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RESEARCH AND REVIEWS IN AGRICULTURE SCIENCE VOLUME V

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PREFACE

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

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

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

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

Editors

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OBSERVATIONAL STUDIES ON *RIHIRBUS TROCHANTERICUS* AND ITS ECONOMIC IMPORTANCE (HEMIPTERA: REDUVIIDAE: HARPACTORINAE)

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Abstract:

Rihirbus trochantericus belong to family Reduviidae and subfamily Harpactorinae of Order Hemiptera. It has been recorded as one of the common predators recorded in the cashew ecosystem and a predator of *Helopeltis spp*. *Rihirbus trochantericus* has also been observed from the cardamom plantation. The present article is an observational study on *Rihirbus trochantericus* that include its brief morphological, morphometric, its brief review and genitalic details. The paper also includes the photographs of live observed eggs, nymphs and adults.

Keywords: *Rihirbus trochantericus*, Predators, Morphological observational, Economic importance

Introduction:

The bugs belonging to genera *Rihirbus* are assassin bugs reported from the tropical parts of the Oriental region. These belong to family Reduviidae and subfamily Harpactorinae of Order Hemiptera. *Rihirbus* Stål, 1861 are medium to large sized bugs. Head is distinctly shorter than pronotum, with a spine behind base of each antenna; scape is slightly shorter or almost as long as combined length of head, pronotum and scutellum; 2^{nd} labial segment is little longer than or as long two segments combined together; anterior pronotal lobe is much shorter and narrower than posterior pronotal lobe, lateral angels of posterior lobe are sharp or rounded; apex of anterior tibia is incurved and armed with a long tooth. (Bhagyasree SN et al, 2017). These bugs have unique morphological characters such as fore tibiae with incurved tips with long tooth on apex. In bugs of genus *Rihirbus*, only apical $2/3^{rd}$ part of fore tibia is bent, the maximum bending point is located about the apical $1/6^{th}$ of the fore tibia, a short process is present at subapical part of fore tibiae against invaginating part of fore femur, and the fore tibia reaches middle of fore coxa, the basal $1/3^{rd}$ to basal half of the fore femur is depressed with inner surface densely covered with short and erect hairs. Some genera of Reduviids are also known to capture and hold on large sized preys due to different-sized spaces or gaps when fore tibia sits against the fore femur (Ping Zhao *et al*., 2014)

Species reported under *Genus Rihirbus*

1. *Rihirbus sinicus* Hsiao & Ren, 1981 – In this species, the anterior pronotal lobe is without an obtuse tubercular lobe, humeral angle of pronotum is rounded and posterior margin is nearly straight**.**
2. *Rihirbus trochantericus* Stål, 1861 In this species, the anterior pronotal lobe has a bituberculate lobe, humeral angles of pronotum are sharper and posterior pronotal margin is convex.
3. *Rihirbus kronganaensis* Truong, Bui, Ha & Cai, 2020 – The individuals are nearly all black except yellow abdomen tip. The species have been reported from the highlands of Vietnam. The post-antennal protuberance is spiny, the humeral angles of pronotum are obtuse; the foretibia is produced into a sharp spine. (Truong Xuan Lam et al.2020)**.**
4. *Rihirbus dentipes* Mayr: reported Sri Lanka**.**
5. *Rihirbus malignus* Miller, 1941: Female reported from Malaysia
6. *Rihirbus famulus* Miller, 1941: Female reported from Malaysia
7. *Rihirbus barbarus* Miller,1941: Female reported from Malaysia
8. *Rihirbus banksi* Miller,1941: Female reported from Malaysia
9. *Rihirbus insulanus* Miller,1941: Female reported from Malaysia
10. *Rihirbus discrepans* Miller,1941: Female reported from Malaysia (Syn et al.2002)

