landfill disposal methods is a matter of concern for long-term negative effects on the environment. Soil contaminants were classified into two types: inorganic and organic. Heavy metals *viz.* mercury, arsenic, lead, and cadmium are examples of inorganic pollutants, whereas organic pollutants *viz*. phenolic compounds, hydrocarbons, petroleum, herbicides, fertilizers, and pesticides. Harmful organic and inorganic compounds are principal causes of environmental pollution and constitute a serious human health hazard (Dhanam, 2017). The limited availability of pollution-free land and the need to safeguard the human health and ecosystem have heightened importance of remediation and rejuvenation of polluted land. Contaminated soil remediation involves the elimination or breakdown of pollutants into non-harmful substances. This can be achieved through various approaches such as biological degradation, heat processes (such as incineration), or chemical-physical processes (such as chemical oxidation, base catalysed dechlorination, or UV oxidation). Bioremediation, specifically, utilizes natural processes to reduce the concentration of contaminants to a safe and harmless state. It involves the use of biological agents, such as microorganisms or enzymes, to degrade, detoxify, mineralize, or modify the contaminants (Wang *et al*., 2021). The increasing need for sustainable techniques to address environmental pollution has led to a growing interest in utilizing biological organisms and plants for the decontamination of polluted environments.

These organisms have the unique ability to absorb and/or convert inorganic contaminants, making them valuable tools in bioremediation processes. Bioremediation offers various advantages, including the opportunity for on-site application, affordability, and minimal technology requirements, which simplify the implementation process.

Moreover, bioremediation can be synergistically combined with other chemical or physical methods to enhance its efficiency and broaden its applicability. In this chapter, our objective is to provide a comprehensive understanding of bioremediation and explore the potential strategies underlying various bioremediation techniques specially focusing on phytoremediation and microbial remediation techniques.

10.2 Concept of Bioremediation:

As part of the SARA (Superfund Amendments and Reauthorization Act) of 1986, the U.S. Environmental Protection Agency (U.S. EPA) endorsed the use of biological remediation as an alternative treatment method for contaminated soil.

This approach, considered an effective and long-lasting clean-up solution, harnesses microbes to remove and breakdown harmful substances in contaminated soil. By utilizing bioremediation, the primary objective is to maintain human wellness and ensure environment sustainability by breaking down and neutralizing harmful components present at contaminated sites (Wang *et al*., 2021).

Biodegradation and bioremediation share a common reliance on microorganisms to convert or metabolize chemicals. Both processes involve the microbial transformation of contaminants.

However, the key differentiation lies in their nature and application. Biodegradation is a natural process that occurs spontaneously in the environment, where microorganisms naturally break down chemicals over time. In contrast, bioremediation is a purposeful method that harnesses the power of microbes to address and mitigate environmental contamination.

Bioremediation is a technique that utilizes bacteria, fungi, and plants to modify or break down contaminants to a minimum level through different metabolic processes of these organisms have the ability to utilize chemical contaminants as a source of energy, allowing them to transform contaminants (Singh *et al*., 2008). It provides a long term in-situ solution instead of merely transferring the problem. This approach involves the degradation of specific organic compounds, leading to the complete mineralization of contaminants into harmless byproducts. Bioremediation can also utilize plants and microorganisms to absorb and detoxify inorganic pollutants. Various contaminants such as chlorinated compounds, agrochemicals, heavy metals, and more can be effectively remediated using bioremediation techniques. The choice of technique depends on factors such as the nature and severity of the pollutant, environmental conditions, cost, and regulatory considerations.

Although complete degradation may not always occur, pollutants can be transformed into intermediate products that may be less or more hazardous and have varying mobility in the environment (Khalid *et al.*, 2017)

10.3 Bioremediation Techniques:

Depending on the soil to be handled and the application location, bioremediation techniques can be divided into two major categories: in-situ and ex-situ procedures.

10.3.1 Ex-Situ Bioremediation Techniques:

Ex-situ bioremediation methods involve the removal of pollutants from contaminated areas and transporting them to different locations for treatment. When choosing an ex-situ bioremediation technique, several factors are considered, such as the treatment cost, extent and form of contamination, pollution magnitude, site location, and geology.

Performance parameters are defined to guide the selection of appropriate ex-situ strategies. Ex-situ technologies offer competitive advantages, primarily the ability to better control the remediation process compared to in-situ methods. Even basic solutions like biopiles provide a contained environment that is easier to predict and manage.

However, ex-situ bioremediation has drawbacks, including higher expenses, the risk of pollution dispersal during excavation and transport, and associated additional costs. Consequently, this method is deemed undesirable (Azubuike *et al.*, 2016).

10.3.2 In-Situ Bioremediation Techniques:

In-situ bioremediation methods involve treating contaminated materials directly at the site of pollution, without the need for excavation. This approach minimizes disruption to the soil structure. As there are no additional costs for excavation, in-situ techniques are more economical than ex-situ methods. However, a significant challenge lies in the expense of designing and implementing sophisticated tools on-site to enhance microbial activity during bioremediation. Nonetheless, this method is relatively simple to implement and offers the crucial advantage of preventing contamination spread that may occur during transportation.

In-situ bioremediation involves the introduction of air, nutrients, and/or microorganisms (either native or foreign) directly into the polluted soil, requiring minimal technological tools. One of the main limitations is its slow kinetics, necessitating extended treatment periods to complete the biodegradation process.

Additionally, the diffusion of oxygen in the soil is typically limited to the upper layer (around 30 cm from the surface), imposing constraints.

In-situ bioremediation approaches have proven effective in treating various types of pollution, including chlorinated solvents, dyes, heavy metals, and hydrocarbon-contaminated sites (Roy *et al.,* 2015).

Table 10.1: Different Bioremediation Techniques, Their Principle and Uses

Methods	**Principle**	**Uses**
In-situ bioremediation techniques		
Biosparging	Injects air/oxygen into the groundwater to enhance aerobic biodegradation of contaminants dissolved in the groundwater.	Petroleum hydrocarbons spill sites (Kao *et al*., 2008).
Bioventing	Enhances microbial activity for degradation of organic compounds using injected air or oxygen.	Light spilled petroleum products (Ho¨hener and Ponsin, 2014).
Bioslurping	Simultaneously extracts free-phase contaminants (liquid) and enhances aerobic biodegradation through the injection of air/oxygen into the groundwater.	Petroleum hydrocarbons, contaminated sites (Kim *et al.*, 2014).
Biostimulation	Provides nutrients and conditions to enhance microbial growth and degradation capabilities.	Polychlorinated biphenyls (PCBs) (Di Gregorio *et al.,* 2013).
Bioaugmentation	Introduces specific microbial strains or consortia to enhance degradation capabilities.	Crude oil-polluted sediments (Fodelianakis *et al.*,2015).
Natural attenuation	Relies on natural processes (e.g., microbial degradation, dilution, sorption) to reduce contaminant concentrations without external interventions.	Ground water contaminated with trichloroethene (TCE) (Adetutu *et al.,* 2015).
Ex-situ bioremediation techniques		
Slurry phase bioremediation		
Bioreactor	Enclosed systems that optimize environmental conditions for microbial degradation of contaminants.	Crude oil-polluted soil (Chikere *et al.*, 2012).
Solid phase bioremediation		
Biopiling	Contaminated soil is stacked into piles or windrows, and microbial degradation is facilitated through periodic aeration, nutrient addition, and moisture control.	Hydrocarbons contaminated soil (Smith *et al.*,2015).
Land farming	Enclosed systems that optimize environmental conditions for microbial degradation of contaminants.	Oil-polluted soil (Silva-Castro *et al.*,2012).

Methods	Principle	Uses
Composting	Promotes degradation of organic contaminants through microbial activity under controlled conditions, often with organic waste.	Petroleum contaminates soil (Wang *et al.*,2011).
Biofilter	Uses a packed bed of organic or inorganic media to support microbial growth and degrade volatile contaminants in air or gas streams.	Water contamination by copper and cadmium (Loutseti *etal.*,2009).

10.4 Phytoremediation:

The word "phytoremediation" originates from the combination of the Greek word "phyto" which stands for plant, and the Latin word "remedium" which signifies the ability to heal or restore (Vamerali *et al.*, 2010). This method uses physical, chemical, biological, biochemical, and microbiological interactions between plants in contaminated areas to reduce the toxicity of contaminants. This process of removing hazardous material from contaminated locations using living plantsassociated with numerous mechanisms, including accumulation or phtoextraction, phytofilteration, phytostabilization, phytovolatilization and phytodegradation. The removal of toxic heavy metals and radionuclides involves extraction, transformation, and sequestration processes. On the other hand, organic pollutants such as hydrocarbons and chlorinated compounds are primarily eliminated through degradation, filtration, stabilization, and volatilization. In some cases, mineralization can occur when specific plants like willow and alfalfa are utilized (Haq *et al.,* 2020).

10.4.1 Phytoextraction:

Phytoextraction, also described as phytoaccumulation, phytoabsorption, or phytosequestration, is a process that involves the uptake and accumulation of contaminants from soil/water through roots of plants, followed by their transfer and storage in the plant biomass or shoots, later harvested (Muthusaravanan *et al.,* 2018). The phytoextraction process can be divided into five main stages: mobilization of pollutants in the rhizosphere, uptake of pollutants by plant roots, translocation from roots to aboveground plant parts, and the accumulation of pollutants in plant tissues. Certain plant species, referred to as hyperaccumulators, have the unique capacity to accumulate high levels of certain contaminants in their tissues. The selection of hyperaccumulator plants is based on their tolerance to the target contaminants and their efficient metal uptake and accumulation capacity. Hyperaccumulator plants are defined as those capable of accumulating 1000 ppm of As, Pb, Co, Ni and Cu; 100 ppm of Cd; or >10,000 ppm of Zn and Mn. Notable families of plants like Brassicaceae, Asteraceae, Fabaceae, Euphorbiaceae, Flacourtiaceae, and Violaceae have been reported to extract heavy metals in significant amount (Kumar *et al*., 1995). Brassicaceae in particular have high potential for phytoextraction due to their ability to maximum heavy metal extraction. Two main types of phytoextraction methods exist: induced phytoextraction or chelate-assisted phytoextraction, which includes enhancing the mobility of heavy metal ions by using synthetic chelates for plant uptake and continuous phytoextraction (Ayyappan *et al.,* 2016).

10.4.2 Phytofiltration:

Phytofiltration also called rhizofiltration, is a technique that relies on the capacity of plant root systems to absorb, concentrate, and precipitate contaminants found in the soil. Through this process, contaminants are transported from the soil into the roots and accumulate in the harvestable portions of the plants. Phytofiltration leverages the natural abilities of plants and the microbes related with their roots to uptake and transform pollutants, with a specific focus on treating soil and addressing soil pollution issues. Due to the fact that some plants may synthesis certain chemicals like phytochelatins within roots which may boost the binding of pollutants like metal ions to roots (Verma *et al*., 2006). The rhizosphere environment differs from the bulk soil, providing unique conditions that can enhance contaminant degradation. Factors such as increased oxygen availability, pH changes, and root exudates create a more favorable environment for microbial activity and contaminant breakdown (Haq *et al*., 2020). Plant roots release various organic compounds (sugars, amino acids, and organic acids) into the rhizosphere. These compounds serve as a food source for soil microorganisms, attracting them to the root zone. Some of these microorganisms possess specific enzymes that can break down contaminants. The terrestrial and aquatic plants can use for in-situ or ex-situ remediation process and the toxins are not passed to shoots are the two main advantages of rhizofilteration. Previous studies have indicated that terrestrial plants (sunflower and Indian mustard) possessing deep and fibrous root systems are well-suited for phytofiltration due to their enhanced ability to absorb metals. Indian mustard, as noted by Raskin and Ensley (2000), has been observed to effectively eliminate a wide range of lead concentrations (4-500 mg l^{-1}). These terrestrial plants have also demonstrated the capability to remove metals such as Cd, Zn, Cu, Ni, and Cr from hydroponic solutions (Dushenkov *et al.,* 1995).

10.4.3 Phytostabilization:

Phytostabilization or phytoimmobilization type of phytoremediation technique used to stabilize or immobilize contaminants in soil using plants. The process of phytostabilization involves planting these selected plants in contaminated areas, where they grow and establish a root system. The plant roots have crucial role in stabilizing contaminants by physically binding or absorbing them and by forming insoluble compounds or metal complexes with organic substance in root zone. They can minimize their movement and ultimately bioavailability of contaminants in the environment reduces, also preventing pollutant discharge into groundwater or their uptake by other organisms. Root exudates play a significant role in phytostabilization by complexation or chelation, process which reduce the mobility and bioavailability of metals by forming less soluble (Cheraghi *et al.,* 2011).

The majority of microbial populations in polluted soil are supported by plants which speed up plant growth and lead to the stabilization of harmful metals. The extensive root system and a low transfer of metals from roots to shoot are prerequisites in plant species to be utilized for phytostabilization (Mendez and Maier, 2008). Phytostabilization is often employed in areas where the complete removal or extraction of contaminants is technically or economically impractical. It can be used in various settings, including abandoned mines, industrial sites, and landfills. The main goal of phytostabilization is to is stabilize pollutants rather than their removal, therefore reduce the risk posed by the contaminants and create a more stable and environmentally sustainable ecosystem.

According to the research conducted by Leung *et al*. (2007) which suggests that *Cynodon dactylon* (commonly known as Bermuda grass) has a high capacity for accumulating arsenic and could be a promising candidate for phytostabilization of arsenic-contaminated sites.

10.4.4 Phytovolatilization:

Phytovolatilization is a process of uptake contaminants, convert them into volatile compounds, and then release into the environment. This process is mediated by plant metabolic activities and transpiration pull (Khan *et al*., 2019). As the contaminants are transformed into volatile compounds, they can be released into the atmosphere through different pathways, one of the main routes of release is through the stomata on the leaf surfaces. These transformations can occur through various enzymatic reactions, microbial interactions, or metabolic processes such as oxidation, reduction, methylation, or other chemical reactions within the plant (Muthusaravanan *et al*., 2018). As a result, the volatile compounds released during phytovolatilization may be in the same form as the original contaminants or in altered forms due to the plant's metabolic activities. Several studies showed that *Brassica juncea* (Indian mustard), *Populus spp*. (poplar trees), *Salix spp*. (willow trees), maize etc have been studied and utilized for phytovolatilization to remove pollutants from soil. rice, azolla, rabbit foot grass, and pickle weed are some aquatic plants that are the finest volatilizers. Sunflowers (*Helianthus annuus*) possess the capability to volatilize selenium (Se) into the atmosphere. This is achieved through the process of assimilating selenium as organic seleno-amino acids from soil, particularly selenocysteine and selenomethionine, which are then released as volatile Se compounds (Terry *et al*., 1992).

10.4.5 Phytodegradation:

Phytodegradation is a process through which plants can break down or degrade contaminants in the environment. Phytodegradation or phytotransformation, refers to the process by which plants capture pollutants from the surrounding and then undergo chemical modifications within their tissues as a result of metabolic processes and enzymatic reactions. This transformation can also occur through the actions of microorganisms associated with the plant's root system. Ultimately, this process leads to the inactivation, degradation, or immobility of pollutants, either in the roots or shoot of plants (Da Conceição Gomes *et al*., 2016). Plants can possess enzymes capable of breaking down specific pollutants like cytochrome P450 monooxygenases and peroxidases enzymes are involved in the metabolism and detoxification of organic compounds. Additionally, plants can also release exudates and enzymes into the rhizosphere, which can enhance microbial activity and promote the degradation of contaminants in the soil (Mahar *et al*., 2016).

10.5 Microorganism Remediation:

Microorganism remediation is a method which utilizes microorganisms to degrade or transform contaminants in soil, resulting in their remediation. Microorganisms such as bacteria, fungi, and archaea possess metabolic capabilities that enable them to break down various pollutants, including organic compounds and certain heavy metals though immobilizing and reducing the bioavailability of contaminants in polluted soil.

Heavy metals are an example of an inorganic contaminant that cannot be broken down by microbes but can be changed into another form because they have different physical and chemical characteristics (Ashraf et al., 2019). Microorganisms can utilize contaminants as a carbon or energy source, metabolizing them and converting them into less harmful substances. Organic pollutants are broken down by microorganisms either through respiration in aerobic condition or through denitrification, methanogenesis, and sulfidogenesis in anaerobic condition. Bacteria are known for their ability to degrade hydrocarbons, pesticides, and other organic pollutants. Fungi, on the other hand, are adept at breaking down complex organic compounds i.e., polycyclic aromatic hydrocarbons (PAHs) and dioxins. Microbial remediation mechanisms include oxidation-reduction reactions, intracellular storage, extracellular complexation, and precipitation of contaminants from the soil and reducing their bioavailability (Yang et al., 2018).

Among these processes, bioaccumulation and biosorption are crucial because they allow microorganisms, or biomass, to bind to and concentrate environmental pollutants. The initial stage involves quick sorption, similar to biosorption, where microbial population and metabolites of microbes bind to contaminants. The second stage is steadier and entails the physiological transport of the sorbate into the interior of cells through an actively metabolically transport system (Chojnacka, 2010).

Understanding and harnessing bioaccumulation and biosorption processes can contribute to the development of efficient microbial remediation strategies for contaminated soil and water environments. Microbes utilize functional groups present in their polysaccharide slime layers to adsorb pollutants. These functional groups have affinity for various contaminants, allowing microbes to bind and immobilize them. In addition to the polysaccharide slime layers, extracellular polymeric substances (EPS) produced by microbes also contribute to the adsorption of pollutants. EPS are composed of nucleic acids, proteins, lipids, and complex carbohydrates. They form a matrix around microbial cells and provide a sticky, gel-like structure. This matrix enhances the adsorption capacity of microorganisms, allowing them to capture and retain pollutants (Gupta and Diwan, 2017). Field testing of promising microorganisms identified in laboratory or greenhouse studies is essential, as environmental variables in the field can lead to different outcomes. The effective utilization of microbes is necessary for successful implementation of microbe-assisted phytoremediation. Various methods such as seed treatment, foliar sprays, and direct inoculation of soils can be employed to introduce inoculants into contaminated soils. A study by Boricha and Fulekar (2009) identified Pseudomonas plecoglossicida as a novel organism suitable for the bioremediation of cypermethrin pesticide. Also, they found that Pseudomonasaeruginosa, Bacillus sp., Streptomyces sp., and Pseudomonas fluorescens were used for remediation against chromium heavy metal. Some bacteria such as Bacillus spp. and P. aeruginosa showed positive result for remediation of lead contaminated soil (Akhtar *et al*., 2013).

10.6 Conclusion:

Bioremediation offers a promising solution for the remediation of polluted soils, providing an eco-friendly and sustainable approach to restore soil quality and ecosystem health. This process offers effective, cutting-edge treatments for a wide range of pollutants. Among the several known bioremediation techniques phytoremediation, rhizoremediation, and bioremediation by bacteria are potentially effective methods to decontaminate soil from pollutant. Continued research and technological advancements are needed to optimize bioremediation strategies, improve efficiency, and expand their applicability to a wide range of contaminants and soil types.

10.7 References:

1. Adetutu, E. M., Gundry, T. D., Patil, S. S., Golneshin, A., Adigun, J., Bhaskarla, V., & Ball, A. S. (2015). Exploiting the intrinsic microbial degradative potential for field-based in-situ dechlorination of trichloroethene contaminated groundwater. *Journal of hazardous materials*, *300*, 48-57.
2. Akhtar, M. S., Chali, B., & Azam, T. (2013). Bioremediation of arsenic and lead by plants and microbes from contaminated soil. *Res Plant Sci*, *1*(3), 68-73.
3. Ashraf, S., Ali, Q., Zahir, Z. A., Ashraf, S., & Asghar, H. N. (2019). Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. *Ecotoxicology and environmental safety*, *174*, 714-727.
4. Ayyappan, D., Sathiyaraj, G., & Ravindran, K. C. (2016). Phytoextraction of heavy metals by Sesuvium portulacastrum L. a salt marsh halophyte from tannery effluent. *International Journal of Phytoremediation*, *18*(5), 453-459.
5. Azubuike, C. C., Chikere, C. B., & Okpokwasili, G. C. (2016). Bioremediation techniques–classification based on site of application: principles, advantages, limitations and prospects. *World Journal of Microbiology and Biotechnology*, *32*, 1-18.
6. Boricha, H., & Fulekar, M. H. (2009). Pseudomonas plecoglossicida as a novel organism for the bioremediation of cypermethrin. *Biology and medicine*, *1*(4), 1-10.
7. Cheraghi, M., Lorestani, B., Khorasani, N., Yousefi, N., & Karami, M. (2011). Findings on the phytoextraction and phytostabilization of soils contaminated with heavy metals. *Biological Trace Element Research*, *144*, 1133-1141.
8. Chikere, C. B., Chikere, B. O., & Okpokwasili, G. C. (2012). Bioreactor-based bioremediation of hydrocarbon-polluted Niger Delta marine sediment, Nigeria. *3 Biotech*, *2*, 53-66.
9. Chojnacka, K. (2010). Biosorption and bioaccumulation–the prospects for practical applications. *Environment international*, *36*(3), 299-307.
10. Da Conceição Gomes, M. A., Hauser-Davis, R. A., de Souza, A. N., & Vitória, A. P. (2016). Metal phytoremediation: General strategies, genetically modified plants and applications in metal nanoparticle contamination. *Ecotoxicology and Environmental Safety*, *134*, 133-147.
11. Dhanam, S. (2017). Strategies of bioremediation of heavy metal pollutants toward sustainable agriculture. *Sustainable Agriculture towards Food Security*, 349-358.
12. Di Gregorio, S., Azaizeh, H., & Lorenzi, R. (2013). Biostimulation of the autochthonous microbial community for the depletion of polychlorinated biphenyls (PCBs) in contaminated sediments. *Environmental Science and Pollution Research*, *20*, 3989-3999.
13. Dushenkov, V., Kumar, P. N., Motto, H., & Raskin, I. (1995). Rhizofiltration: the use of plants to remove heavy metals from aqueous streams. *Environmental science & technology*, *29*(5), 1239-1245.
14. Fodelianakis, S., Antoniou, E., Mapelli, F., Magagnini, M., Nikolopoulou, M., Marasco, R., & Kalogerakis, N. (2015). Allochthonous bioaugmentation in ex situ

treatment of crude oil-polluted sediments in the presence of an effective degrading indigenous microbiome. *Journal of hazardous materials*, *287*, 78-86.