***Rihirbus trochantericus* Stal 1861**

Rihirbus trochantericus species clearly show sexual dimorphism with females larger and wider as compared to males. Their polymorphic population makes their identification complicated at species level. The adult takes about 49 days to develop from egg as reported from southern India. (Bhat *et al.,* 2013). Body size is medium to large, clothed with erect short yellow setae; head, femur and tibia with fine setae of varying lengths; thorax is densely covered with short setae; anterior part of meso- and meta-pleura of thorax, anterior margin of each abdominal sternum are profused with lateral white tufted setae; corium is with dispersed white tufts setae; anterior margin and basal part of corium is with bent yellow short setae; ventral surface of fore trochanter and fore femur and apical part of fore tibia is densely clothed with short erect yellow setae. Ante-ocular part is subequal to postocular length; post-antennal protuberance is short and spiny; 1st rostral segment is slightly thickened and distinctly extends beyond posterior margin of eyes; 1st antennal segment is the longest, subequal to or longer than combined length of head and pronotum. Anterior lateral angle of pronotum is short and conical; anterior pronotal lobe is slightly shiny and with deep impression, medially deep and longitudinally sulcate, subbasal part bears a pair of larger protuberances; posterior pronotal lobe is bulged, shallowly wrinkled or reticulately rugose, distal part is somewhat flat, lateral and posterior pronotal angles are round and slightly prominent; postolateral margins are slightly concave and turned upward; posterior margin of pronotum is slightly convex; scutellum beset with "V"-shaped carinae, apical part is rounded in shape; fore femur is thickened with distinct incurved basal half; fore wing distinctly extends beyond abdominal tip; connexivum of abdomen is moderately dilated in female, especially 4^{th} to 6^{th} abdominal segments. Male genitalia: Pygophore is rounded, median pygophore process is short in length; parameres are clavate, with hairs on apical part; basal plate of phallobase is slightly shorter than and thicker than plates, pedicel is short and wide; phallosome is elliptical; dorsal phallotheca is sclerotized, apical part is gradually widened and widely concave in apex. (Feng Gao *et al.*, 2015)

Life cycle – Eggs: Female *Rihirbus trochantericus* lays elongated eggs singly as well as in groups of about 26 eggs in 3-7 clusters per female. Eggs are elongate, oval and dark brownish with flower-like opercular structure and are glued basally to the substratum. The incubation period is 13.00 ± 0.69 days. (Bhat *et al.*, 2013).

Nymph: The newly hatched nymphal instars started to feed 6 to 7 hrs after eclosion, showing a preference for small and sluggish prey. The stadial durations of I^{st}, II^{nd}, III^{rd}, IV^{th} and V^{th} nymphs were 12.39 ± 1.13, 7.00 ± 0.39, 7.56 ± 0.35, 9.28 ± 0.64 and 12.78 ± 1.27 days, respectively. The survival rate of nymphal instars was found to be about 40% only due to abnormal hatching and moulting causing 60% nymphal mortality. (Bhat *et al*. 2013).


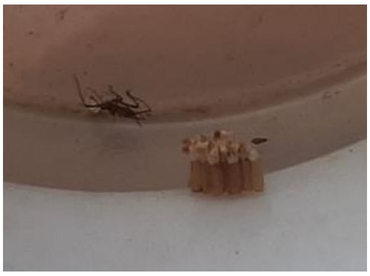

Figure 1 & 2: Eggs laid by Female *Rihirbus trochantericus*

Fig. 3: Nymphs of *Rihirbus trochantericus*


Figure 4 & 5: Adult *Rihirbus trochantericus*

Adult: The total developmental period of *Rihirbus trochantericus* from egg to adult reported was 49.00 ± 2.48 days. The adult male longevity and total male longevity was shorter (61.00 ± 3.12 and 107.13 ± 2.70 days) than that of the female (66.60 ± 5.73 and 117.9 ± 3.83 days). The oviposition period of *Rihirbus trochantericus* lasted for 34.62 ± 3.49 days, the preoviposition period 17.88 ± 0.72 and postoviposition period was 9.75 ± 0.70 days. The survival rates for males and females were 107.13 ± 2.70 and 117.9 ± 3.83 days, respectively with sex ratio 1: 0.7. (Bhat *et al*. 2013).