15. Gupta, P., & Diwan, B. (2017). Bacterial exopolysaccharide mediated heavy metal removal: a review on biosynthesis, mechanism and remediation strategies. *Biotechnology Reports*, *13*, 58-71.
16. Haq, S., Bhatti, A. A., Dar, Z. A., & Bhat, S. A. (2020). Phytoremediation of heavy metals: an eco-friendly and sustainable approach. *Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation*, 215-231.
17. Höhener, P., & Ponsin, V. (2014). In situ vadose zone bioremediation. *Current opinion in biotechnology*, *27*, 1-7.
18. Kao, C. M., Chen, C. Y., Chen, S. C., Chien, H. Y., & Chen, Y. L. (2008). Application of in situ biosparging to remediate a petroleum-hydrocarbon spill site: Field and microbial evaluation. *Chemosphere*, *70*(8), 1492-1499.
19. Khalid, S., Shahid, M., Niazi, N. K., Murtaza, B., Bibi, I., & Dumat, C. (2017). A comparison of technologies for remediation of heavy metal contaminated soils. *Journal of Geochemical Exploration*, *182*, 247-268.
20. Khan, I., Iqbal, M., & Shafiq, F. (2019). Phytomanagement of lead-contaminated soils: critical review of new trends and future prospects. *International Journal of Environmental Science and Technology*, *16*, 6473-6488.
21. Kim, S., Krajmalnik-Brown, R., Kim, J. O., & Chung, J. (2014). Remediation of petroleum hydrocarbon-contaminated sites by DNA diagnosis-based bioslurping technology. *Science of the total environment*, *497*, 250-259.
22. Kumar, P. N., Dushenkov, V., Motto, H., & Raskin, I. (1995). Phytoextraction: the use of plants to remove heavy metals from soils. *Environmental science & technology*, *29*(5), 1232-1238.
23. Leung, H. M., Z. H. Ye, and Ming Hung Wong. "Survival strategies of plants associated with arbuscular mycorrhizal fungi on toxic mine tailings." *Chemosphere* 66, no. 5 (2007): 905-915.
24. Loutseti, S., Danielidis, D. B., Economou-Amilli, A., Katsaros, C., Santas, R., & Santas, P. (2009). The application of a micro-algal/bacterial biofilter for the detoxification of copper and cadmium metal wastes. *Bioresource technology*, *100*(7), 2099-2105.
25. Mahar, A., Wang, P., Ali, A., Awasthi, M. K., Lahori, A. H., Wang, Q., ... & Zhang, Z. (2016). Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: a review. *Ecotoxicology and environmental safety*, *126*, 111-121.
26. Mendez, M. O., & Maier, R. M. (2008). Phytostabilization of mine tailings in arid and semiarid environments—an emerging remediation technology. *Environmental health perspectives*, *116*(3), 278-283.
27. Muthusaravanan, S., Sivarajasekar, N., Vivek, J. S., Paramasivan, T., Naushad, M., Prakashmaran, J., ... & Al-Duaij, O. K. (2018). Phytoremediation of heavy metals: mechanisms, methods and enhancements. *Environmental chemistry letters*, *16*, 1339-1359.
28. Raskin, I., & Ensley, B. D. (2000). *Phytoremediation of toxic metals*. John Wiley and Sons.
29. Roy, M., Giri, A. K., Dutta, S., & Mukherjee, P. (2015). Integrated phytobial remediation for sustainable management of arsenic in soil and water. *Environment international*, *75*, 180-198.

30. Silva-Castro, G. A., Uad, I., Rodríguez-Calvo, A., González-López, J., & Calvo, C. (2015). Response of autochthonous microbiota of diesel polluted soils to land-farming treatments. *Environmental Research*, *137*, 49-58.
31. Singh, S., Kang, S. H., Mulchandani, A., & Chen, W. (2008). Bioremediation: environmental clean-up through pathway engineering. *Current opinion in biotechnology*, *19*(5), 437-444.
32. Smith, E., Thavamani, P., Ramadass, K., Naidu, R., Srivastava, P., & Megharaj, M. (2015). Remediation trials for hydrocarbon-contaminated soils in arid environments: evaluation of bioslurry and biopiling techniques. *International Biodeterioration & Biodegradation*, *101*, 56-65.
33. Smith, E., Thavamani, P., Ramadass, K., Naidu, R., Srivastava, P., & Megharaj, M. (2015). Remediation trials for hydrocarbon-contaminated soils in arid environments: evaluation of bioslurry and biopiling techniques. *International Biodeterioration & Biodegradation*, *101*, 56-65.
34. Terry, N., Carlson, C., Raab, T. K., & Zayed, A. M. (1992). *Rates of selenium volatilization among crop species* (Vol. 21, No. 3, pp. 341-344). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.
35. Vamerali, T., Bandiera, M., & Mosca, G. (2010). Field crops for phytoremediation of metal-contaminated land. A review. *Environmental Chemistry Letters*, *8*, 1-17.
36. Verma, P., George, K. V., Singh, H. V., Singh, S. K., Juwarkar, A., & Singh, R. N. (2006). Modeling rhizofiltration: heavy-metal uptake by plant roots. *Environmental Modeling & Assessment*, *11*, 387-394.
37. Wang, M., Chen, S., Jia, X., & Chen, L. (2021). Concept and types of bioremediations. In *Handbook of bioremediation* (pp. 3-8). Academic Press.
38. Wang, Z., Xu, Y., Zhao, J., Li, F., Gao, D., & Xing, B. (2011). Remediation of petroleum contaminated soils through composting and rhizosphere degradation. *Journal of Hazardous Materials*, *190*(1-3), 677-685.
39. Yang, Z., Shi, W., Yang, W., Liang, L., Yao, W., Chai, L., ... & Liao, Q. (2018). Combination of bioleaching by gross bacterial biosurfactants and flocculation: A potential remediation for the heavy metal contaminated soils. *Chemosphere*, *206*, 83-91.

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11. IPM: An Approach towards Sustainable Pest Management

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Abstract:

Integrated Pest Management (IPM) is a holistic and sustainable approach to managing pests, aiming to minimize the reliance on chemical pesticides while effectively addressing pest-related challenges. This strategy combines various techniques and strategies, considering the ecological, economic, and social aspects of pest management. The fundamental principles of IPM involve identifying and monitoring pests, establishing acceptable pest levels, implementing a range of control methods, and involving stakeholders in decision-making processes. The key components of IPM encompass cultural practices, biological controls, physical and mechanical measures, genetic approaches, and judicious use of chemical controls. IPM offers numerous benefits, including environmental sustainability by reducing the ecological impact of pest control, economic advantages through cost savings and increased productivity, enhanced human health and safety by minimizing pesticide exposure, and the prevention of pesticide resistance. Additionally, IPM contributes to the development of sustainable agricultural systems and compliance with regulatory requirements. Ultimately, IPM represents a promising approach towards achieving sustainable pest management, fostering ecological equilibrium, and safeguarding both ecosystems and human well-being.

Keywords:

Integrated Pest Management, environmental sustainability, pesticide resistance, sustainable pest management

11.1 Introduction:

Integrated Pest Management (IPM) is an environmentally sustainable approach to safeguarding crops by employing a decision support system for the careful selection and integration of pest control tactics. This strategy is founded on a comprehensive cost/benefit analysis that takes into account the economic, societal, and environmental impacts, as outlined by Kogan in 1998. Both the Food and Agriculture Organization of the United Nations (2005) and the European Union (EU Framework Directive 2009/128/EC 2009b) have defined IPM as the incorporation of all available methods of plant protection, followed by the integration of appropriate measures to deter the proliferation of harmful organisms.

The objective is to maintain the use of plant protection products and other interventions at levels that are economically and ecologically justified, while also minimizing risks to human health and the environment. Crop protection, which encompasses the management of plant diseases, weeds, and other pests, plays a pivotal role in steering agriculture towards more environmentally sustainable farming systems in the 21st century. The integrated management of weeds, pests, and diseases, facilitated by crop protection, is particularly crucial. Pesticides serve as a vital tool for farmers and growers, enabling them to achieve economically viable yields of marketable crops that meet the requirements of the supply chain.

11.2 The Origin of The Concept:

Integrated Pest Management (IPM) emerged as a response to the challenges posed by the widespread use of broad-spectrum insecticides, such as DDT. Entomologists at the University of California pioneered this new approach, known as integrated control. The primary objective was to address issues like secondary pest outbreaks and pesticide resistance.

The key innovation of IPM was the integration of biological and chemical control methods, with chemical control serving as a supplementary tool to biological control. Fundamental concepts like the "economic injury level" and "economic threshold" Stern *et al.,* (1959), forming the basis for decision-making in pest control. Over time, the concept of integrated control expanded to encompass a broader range of control measures, including cultural and mechanical methods. Contributions from researchers such as Franz (1961), van den Bosch (1962), and Smith and Huffaker (1973) played a significant role in the development and advancement of integrated control. Particularly, biological control gained prominence within IPM, recognizing the benefits of utilizing natural enemies to regulate pest populations.

11.3 Principles of Integrated Pest Management:

A. **Definition and Concept of IPM**: Integrated Pest Management (IPM) is an ecological approach that focuses on managing pests by integrating multiple strategies while reducing reliance on chemical pesticides. This approach recognizes the significance of comprehending the biology, ecology, and environmental interactions of pests in order to develop effective pest management strategies Reuveni *et al.*, (1998).

B. **Pest Identification and Monitoring:** Accurate identification and monitoring of pests are fundamental steps in IPM. By identifying the pest species and understanding its life cycle and behavior, targeted control measures can be implemented. Regular monitoring helps to assess pest populations, determine thresholds, and make informed decisions regarding intervention.
C. **Thresholds and Decision-Making**: In Integrated Pest Management (IPM), thresholds are defined as the point at which pest populations or damage levels warrant the implementation of control measures. The establishment of economic and ecological thresholds plays a crucial role in optimizing the utilization of control strategies and minimizing unnecessary interventions. Decision-making within IPM takes into account a range of factors, including economic feasibility, environmental impact, and social acceptability.
D. **Integrated Control Strategies**: IPM utilizes a diverse range of control strategies to effectively manage pests. These strategies encompass cultural control practices such as crop rotation and habitat manipulation, biological control methods involving the use of predators and parasites, physical and mechanical controls including traps and barriers, genetic control approaches such as the sterile insect technique and the cultivation of resistant plant varieties, and the careful and targeted application of chemical control methods. By employing this comprehensive array of strategies, IPM aims to address pest issues while minimizing the reliance on chemical pesticides.
E. **Stakeholder Engagement and Education**: IPM recognizes the importance of involving stakeholders, such as farmers, policymakers, and the general public, in the decision-making process. Stakeholder engagement helps in fostering a collaborative approach and promoting the adoption of IPM practices. Education and outreach programs play a crucial role in raising awareness about IPM principles and methods.

11.4 Components of Integrated Pest Management:

A. **Cultural Control Practices**: Cultural control practices involve modifying agricultural practices to create unfavorable conditions for pests. Examples include crop rotation, diversification, intercropping, and the use of resistant varieties. These practices disrupt pest life cycles, enhance biodiversity, and reduce pest pressure.
B. **Biological Control Methods**: Biological control methods utilize natural enemies, such as predators, parasitoids, and pathogens, to suppress pest populations. This component of IPM involves the conservation and augmentation of beneficial organisms through habitat manipulation, release programs, and provision of alternative food sources Nomikou *et al., (*2001), Urbaneja *et al.,* (2007), Sani *et al., (*2020).
C. **Physical and Mechanical Controls**: Physical and mechanical controls physically prevent pests from reaching crops or remove them from the environment. Examples include the use of insect-proof nets, traps, barriers, and mechanical removal methods. These measures can be targeted and minimize the reliance on chemical pesticides Shah *et al.*, (2019).
D. **Genetic Control Approaches**: Genetic control approaches involve the use of genetically modified organisms (GMOs) or traditional breeding techniques to develop pest-resistant cultivars. This component of IPM focuses on enhancing the natural resistance of crops to pests, reducing the need for chemical interventions Mishra *et al.*, (2016).

11.5 GM Crops as A Route for Delivery of Sustainable Crop Protection:

Modern agriculture, with its vast monocultures of lush fertilized crops, provides an ideal environment for adapted pests, weeds, and diseases. This vulnerability has implications for food security: when new pesticide resistant pest biotypes evolve, they can devastate crops. Even with existing crop protection measures, so sustainable ways of preventing these losses are needed. Development of resistant crop cultivars can make an important contribution. Resistance based on single genes does not protect against the full spectrum of pests, weeds, and diseases, and is more likely to break down as pests evolve counter-resistance. GM (genetic modification) techniques greatly facilitate transfer of genes and thus provide a route to overcome these constraints. Effective resistance traits can be precisely and conveniently moved into mainstream crop cultivars. Resistance genes can be stacked to make it harder for pests to evolve counter-resistance and to provide multiple resistances to different attackers. GM- based crop protection could substantially reduce the need for farmers to apply pesticides to their crops and would make agricultural production more efficient in terms of resources used (Land, energy and water). Resistance based on single genes does not protect against the full spectrum of pests, weeds, and diseases, and is more likely to break down as pests evolve counter-resistance

- **Chemical plant protection in conventional crop production:** Conventional crop production on most farms typically relies on the use of mineral fertilizers and chemical plant protection products (PPPs). Mineral fertilizers provide crops with ample nutrient supply, while PPPs are employed to combat harmful bacteria, fungi, animal pests, and weeds. The integration of mineral fertilizers, chemical plant protection, and modern high-yield crop varieties enables the current intensive crop production system, characterized by tight crop rotations and monocultures. This combination of inputs and practices facilitates maximum productivity in conventional agriculture.

11.6 Major Recurring Themes of Sustainability in Crop Protection:

A. **Are current crop protection practices sustainable:** Do we believe that complete sustainability is achievable? Are integrated crop protection and sustainability symbiotic or antagonistic? That crop protection is of critical importance to any food production system, now or in the future; that the way in which we protect our crops today has significant implications for future generations.
B. **The concept of sustainability:** “Development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs “emphasizes intergenerational factors but is vague in relation to the key elements of either present or future needs. Land quality, natural heritage, rural populations, energy and rural infrastructure as critical elements of sustainability. Most of these elements are also important when assessing future crop protection needs in any agricultural system.
C. **The biological roots of sustainability:** Biological control, chemical-based conventional crop protection, landscape management, and pest, weed, and disease forecasting all rely on and contribute to our functional comprehension of the biological processes that regulate interactions between organisms, which farming practices aim to manage. The challenges encountered in promoting biological control

through the utilization of soil-borne plant pathogens highlight the significance of this approach. It emphasizes the necessity for holistic crop protection strategies to be rooted in a profound understanding of the ecology of the organisms involved. Moreover, it underscores the importance of pursuing various advancements in crop protection to effectively address these issues.

D. **Anticipation and sustainability:** Most of the agrochemicals which are applied to our crops are wasted, because they are either applied to give protection against "pest" outbreaks which do not occur, or because they fall on a non-target area. With hindsight, chemicals could have been saved by making applications only to pest or disease outbreaks which developed to levels of economic significance. Anticipation also involves the development of new technologies and modifications to existing technologies so as to meet changing needs. There is likely to be for some time a continued development of conventional types of chemical control agents, together with more novel strategies, such as a stimulo-deterrent diversionary strategy, where semio-chemicals are used to modify behaviour and, as a consequence, give protection.
E. **Experimentation on sustainable farming systems:** Sustainable methods of crop protection will be based upon a better understanding of ecological principles, especially inter-specific interactions. Where either interactions or scale are important, a systems blueprint derived as the sum of information from a series of targeted studies, i.e., the effects of single bio-control agents, will be unsuccessful. Only studies which include the monitoring of whole systems will provide information which draws upon the full range of complexities.

11.7 Benefits of Integrated Pest Management:

A. **Environmental Sustainability:** A key advantage of IPM is its strong commitment to environmental sustainability. In contrast to conventional pesticide-centered approaches, IPM strives to minimize the reliance on chemical pesticides and instead prioritizes long-term pest management strategies. This approach significantly reduces the detrimental effects on ecosystems, non-target organisms, and water sources. By fostering ecological balance and biodiversity, IPM plays a crucial role in preserving the overall health of agricultural and urban ecosystems.
B. **Economic Advantages:** IPM can lead to economic benefits for farmers, agricultural industries, and society as a whole. While initial implementation of IPM practices may require investment in training, infrastructure, and monitoring, the long-term cost savings are significant. IPM reduces the need for frequent pesticide applications, leading to lower input costs for farmers. Moreover, by minimizing crop damage and yield losses, IPM contributes to increased productivity and profitability. Additionally, IPM can reduce pesticide residues, improving market access for farmers and ensuring consumer confidence in the safety of agricultural products.
C. **Human Health and Safety:** The emphasis on reducing dependence on chemical pesticides within IPM has significant implications for improving human health and safety. Pesticides have been linked to numerous health risks, ranging from acute poisoning to chronic illnesses and developmental disorders. By adopting alternative pest management strategies like biological controls and cultural practices, IPM mitigates the exposure of farmers, workers, and communities to hazardous chemicals. This approach also reduces the likelihood of pesticide residues in food, thereby safeguarding consumer health. Additionally, IPM advocates for the use of less toxic and

more selective pesticides, enabling targeted control while minimizing harm to beneficial organisms and pollinators.

D. Reduced Pesticide Resistance: Conventional pest control methods often rely on the repeated use of chemical pesticides, leading to the development of pesticide resistance in target pests. In contrast, IPM employs a diverse range of control strategies, including biological controls and cultural practices, which can help prevent or delay the onset of resistance. By integrating different pest management tactics, IPM reduces the selective pressure on pests, making it more challenging for them to develop resistance. This enhances the long-term effectiveness of pest control measures.

E. Sustainable Agricultural Systems: IPM aligns with the principles of sustainable agriculture by promoting the use of integrated and ecologically sound pest management practices. By reducing reliance on chemical inputs, IPM supports the development of resilient and sustainable agricultural systems. It encourages the preservation of natural resources, soil health, and biodiversity, thereby fostering long-term productivity and environmental stewardship.

F. Compliance with Regulatory Requirements: IPM aligns with regulatory frameworks and policies that aim to minimize the environmental and health risks associated with pesticide use. Many countries have implemented regulations and guidelines promoting the adoption of IPM as a preferred pest management strategy. By adhering to these requirements, farmers and industries can ensure compliance and maintain their market access both domestically and internationally.

11.8 Conclusion:

The integration of crop protection and production aims can result in systems based on ecological principles and which optimize resource use. The role of native organisms and natural processes to regulate weeds, pests and diseases should allow a use of crop protection materials which is both more targeted and less extensive. Such systems will be more sustainable**.**

11.9 References:

1. Kogan M. Integrated pest management: historical perspectives and contemporary developments. Annual Review of Entomology. 1998; 43:243–270.
2. European Union (2009b) Directive 2009/128/EC of the European parliament and of the council of 21 October2009 establishing a framework for community action to achieve the sustainable use of pesticides. Journal of European Union 52(L309):71–86.
3. Food and Agriculture Organization of the United Nations. International code of conduct on the distribution and use of pesticides: revised version. Food and Agriculture Organization of United Nations, Rome. 2005.
4. Franz JM. Biological control of pest insects in Europe. Annual Review of Entomology. 1961; 6:183–200.
5. Smith R, Huffaker C. Integrated control strategy inthe United States and its practical implementation. EPPO Bull. 1973; 3:31–46.
6. Stern VM, Smith RF, van den Bosch R, Hagen KS. The integrated control concepts. Hilgardia. 1959; 29:81–101.

7. Van den Bosch R, Stern VM. The integration ofchemical and biological control of arthropod pests. Annual Review of Entomology. 1962; 7:367–386.
8. Reuveni, R., and Reuveni, M. Foliar-fertilizer therapy—a concept in integrated pest management. Crop protection, 1998; 17(2), 111-118.
9. Shah, M.A.; Malik, K.; Bhatnagar, A.; Katare, S.; Sharma, Sanjeev.; Chakrabarti, S.K. Effect of temperature and cropping sequence on the infestation pattern of *Bemisia tabaci* in potato. *Indian J. agric. Sci.* **2019**, *89*, 1802-1807.
10. Nomikou, M.; Janssen, A.; Schraag, R.; Sabelis, M.W. Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. *Exp. Appl. Acarol.* **2001**, *25*, 71-291.
11. Urbaneja, A.; Sanchez, E.; Stansly, P.A. Life history of *Eretmocerus mundus*, a parasitoid of *Bemisia tabaci*, on tomato and sweet pepper. *BioControl* **2007**, *52*, 25-39.
12. Sani, I.; Ismail, S.I.; Abdullah, S.; Jalinas, J.; Jamian, S.; Saad, N. A review of the biology and control of whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae), with special reference to biological control using entomopathogenic fungi. *Insects* **2020**, *11*, 619.
13. Mishra, M.; Saurabh, S.; Maurya, R.; Mudawal, A.; Parmar, D.; Singh, P.K. Proteome analysis of *Bemisia tabaci* suggests specific targets for RNAi mediated control. *J. Proteom.* **2016**, *132*, 93-102.

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12. Post-Harvest Technology of Seed Crops

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Abstract:

The production and storage of healthy seeds and grains have become increasingly important in recent times, as they are vital for achieving high crop yields in subsequent seasons. However, during the storage process, significant losses of seeds can occur due to various biological and nonbiological factors. These losses not only affect the market value of the seeds but also impact their quality. To address this issue, it is crucial to examine the factors that contribute to seed losses during storage.

By understanding these factors, appropriate measures can be taken to minimize losses and ensure the quality and safety of the crop. Implementing careful postharvest handling techniques plays a critical role in maintaining seed quality. To assess losses during the storage process and mitigate them effectively, suitable methods need to be established. These methods should be efficient, cost-effective, and convenient to implement. While the focus of this chapter is on the needs of developing countries, the information provided can also be relevant in more industrialized countries. The chapter provides a comprehensive review of postharvest techniques that can be employed to maintain seed quality. These techniques aim to achieve high-quality seeds that meet both national and international standards, thereby meeting the demands of suppliers. The emphasis is on identifying better, economical, convenient, and productive methods that can be adopted in various contexts.