Remarks: A distinct sexual dimorphism is seen in *Rihirbus trochantericus* with respect to size, shape and color. Females are stout and distinctly larger (19.2-20.1 mm length) with a conical abdominal base, whereas males are lean and comparatively smaller in size (13.2-15.1 mm) with a round abdominal base. Also, there is a distinct colour difference; females are uniformly black and males are dull brownish yellow in the rostrum, thorax, pronotum, scutellum, anterior wings and legs up to the femur. The photographs of living stages were clicked by the author (Fig. 1 & 2: Eggs laid by the female; Fig. 3: Nymphs; Fig. 4 & 5: Adult; Fig. 6: Head and Rostrum; Fig. 7: Ventral view; Fig. 8: Lateral view.

Fig. 6: Head and Rostrum

Fig. 7: Ventral View

Fig. 8: Lateral View

Economic importance - *Rihirbus trochantericus* Stal is one of the common predators recorded in the cashew ecosystem. *Rihirbus trochantericus* is known to attack prey in an absolute sequential pattern: i.e. initializing through arousal -approach -capture -probe -piercing and sucking. *Rihirbus trochantericus* Stal has also been recorded as a predator of *Helopeltis spp*. Mass culture technique for *Rihirbus trochantericus* has also been standardized using a prey i.e, larvae of wax moth *Galleria mellonella* Linnaeus to explore its predatory potential in laboratory conditions. (Bhat *et al*. 2013). *Rihirbus trochantericus* was also observed from the cardamom during research conducted in 2010 - 2011 at Indian Cardamom Research Institute, Species Board, Myladumpara, India. The findings may help to improve the future IPM strategies against various pests such as *Helopeltis* in cashew.

References

1. Bhat, P. S., Srikumar, K. K., Raviprasad, T. N., Vanitha, K., Rebijith, K. B., & Asokan, R. (2013). Biology, behavior, functional response and molecular characterization of *Rihirbus trochantericus* Stal var. luteous (Hemiptera: Reduviidae: Harpactorinae) a potential predator of Helopeltis spp.(Hemiptera: Miridae). *Entomological news*, *123*(4), 264-277.
2. Bhagyasree, S. N. (2018). Generic notes on the Assassin bugs of the Subfamily Harpactorinae (Hemiptera: Reduviidae) of Karnataka. *Journal of Entomology and Zoology Studies*, *6*(1), 1366-1374.
3. Zhao, P., Pham, M., Truong, X. L., & Cai, W. (2014). Flexitibia, a new genus of Harpactorinae (Hemiptera: Heteroptera: Reduviidae), with a discussion on the functional morphology of fore legs of the related genera. *Zootaxa*, *3795*(5), 564-570.
4. Lam, T. X., Hoa, B. T. Q., Linh, H. N., & Cai, W. (2020). A new species of the assassin bug genus Rihirbus (Hemiptera: Heteroptera: Reduviidae) from Vietnam. *Zootaxa*, *4780*(3), zootaxa-4780.
5. Gao, F., Zhao, P., Webb, M., & Cai, W. (2015). A taxonomic review of the polymorphic assassin bug genus *Rihirbus Stål* (Hemiptera: Reduviidae: Harpactorinae). *Zootaxa*, *3963*(4), 502-516.
6. Saroj, P. L., Bhat, P. S., & Srikumar, K. K. (2016). Tea mosquito bug (*Helopeltis spp*.)–A devastating pest of cashew plantations in India: A review. *Indian Journal of Agricultural Sciences*, *86*(2), 151-62.
7. Sahayaraj, K., & Balasubramanian, R. (2016). *Artificial rearing of reduviid predators for pest management* (p. 180). Singapore: Springer.