12.1 Introduction:

Post-harvest technology plays a crucial role in ensuring the quality and safety of cereals, pulses, and oilseeds after they are harvested. It encompasses a range of practices, techniques, and tools designed to minimize losses, enhance storage life, and add value to these agricultural commodities. Cereals, pulses, and oilseeds are staple food crops that are vital for global food security. However, improper handling and storage practices during and after harvest can result in significant losses, both quantitatively and qualitatively.

Factors such as moisture content, temperature, pests, and diseases can contribute to spoilage, degradation, and reduced nutritional value of these commodities. Post-harvest technology aims to address these challenges and maximize the efficiency and profitability of the entire supply chain. One of the primary goals of post-harvest technology is to minimize post-harvest losses. This involves adopting appropriate harvesting techniques, such as using modern machinery to reduce damage to the crops and minimize losses during threshing and cleaning. Additionally, efficient drying methods are employed to reduce moisture content to safe levels, preventing the growth of molds and fungi [1-4].

Storage is another critical aspect of post-harvest technology. Proper storage conditions help maintain the quality of cereals, pulses, and oilseeds over an extended period. Processing is an integral part of post-harvest technology, particularly for oilseeds and pulses. It involves activities such as cleaning, grading, sorting, milling, and oil extraction. These processes help remove impurities, improve hygiene, enhance market value, and create value-added products.

The integration of post-harvest technology in cereals, pulses, and oilseeds not only enhances food security but also contributes to rural livelihoods and economic development. It improves the income of farmers by reducing losses and increasing market opportunities for higher-quality produce [5].

12.2 The Post-Harvest Technology for Cereals:

Cereals are an essential component of human diets worldwide, including in India. They are the seeds or grains of grasses and are cultivated to obtain the fruit or seed, which is commonly known as the caryopsis. The caryopsis consists of three main parts: the germ, endosperm, and bran. Cereals such as wheat, rice, maize, oat, barley, rye, millet, and sorghum are of great importance in India, providing a significant portion of the staple diet for many people, particularly those in low-income groups and rural areas. While each type of cereal crop requires specific post-harvest treatment based on its unique characteristics, there are certain general principles that apply to most cereals. These principles are aimed at preserving the quality, reducing losses, and enhancing the nutritional value of the harvested grains.

One important aspect of post-harvest treatment is the preparation of harvested cereal grains for storage. This involves activities such as cleaning, drying, and conditioning. Cleaning ensures the removal of impurities such as dirt, stones, chaff, and broken grains. Drying is crucial to reduce the moisture content of the grains, as excessive moisture can lead to spoilage and mold growth during storage. Conditioning involves equalizing the moisture levels within the grain mass to prevent moisture migration and subsequent quality deterioration.

Primary processing is another key stage in the post-harvest treatment of cereals. It involves further treatment of the grains to clean them, remove the husk or outer covering, or reduce the particle size. Primary processing steps can include dehusking or hulling, threshing, winnowing, and milling. Dehusking or hulling removes the outer covering of the grain, such as the husk or hull, which is often inedible or undesirable. Threshing separates the grains from the straw or stalk, while winnowing helps remove chaff or lighter impurities through air separation. Milling involves grinding or crushing the grains to produce various products such as flour, semolina, or cracked grains.

The third stage, known as secondary processing, involves transforming the grains into edible products. This stage typically includes processes such as fermentation, baking, puffing, flaking, frying, and extrusion. These techniques add value to the primary cereal products and offer a wider variety of food options, including bread, cakes, pastries, breakfast cereals, snacks, and more [6].

The post-harvest technology for cereals includes the following methods:

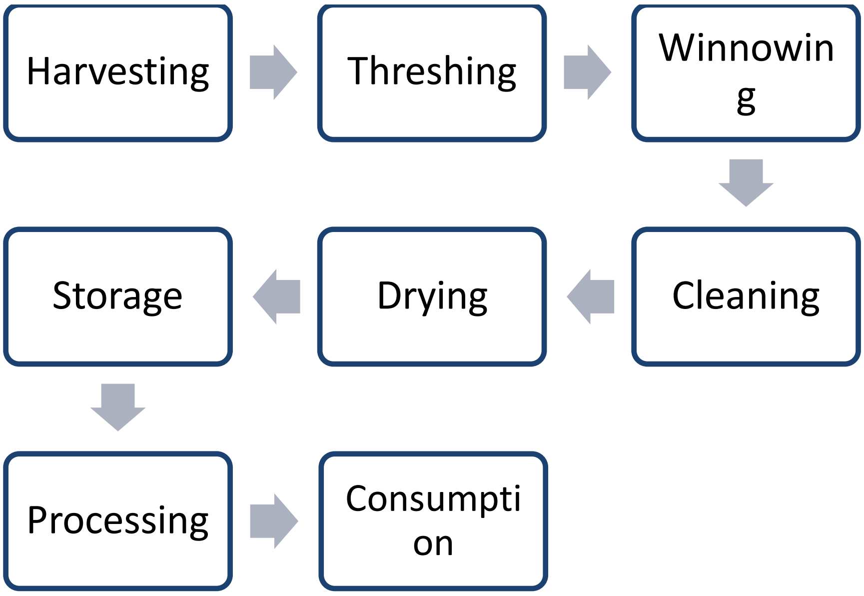

Figure 12.1: The post-harvest technology for cereals flow chart

12.2.1 Harvesting:

The timing of cereal crop harvesting is crucial and should be determined based on the crop's maturity stage and the prevailing climatic conditions. The timing of harvest can greatly impact the quality and storage characteristics of the grain. Harvesting cereals typically begins before the grains reach full maturity. Harvesting too early can result in underdeveloped grains with lower yields and reduced quality. However, allowing the crop to remain in the field until it is fully ripe can increase the risk of mold growth, insect infestation, and unfavorable weather conditions, which can lead to grain damage and deterioration.

Figure 12.2: Mechanical and manual harvesting of wheat

12.2.2 Milling:

Traditional milling technology involves several steps:

A. **Washing:** The grains are washed or rinsed briefly to soften the outer layers and then hulled in one step. This helps remove dirt, dust, and impurities from the grains.
B. **Pounding:** The hulled grains are pounded in a wooden mortar to detach the hulls and bran from the grain. This process involves manual labour and is typically done for a few minutes.
C. **Sun-drying:** The pounded grains are spread out in a shallow layer to dry in the sun. This helps reduce moisture content and facilitates the subsequent winnowing process.
D. **Winnowing:** The dried grains are subjected to winnowing, which involves tossing them in the air or using wind to separate the lighter hulls and bran from the heavier grains. This process relies on the difference in weight and density between the grains and the husks.
E. **Washing:** After winnowing, the grains are washed again, this time for a longer duration. This washing step removes any remaining hulls through flotation and also increases the moisture content of the grains.
F. **Resting:** The washed grains undergo a conditioning period where they are exposed to the sun for a brief period of time, typically 1 to 2 hours. This step helps stabilize the moisture content and further prepares the grains for the subsequent steps.
G. **Pounding:** The conditioned grains are pounded once again to remove any remaining hulls or impurities. This step is similar to the initial pounding but may be shorter in duration.
H. **Sieving:** The flour produced from the previous pounding step is hand-sieved to separate any coarse particles or residue. The collected flour is retained, while the residue is returned for further pounding.

Modern milling techniques may involve additional steps such as tempering, debranning, conditioning, grinding, and sifting, depending on the specific requirements and desired end products. These processes are often integrated into a continuous flow system, where the grains move through various stages without manual intervention, resulting in higher throughput and consistent product quality.

12.2.3 Threshing:

Threshing is an important step in the cereal production process, specifically in separating the grains from the rest of the plant material. It typically involves three main operations:

a. **Separating the grain from the panicle:** In this step, the harvested cereal crop, which includes the panicles (seed heads) containing the grains, is subjected to mechanical or manual methods to detach the grains from the panicle. Traditional methods include beating the panicles with sticks or threshing flails, which separate the grains through impact or mechanical agitation. Modern threshing machines, such as combine harvesters, use a combination of rotating drums and concaves to separate the grains from the panicles more efficiently.

b. **Sorting the grain from the straw:** Once the grains are separated from the panicles, they are still mixed with straw, stalks, and other plant debris. The next step involves separating the grains from this material. Mechanical methods like shaking or vibrating machines, known as straw walkers or sieves, are commonly used in modern threshing machines to separate the straw from the grains. The straw is usually discharged from the machine while the grains continue through the system for further processing.
c. **Winnowing the chaff from the grain:** After the straw is separated, the grains are still covered with an outer protective layer called chaff. Winnowing is the process of separating the chaff from the grains. Traditionally, this was done by tossing the grains and chaff in the air, allowing the wind to blow away the lighter chaff while the heavier grains fell back down. In modern farming, mechanized winnowers or air separators are employed. These machines use air currents to blow away the chaff, while the grains, which are heavier, fall down and are collected for further processing or storage.

12.2.4 Drying:

Drying is an essential step in preparing cereals for storage or further processing. Proper drying helps reduce the moisture content of the grains, which is crucial for preventing mold growth, spoilage, and maintaining their quality [10,11]. While sun drying is a cost-effective method in which involves spreading the cereal grains in a thin layer on clean and dry surfaces, such as concrete pavements, drying beds, or mats.

The grains are exposed to the sun's heat and air circulation, allowing moisture to evaporate. Sun drying is often used in regions with abundant sunlight and low humidity [6,9]. Cereal grains must be dried to 10-15% moisture before storage.

Figure 12.3: Mechanical and Sun Drying of Wheat

12.2.5 Storage:

Storing dried cereal grains properly is crucial to maintain their quality and prevent spoilage. Here are some key points regarding the storage of cereal grains:

a. **Inspection and moisture content testing**: Regular inspection of stored grains is necessary to detect any signs of spoilage, such as mold growth, insect infestation, or unusual odors. Additionally, monitoring the moisture content of the grains is essential. Moisture levels should be periodically tested using moisture meters to ensure they remain within the recommended range for safe storage.
b. **Redrying:** If stored grains have picked up moisture and their moisture content exceeds the safe storage range, they must be re-dried to prevent spoilage. Re-drying can be done using artificial dryers, as mentioned earlier, to lower the moisture content back to the appropriate level for storage.
c. **Insect and rodent control:** Cereal grains are susceptible to insect infestation and rodent damage. To protect the stored grains, insecticides may be used to control insects and prevent their proliferation. These insecticides should be applied following approved guidelines and regulations to ensure food safety. Additionally, it's crucial to store the grains in rodent-proof containers or structures to prevent access by rodents, which can cause contamination and significant losses.
d. **Temperature and ventilation**: Proper temperature and ventilation conditions in the storage area are important for maintaining grain quality. Generally, cool temperatures (around 10-15°C or 50-59°F) are recommended to slow down biological activities and reduce the risk of spoilage. Adequate ventilation helps prevent the accumulation of moisture and allows for air circulation, helping to maintain grain quality and reduce the risk of mold growth [8].
e. **Good storage practices:** Other good storage practices include maintaining cleanliness in the storage area, preventing cross-contamination between different grain batches, and implementing a first-in, first-out (FIFO) system to ensure that older grain is used before newer batches. Additionally, periodic monitoring of stored grains, including temperature, moisture content, and pest activity, is essential to identify any issues early and take appropriate actions [13].

12.3 The Post-Harvest Technology for Pulses:

Pulses are the dried edible seeds of plants in the legume family, which includes crops like lentils, chickpeas, beans, and peas. These crops are primarily cultivated for their dry seeds rather than their fresh produce.

One of the key benefits of pulses is their ability to fix nitrogen from the atmosphere into the soil with the help of symbiotic bacteria. This nitrogen fixation process improves soil fertility and reduces the need for synthetic fertilizers, making pulses environmentally sustainable crops. Pulses come in various shapes, sizes, and colours, depending on the specific type of legume. They can be consumed in different forms, including whole or split, and can be prepared in various culinary dishes around the world. Pulses can also be ground into flours, which are used in baking and cooking, or further processed to obtain specific fractions such as protein, fiber, and starch, which have diverse applications in the food industry.

Post-harvest technology for pulses involves a series of processes and techniques to handle, store, process, and preserve pulses after they are harvested. The main objectives of post-harvest technology for pulses are to maintain their quality, prevent losses, and enhance their value.

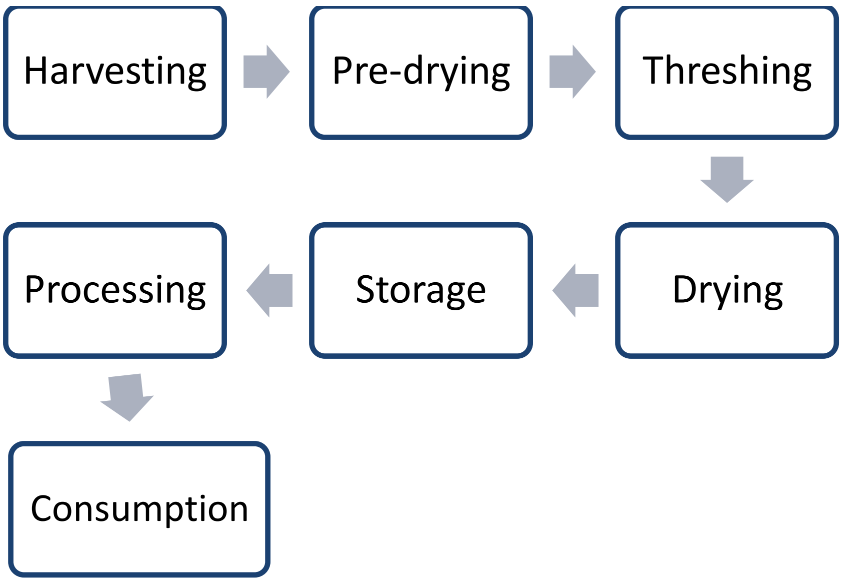

Figure 12.4: The Post-Harvest Technology for Pulses Flow Chart

12.3.1 Harvesting:

Harvesting of pulse crops can be done by hand or by machines, depending on the scale of cultivation and available resources. Hand harvesting is a common practice, where the plants are pulled up and allowed to pre-dry in the sun. This is typically done early in the morning when the dampness of the night helps minimize shattering losses. In some cases, chemical defoliants may be applied to the plants before harvesting. This treatment helps speed up the drying process and reduces the quantity of plant matter, making threshing operations more efficient.

Pulses are an essential component of a vegetarian diet, particularly in countries like India where they are a major source of protein. Pulses such as Bengal gram (chickpeas), pigeon pea, black gram, green gram, and lentils are widely consumed. These pulses are often dehusked and split, as this processing method helps enhance their digestibility and makes them rich in proteins.

12.3.2 Pre-Drying:

Pre-drying is an important stage in the post-harvest system of pulses. It refers to the process of drying the harvested product before proceeding with the next operation, which is typically threshing. The purpose of pre-drying is to ensure that the harvested pulses are adequately dried to facilitate efficient threshing and minimize the risk of spoilage.

Proper drying is crucial to prevent the growth of molds, fungi, and bacteria, which can lead to quality deterioration and loss of the crop. During pre-drying, the harvested pulses are exposed to air and sunlight to reduce their moisture content. This can be achieved by spreading them in thin layers on clean surfaces, such as drying mats, concrete yards, or tarpaulins. The pulses are turned regularly to ensure uniform drying and prevent the formation of hotspots or moisture pockets.

12.3.3 Threshing:

Threshing is the process of separating the grains from the plants after harvesting. It is a critical operation in the post-harvest handling of pulses and needs to be carried out carefully to preserve the quality of the product and minimize losses.

Threshing can be performed using various methods, including manual, animal-powered, or machine-powered techniques.

a. **Manual threshing:** Manual threshing involves beating the harvested plants to separate the grains. This can be done by hand using tools like sticks, flails, or by trampling the plants underfoot. The aim is to remove the grains from the plants while minimizing breakage and damage.
b. **Animal-powered threshing:** In some traditional agricultural practices, animals such as bullocks or horses are used to trample or walk over the harvested plants. The weight and movement of the animals help to separate the grains from the plants.
c. **Machine-powered threshing:** Modern agricultural practices often employ threshing machines like combine harvesters or specialized threshers. These machines use mechanical means, such as rotating drums or blades, to separate the grains from the plants. Machine threshing is usually faster and more efficient, particularly for larger-scale operations.

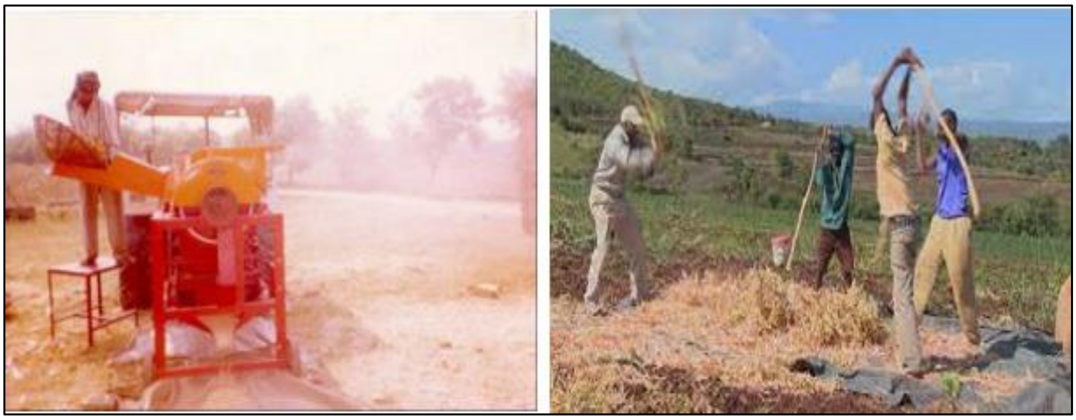

Figure 12.5: Mechanical and Manual Threshing of Wheat

Regardless of the method used, care should be taken during threshing to avoid excessive breakage of grains or husks. The objective is to separate the grains intact while minimizing damage, as broken grains are more susceptible to insect infestation and mold growth.

12.3.4 Drying:

After threshing, the moisture content of grains is often higher than the desired level for safe storage, typically around 13-14%. The drying process is crucial to reduce the moisture content of the grains to the appropriate level for storage and processing.

There are two primary methods used for drying grains:

A. Natural drying: Natural drying involves exposing the threshed grains to air, either in the sun or shade. The grains are spread in thin layers on a drying floor or platform, allowing them to come into direct contact with the air.

The duration of natural drying can vary depending on factors such as weather conditions, initial moisture content, and the desired moisture level for safe storage. Regular turning of the grains is necessary to ensure uniform drying. Natural drying is commonly practiced in areas with adequate sunlight and low humidity [7].

B. Artificial drying: In situations where natural drying is not feasible or practical, artificial drying methods are employed. Artificial drying involves the use of equipment to facilitate the drying process [12]. There are two main types:

a. **Heated air drying:** This method utilizes heated air to rapidly remove moisture from the grain. Grain dryers, such as batch dryers or continuous flow dryers, blow heated air through the grain mass, promoting evaporation and drying. The temperature and airflow are controlled to ensure efficient and uniform drying while avoiding damage to the grains.
b. **Unheated air drying (dehumidification)**: In this method, unheated or slightly heated air is circulated through the grain mass using dehumidifiers or fans. The air's relative humidity is reduced, allowing it to absorb moisture from the grain, resulting in drying. Unheated air drying is suitable for regions with high humidity or when temperature-sensitive crops are being dried.

12.3.5 Storage:

The storage process is crucial for maintaining the quality and preserving the edible condition of pulses. However, pulses are more challenging to store compared to cereals because they are more susceptible to damage from insects and microorganisms.

This can lead to both quantitative losses (reduced quantity) and qualitative reduction (diminished nutritive value) of the stored pulses. Insects, particularly weevils, are a common cause of damage to stored pulses. Weevils are prolific pests that breed rapidly and can cause serious deterioration in the nutritive value of the grains.

Insect infestation not only results in grain losses but also increases milling losses due to breakage and powdering of the grains. The storage conditions play a vital role in preventing infestation and maintaining the quality of stored pulses. Here are some key considerations:

a. Temperature: Pulses should be stored in cool conditions, preferably below 15°C, to slow down insect activity and reduce the risk of mold growth.

b. Relative humidity (RH): Maintaining low humidity levels is crucial, as higher humidity promotes the rapid proliferation of insects. The ideal RH for pulse storage is below 70%. Using dehumidifiers or moisture control methods can help maintain suitable humidity levels.

c. Clean and dry storage structure: The storage structure should be clean, dry, and free from pests, molds, and other contaminants. Regular cleaning and fumigation of storage facilities are important to prevent infestation.

d. Packaging: Pulses should be stored in appropriate packaging materials that provide protection against moisture, insects, and rodents. Common packaging options include jute bags, polypropylene bags, or hermetically sealed containers.

e. Pest control measures: Integrated pest management practices, such as the use of pheromone traps, insecticides, or natural pest control methods, can be employed to prevent and control insect infestation.

f. Monitoring: Regular monitoring of stored pulses is essential to detect any signs of infestation or quality deterioration. This can involve visual inspections, sampling, and checking moisture content.

By implementing proper storage practices and maintaining suitable conditions, the shelf life of pulses can be significantly extended, minimizing losses and preserving their nutritive value [13].

12.4 The post-harvest technology of Agriculture Oil Seeds:

Oilseeds are indeed seeds that are primarily cultivated for the production of edible oils. They are considered high-value agricultural commodities due to their use in the production of refined edible oil products.

With the increasing global population, there is a growing demand for high-quality seed oils. Sesame is an important oilseed crop because of its excellent health effects, primarily attributed to the presence of polyunsaturated fatty acids in sesame oil.

These fatty acids are beneficial for human health. Sesame oil adds nutritional value to the diet by providing high-quality protein and vegetable oil, along with oil-soluble vitamins such as vitamin A.

In India, some major oilseeds include groundnut (peanut), soybean, rapeseed mustard, linseed, sesamum (sesame), and castor. Among these, groundnut and rapeseed mustard are the dominant oilseeds, accounting for approximately 85 percent of the total oilseed production in the country [13].

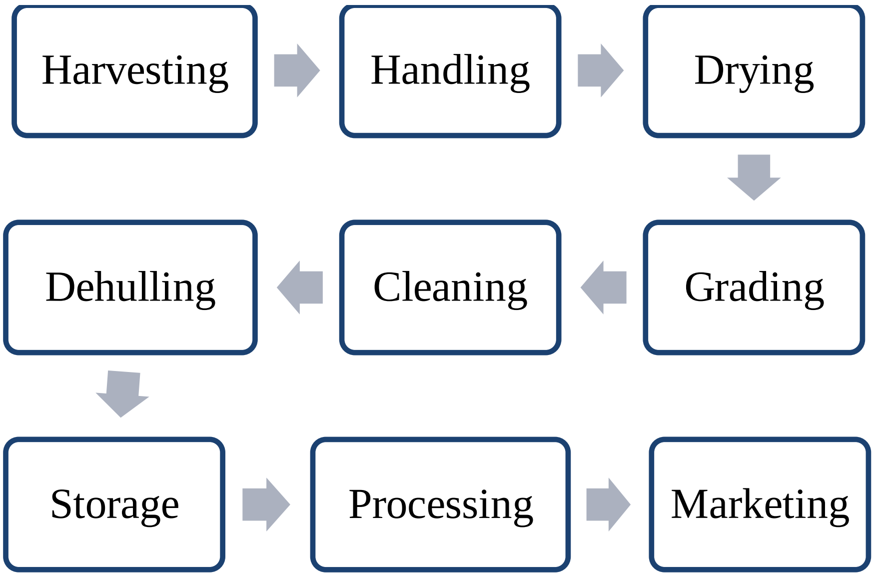

Figure 12.6: The post-harvest technology for Oil Seed flow chart

Post-harvest technology of oilseeds encompasses various techniques and practices aimed at reducing losses and enhancing the quality and value of oilseed crops and their products. Some important aspects of post-harvest technology for oilseeds include:

12.4.1 Handling, Drying, and Storage:

Proper handling, drying, and storage are indeed crucial for oilseeds to maintain their quality and prevent deteriorative processes, enzyme action, and microbial spoilage. Here are the key aspects of handling, drying, and storage for oilseeds:

A. Grading:

Grading of oilseeds is essential to assess their overall quality, moisture content, freedom from impurities, and to evaluate their milling quality in terms of oil yield and quality. Grade specifications for different oilseeds consider factors such as non-prime seeds (damaged, insect-infested, slightly damaged, shrivelled, immature), impurities or foreign matter, moisture content, oil content, and quality indices of the extracted oil (colour, acid value, iodine value, etc.).

B. Cleaning:

Oilseeds often contain various foreign materials such as sand, stones, stalks, weed seeds, and foliage, which are accumulated during harvesting, handling, and transportation. It is important to clean the seeds before storing them. Cleaning processes may involve mechanical separation techniques like sieving, winnowing, aspiration, or using specific equipment like gravity separators, destoners, and sieves to remove impurities and foreign matter.

C. Drying:

Proper drying of oilseeds is essential to reduce their moisture content to a safe level for storage and processing. Drying helps prevent microbial growth, enzyme activity, and the onset of deteriorative processes. The specific drying methods may vary depending on the type of oilseed and available resources. Natural drying, involving exposure to air and sunlight, can be suitable under favorable weather conditions. Artificial drying methods, such as heated air dryers or dehumidifiers, may be used in situations where natural drying is not feasible or rapid drying is required. Care should be taken to ensure that the drying process does not adversely affect the quality of the oilseeds.

D. Storage:

Proper storage conditions are crucial for maintaining the quality and preventing spoilage of oilseeds. Here are some important considerations:

a) Temperature and humidity: Oilseeds should be stored in cool and dry conditions to minimize the risk of microbial growth, insect infestation, and oil rancidity. The ideal storage temperature depends on the specific oilseed but is generally below 15°C.
b) Moisture control: Oilseeds should be dried to a safe moisture content level before storage. The moisture content for different oilseeds may vary, but it is generally recommended to keep it below the critical level that allows microbial growth and oil deterioration.
c) Packaging: Oilseeds should be stored in clean, moisture-proof, and insect-proof containers such as jute bags, polypropylene bags, or hermetically sealed containers to protect them from external contaminants and pests.
d) Pest control: Implementing pest control measures, such as regular monitoring, proper cleaning, fumigation, and using insecticidal treatments, can help prevent insect infestation and protect the stored oilseeds.

Regular monitoring of stored oilseeds is essential to detect any signs of spoilage or quality deterioration. By following proper handling, drying, and storage practices, the quality of oilseeds can be preserved, ensuring better processing and production of high-quality oil products.

12.4.2 Processing:

Oilseeds can undergo various processing techniques such as crushing, extraction, refining, and packaging. Mechanical pressing or solvent extraction methods are commonly used to extract oil from oilseeds.

12.4.3 Value Addition:

post-harvest technology enables the production of value-added products from oilseeds. This can include the production of edible oils, protein-rich oilseed meals for animal feed, oilcake-based products, and oilseed by-products such as lecithin.

12.4.4 Quality Control:

Implementing quality control measures throughout the post-harvest process helps ensure that the oilseed products meet the desired standards in terms of purity, oil content, and nutritional value [13].

12.5 Conclusion:

The post-harvest technology of cereals, pulses, and oilseeds plays a vital role in preserving the quality and nutritional value of these agricultural commodities after they are harvested. It involves a series of practices and techniques aimed at reducing losses, enhancing storage life, maintaining food safety, and maximizing economic returns. By implementing these techniques, farmers, processors, and consumers can benefit from improved economic returns, safe and nutritious food products, and sustainable agricultural practices.

12.6 Reference:

1. Delouche JC, Caldwell WP. Seed vigor and vigor tests. Proceeding of Association of Official Seed Analyst. 1960; 50:124–129.
2. Delouche JC. Planting seed quality. In: Proceeding of 1969 Beltwide Cotton Prod.-Mech. Conference. New Orleans. January 1969. p. 16–18.
3. Grabe DF. Agronomic significance of seed deterioration. Agronomy Abstract. 1965; 57:40.
4. Woodstock LW. A respiration test for corn seed vigor. Proceeding of Association of Official Seed Analyst. 1966; 56:95–98.
5. Gregg BR, Billups GL. Seed Conditioning Technology Part A. Science Publishers. USA. 2010, Vol. 2, p. 1–2.
6. Boxall RA, Brice JR, Taylor SJ, Bancroft RD. Crop post-harvest, science and technology, volume 1, principles and practice. In: Golob P, Farrell G, Orchard E (Eds) Crop Post Harvest: Science and Technology. Blackwell Science Ltd, Oxford, UK. 2002. p. 141–204. doi: 10.1002/9780470751015.ch5.
7. Colliver DG, Brook RC, Peart RM. Optimal management procedure for solar grain drying. American Society of Agricultural Engineers. Chicago. 1978; 12:78–35.
8. Harrington JF. Seed storage and longevity. Cited in: Kozlowski TT, Seed Biology. 1972; 3:145–245.
9. [9] Kiaya V. Post-harvest Losses and Strategies to Reduce Them. New York: Action Contre la Faim (ACF International). 2014.
10. [10] López J, Uribe E, Vega-Gálvez A, Miranda M, Vergara J, Gonzalez E, Di Scala K. Effect of air temperature on drying kinetics, vitamin C, antioxidant activity, total phenolic content, non-enzymatic browning and firmness of blueberries variety Of Neil. Food and Bioprocess Technology. 2010; 3:772–777.
11. Mujumdar AS, Law CL. Drying technology: Trends and applications in post-harvest processing. Food and Bioprocess Technology. 2010; 3:843–852.
12. Chen XD, Mujumdaer AS (Eds) Drying Technologies in Food Processing. Oxford: Blackwell. 2008.
13. https://www.agrifarming.in/post-harvest-technology-of-cereals-pulses-and-oilseeds

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13. Role of Artificial Intelligence in Agricultural Marketing

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Abstract:

Artificial Intelligence (AI) has emerged as a transformative force across various industries, and its application in agriculture is rapidly gaining momentum. This abstract delves into the pivotal role that AI plays in revolutionizing agricultural marketing. As the agricultural sector grapples with the challenges of global food security, sustainable farming, and evolving consumer preferences, AI offers innovative solutions to enhance market efficiency, product quality, and farmer profitability. It explores how AI technologies, such as machine learning, data analytics, and predictive modeling, are reshaping the landscape of agricultural marketing. AI-driven insights facilitate improved decision-making at every stage of the supply chain, from planting and harvesting to distribution and consumer engagement. The integration of Artificial Intelligence in agricultural marketing represents a paradigm shift that empowers stakeholders to navigate the complexities of the modern food industry efficiently and sustainably. As AI continues to evolve, its role in agriculture is expected to expand, offering even greater opportunities for increased productivity, profitability, and environmental stewardship. This abstract underscore the critical importance of embracing AI as a transformative force in shaping the future of agricultural marketing.

13.1 Introduction:

Nowadays, the quick improvement of innovation; has driven to the broad utilize of advanced applications such as blockchain, the Web of Things, and manufactured insights in numerous divisions and to alter the conventions of doing commerce both exclusively and organizations (Gür, 2022). In specific, manufactured insights, recognized as the ponder of how to construct or program computers to empower them to what minds can do (Broadbent 1993; Boden, 1996 is one of these modern advances, and is utilized in generation and showcasing forms in numerous divisions. It is conceivable to see manufactured insights applications in numerous divisions such as wellbeing administrations, back, excitement, vitality, tourism, generation, defense industry, and car. Depending on the propels in counterfeit insights innovations, vital advancements are watched in numerous segments and manufactured insights has ended up one of the foremost imperative issues on the plan in numerous nations (Akyilmaze2021) Another division where counterfeit insights has begun to be utilized is the rural division. After the 2000s, the issues of agrarian generation and satisfactory nourishment supply, which are shown as one of the foremost critical issues of the thousand years, are at the beat of the plan of policymakers. The worldwide plague experienced particularly between 2020-2022 and the ensuing tall swelling issue caused a genuine increment in input costs for endeavors and producers working on agrarian generation and showcasing. To manage with these issues and to survive within the division, most undertakings and little makers gave up a few of their capital and went down the street of shrinkage.

It is anticipated that the world populace will increment to over 10 billion by 2050. To meet the nourishment needs of the increasing population and to meet other needs, agribusiness and nourishment generation must increment by 70%. Usually, exceptionally troublesome for the agri-food industry. To begin with of all, sufficient arable land will be required. Considering the scarcity of assets, climate alter, scourges and other socio-economic variables; it is vital to calculate the wants accurately and to utilize the proper estimation procedures in all agrarian generation and promoting forms (Ayed and Hanana, 2021).

Agriculture is vital for each nation’s financial segment. Everybody is straightforwardly and by implication subordinate on agrarian items for regular needs. The request for nourishment is rising beside the worldwide populace on a day-by-day premise. At this point, the farmers' conventional procedures are inadequately to meet the request.

A few novel robotization methods are required to satisfy the current demand universally for agriculture produce. Manufactured insights are playing a really vital part within the agribusiness segment for changing the farming industry.

AI has the potential to alter conventional agribusiness by expanding proficiency of time, labor, and assets, improving natural maintainability, giving exactness in checking and information investigation for superior farming comes about. AI valuable in agribusiness from seed to seed has progressing trim generation, security, harvests, preparing and showcasing. Various Hi-tech computers-based devices and Agri-bots have as of now been presented to decide different significant parameters for improved agriculture. In this article, we'll examine how Fake Insights is revolutionizing agribusiness by utilizing more productive strategies beside the challenges in AI selection.

13.2 Use of AI in Agriculture Marketing:

Farmers would confront various challenges, fair as they would with conventional rural strategies. AI is being broadly utilized in this segment to address these challenges. Counterfeit insights have gotten to be a game-changing innovation in agribusiness. AI benefits agriculturists in a assortment of ways, which are point by point underneath.

Environmental protection: - AI permits for more productive ways to create, gather and offer edit items, as well as a center on assessing inadequate crops and making strides agrarian hones for eco-friendly edit generation. AI gives us with more exact information almost creepy crawly bug invasions, illnesses and weeds, as well as different management strategies. AI strategies based on mechanical autonomy, computer vision, and machine learning may help agriculturists in splashing chemicals as it were where the bugs are, lessening the utilize of chemical substances splashed on the whole zone.

Environmental protection through pesticide diminishment may be a major useful advantage of AI innovation. Subsequently, AI innovation helps composers in bother control and pesticide buildup lessening.

Weather and cost determining: - Climate plays an critical portion in agrarian choice making and arranging. Counterfeit insights innovation may permit agriculturists to get meteorological information, which would be accommodating for convenient sowing, gathering, splashing and other agronomic hones; expanding trim surrender and benefits by diminishing trim peril. Climate forecasts can to offer assistance with bother administration; taking safety measures by receiving hones on time, decreases input costs and abdicate misfortune. Ranchers can utilize cost determining to induce a clearer idea of trim costs within the coming weeks, permitting them to maximize benefit.

Detection of insect-pests and disease: -AI strategies are able to screen creepy crawly bothers and maladies, and are accommodating in recognizing bugs as well as ranges that are affected by them. Ready to presently distinguish plant maladies and bothers utilizing picture acknowledgment innovation based on profound learning.

This method builds models that can "keep an eye" on plant wellbeing by utilizing picture classification, location, and division strategies. By utilizing AI methods checking, discovery and administration of creepy crawly bugs and plant illness are made simpler and eco-friendly. After using AI-based methods, there's a recognizable diminish within the amount and number of pesticide applications; able to precisely recognize and check a expansive number of creepy crawlies. AI computer vision encompasses a shinning future for following the condition of our nourishment frameworks. In expansion to bringing down labor wasteful aspects, it too does so without compromising the exactness of the information.

Soil wellbeing checking- Nowadays, great soil wellbeing is basic to meet the expanding request for nourishment. Be that as it may, utilizing customary strategies, we are incapable to decide the soil properties for each trim. Manufactured insights (AI) and machine learning (ML) innovations have made it conceivable to track soil characteristics in ranches, such as quality, richness, microorganism, and supplement insufficiency, as well as vegetation design, either through picture capture with a camera acknowledgment apparatus or by employing a profound learning-based apparatus.

Visual discernment AI can analyze and translate this information much faster than people in arrange to screen trim wellbeing, make precise abdicate forecasts, and recognize edit ailing health. AI models can caution agriculturists to specific issue zones so they can react right absent.

Innovation in collecting strategies- Trim collecting requires a part of work and exertion. AI based computer vision show is accommodating in watching and evaluating trim development without having to contract more individuals. An assortment of agribots have as of now been created to mechanize gathering; diminish misfortunes, costs, natural impact, and nourishment squander. AI-powered devices beat human agrarian laborers in terms of speed, trouble, and exactness. A critical parcel of that work is presently being dealt with by AI with ease and exceptional productivity.

Intelligent spraying- By utilizing UAVs prepared with computer vision AI, ecofriendly bug administration is conceivable as required sum of pesticides or fertilizers to be showered consistently in target splashing zone. With real-time acknowledgment of target splashing zones, UAV sprayers can work with extraordinary precision in terms of the region and sum to be showered. As a result, able to reduce creature poisonous quality, common asset defilement, and pesticide buildup in crops.

Virginia Tech has created a shrewd splash framework based on servo engine-controlled sprayers that utilize computer vision to recognize weeds, analyzes the measure, shape, and color of each troublesome plant in arrange to convey correct sums of herbicide.

Livestock health monitoring: - We can't disregard the significance of creatures in our agribusiness framework and they tend to require a bit more following than plants. Cattle Eye is a great outline of an AI-first agrarian company.

Administration of cowshed made less demanding by utilizing cameras and rambles (UAVs) for information collection. Following creature wellbeing and behavior, distinguishing bizarre behavior and observing vital exercises such as giving birth are all made conceivable with ease and exactness by utilizing overhead cameras and computer vision calculations.

Farther following and perception of cattle can be valuable for rapidly spotting issues and advising ranchers approximately the wellbeing of their animals and their get to nourishment and water. Benefits and Challenges of AI in horticulture Points of interest.

13.3 Benefits and Challenges of AI in Agriculture Marketing:

Advantages:

- Farming machinery with AI capabilities empowers makers to create more crops with less exertion and cost. With AI and mechanization, ranches can total assignments without contracting more specialists. A few illustrations incorporate driverless tractors, cleverly water system and treating frameworks, shrewd splashing, vertical cultivating computer program, and AI-based gathering robots.
- AI helps ranchers in overcoming key rural challenges such as advertise request examination, cost determining, and deciding ideal periods for sowing and collecting crops based on climate estimating.
- Farmers can make way better choices and conduct more viable cultivating with the assistance of eco-friendly AI methods. Moreover, it empowers ranchers to decide the exact locales that require pesticide application, fertilization, and water system, making a difference them to maintain a strategic distance from overusing assets and chemicals on their crops.
- The utilize of progressed AI-based advances has other benefits on the agri-food supply chain, such as cutting representative preparing costs, diminishing the time required to fathom issues, diminishing the sum of human blunders, bringing down human intercession, and giving computerized great, exact, and robust decision-making at the proper time at a low fetched.

13.4 Challenges of AI Adoption in Agricultural Marketing:

Although there is a parcel of potential here, there are still a few impediments.

- The lion's share of ranchers around the world are new with the utilize of AI-enabled instruments and arrangements.
- The tall cost of these applications, which may increment costs and input costs, may be a advance issue. These strategies are too futile for small-scale ranches or country zones.
- Another case of a innovative challenge is the truth that robots can as it were perform the errands for which they have been outlined or modified, and in the event that those assignments are changed, they regularly come up short or deliver futile comes about.
- The risk of unemployment is the greatest social challenge; in reality, robots and brilliantly machines seem take over most of the tedious jobs and tasks; as a result, human inclusion is diminishing, which is able posture a genuine challenge to business benchmarks.
- Adopting AI and imaginative innovations in farming for immature countries can be troublesome.

13.5 Use of Artificial Intelligence in Agriculture Production and Marketing Process:

Artificial intelligence is utilized in showcase examination, client recognizable proof, showcasing technique, arranging, item administration, cost procedure, dispersion channels and supply chain administration, promoting communication, in brief, nearly all promoting exercises (Kamran, 2021:3). In this portion of the consider, instruments and innovations that utilize manufactured insights in rural generation and promoting forms are clarified with illustrations.

Pandu et al., (2022) portray the sorts of counterfeit insights utilized in farming beneath four headings: Manufactured Contract Insights (ANI): Too known as frail counterfeit insights, which incorporates the application of fake insights to as it were certain assignments. Alexa, Siri, Sofia, and Driverless cars are cases of this. Fake Common Insights (AGI): It is known as a capable fake insight that incorporates machines competent of performing any mental assignment that a human can do. For illustration, robots in farming.

Fake Super Insights (ASI): A term that alludes to the time when the capabilities of computers will outlive people. Sub-fields of counterfeit insights: Master frameworks (ES), Web of Things (IoT), Cloud computing, Machine learning, Mechanical technology, Computer vision, Common dialect handling, Profound learning, Common dialect handling, Programmed thinking, Discourse acknowledgment, and Information representations can be given as the illustrations (Pandu et al., 2022).

Robots (non-AI) have been utilized in agribusiness for very a few times. For case, draining with robots has been utilized for around twenty a long time. Be that as it may, manufactured intelligence-supported robots within the rural segment are very modern. Robots are utilized for different purposes in horticulture. These incorporate: trim disclosure, bug and weed control, gathering, splashing, pruning, draining, phenotyping, and sorting (Shamshiri et al.

2018). Within the plan of such robots, it is exceptionally imperative to be able to adjust to their environment and discover their way in field conditions. Most AI robots within the farming segment are still within the early stages of improvement, and numerous are taking shape in test offices, investigate ventures, and inquire about centers. Few of these plans have come to commercial scale, and the larger part of them cannot compete with the speed of people in carrying out their exercises (for case, weeding and collecting robots) (Shamshiri et al. 2018).

13.6 Conclusion:

Previous studies on the utilize of manufactured insights in generation and promoting forms within the rural segment were inspected and the concept of manufactured insights, which has been broadly utilized in computerized showcasing recently, is clarified within the consider. It is seen that fake insights have reached a usable level in numerous forms within the rural division.

Saxena et al., (2022) expressed in their consider in India that the appropriation of counterfeit insights within the agrarian segment may result in expanded generation capacity, decreased generation costs and more productive utilize of time.

Exact automation is needed to realize real-time administration in agribusiness and Manufactured insights will be able to help within the move from ordinary horticulture to accuracy horticulture. AI-based innovations and progressed methodologies in agribusiness increment efficiency and trim generation rate.

In any case, farming cannot be totally subordinate on manufactured insights. Within the think about, the need of information and need of mindfulness of Indian agriculturists were moreover communicated as boundaries to the utilize of unused advances within the nation. In another consider, Saxena et al., (2020) state that manufactured insights can have a critical advantage in increasing the generation capacity of agriculturists in India, whereas moreover expressing that R&D forms in rural generation will experience a perfect alter. The greatest barriers to counterfeit insights within the move from conventional horticulture to advanced horticulture is constrained get to to this innovation, tall costs and the speed of ranchers embracing this innovation. Within the think about, it is prescribed to supply ranchers with the opportunity to get to counterfeit insights advances through a reasonable and open-source stage (Saxena et al., 2020).

ABOUT THE BOOK

"Current Advances and Trends in Agricultural Sciences" is a comprehensive and up-to-date book that delves into the cutting-edge developments and emerging trends in the field of agricultural sciences. This book serves as a valuable resource for researchers, scholars, students, and professionals in the agricultural industry who seek to understand and contribute to the latest advancements in this critical field. Agriculture is a foundational pillar of human civilization. Since the dawn of history, it has been the lifeblood of societies, providing sustenance, livelihoods, and the raw materials for countless industries. Yet, in our modern world, agriculture is anything but static. It is a dynamic and multifaceted field that continually adapts to the demands of a growing global population, environmental challenges, and technological advancements. Each chapter features case studies, real-world examples, and contributions from leading experts in the respective fields. "Current Advances and Trends in Agricultural Sciences" not only provides a snapshot of the current state of agricultural research but also offers insights into the direction in which this dynamic field is heading. It is a must-read for anyone interested in the sustainable and innovative future of agriculture. This book aims to encapsulate the breadth and depth of agricultural sciences in a comprehensive and accessible manner. We recognize the diverse audience that agriculture attracts, from agronomists to economists, from biotechnologists to policymakers, and from environmentalists to consumers. With this diversity in mind, we have crafted this book to be a valuable resource for all. Each chapter is written by experts in their respective fields, providing in-depth insights, research findings, and practical knowledge. Furthermore, we have strived to present this information in a way that is engaging, informative, and thought-provoking.

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