SMOKE WATER IN AGRICULTURE: A REVIEW OF ITS ROLE IN SEED GERMINATION AND PLANT GROWTH

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Abstract:

Fire in forests is a recurring event which causes loss of vegetation, but at the same time useful plant materials are released into the atmosphere which is beneficial for other plant species to grow well. Smoke water is a combusted plant material which is mostly obtained from plant species and is considered as fire derived, which has the ability to show positive growth response towards the germination of seeds and can be used as an herbicide by farmers. Evidence shows that natural fire to vegetation has increased seed germination in soil thus smoke water is gaining popularity in the agricultural sector. Its various advantageous activity is yet to be discovered and thus studying about smoke water can actually bring some changes in future, because various studies from all over the world like China, Sri Lanka, Amazon Forest, etc, plant species have shown positive response towards smoke waters and are documented as good promoters for germination. Moreover, various experiments are carried out on particular plant species to study the activity of smoke water and its advantageous effects, it is proved that there exist some bioactive components which help in the germination of seeds. Production of smoke water is an easy and inexpensive method and thus it can be used widely if its advantageous properties are identified. Various experimental trials have been conducted to study its further application and how it can replace existing techniques. This review focuses on the historical background, compounds present in smoke water, its action as a biostimulant, apparatus used for its preparation, scientific evidence proving its potential in sustainable farming of compatible plant species.

Keywords: Smoke water, Seed Germination, Biostimulant, Sustainable

Introduction:

Forest fires have become more frequent and have resulted in huge loss of natural habitat, most of this incident is caused by humans i.e., anthropogenic activities. So there are various plants which develop thick bark, fire resistance needles or serotinous cones which are considered as adaptation towards areas which are prone to recurring fire (Chou *et al.,* 2012). The area where there is fire, it removes the existing plants but it also helps in creating a space for the growth of new plants. The space created and the burned plants provide nutrients for the growth of new plants (Chou *et al.,* 2012). Smoke water is a combusted plant material which can be used for the stimulation of seed germination, plant development, seedling fresh weight, increase in the secondary roots in the seedlings, there are various advantageous purposes for various plant species (Zhou *et al.,* 2014; Ferraz *et al.,* 2013) and it can also show the herbicidal properties which can be used in agricultural techniques and can help farmers (Garrido *et al.,* 2023). Smoke water is not only limited to germination of seeds but its positive activity is seen in flowering, rooting, photosynthesis and also in modulating of somatic embryogenesis (Garrido *et al.,* 2023). Herbicidal activity is brought by using smoke water against weeds in which smoke water decreases the activity of germination of seeds (Garrido *et al.,* 2023). Smoke water techniques is yet to be explored and it is gaining attention, it has helped in the improvement of germination of various medicinal plants, ornamentals, horticultural, weeds and food crops also it has been reported that around 1200 species of plant species shows positive response towards smoke water (Sreekissoon *et al.,* 2021; Alahakoon *et al.,* 2020). Some of the common techniques involved are smoke water moistened filter paper, pulse treatment or seed priming for seed germination. There are various fire derived chemicals which help in the germination of seeds, such as karrikinolide, mandelonitrile (Çatav *et al.,* 2018).

History: The beginning of Smoke water usage

For ages, traditional agricultural practices have made use of fire and smoke. Biologically active substances that may find application in horticulture and agriculture have been isolated from smoke in recent years. The use of smoke-water or smoke-derived butenolide (also known as karrikinolide, KAR1) for the production of horticultural and agricultural crops is been highlighted. Treatments with smoke-water have demonstrated encouraging outcomes in terms of increasing agricultural output, seed germination, and seedling growth. Under certain circumstances, smoke-water solution might encourage seed growth even in unfavourable settings like extremes of temperature and low osmotic potentials. When seeds are sown in drought-prone settings, this effect is quite significant.

Many indigenous cultures use slash-and-burn methods to clear forests and turn them into agricultural fields. In Africa, fire is used by subsistence farmers to remove undesired biomass before planting the next crop and by pastoralists to promote the development of grass for their cattle (Simorangkir, 2007). The cheapest, fastest, and most efficient way to clear land is via fire, which also has the added benefit of supplying nutrients to the soil through ash leftovers. Australia's traditional Aborigines use fire to increase the availability of commercially significant plants and animals. The Alyawara Aborigines of Central Australia lit fires that covered a comparatively tiny region but significantly positively impacted on the productivity of various grass species (Gould, 1971; Harris, 1977; Jones, 1980). As a result, they can cultivate using fire as an inexpensive technique (O'Connell *et al.,* 1983). To manage weeds of taro, yam, and taamu, the majority of Samoan small-scale farmers use traditional pull-and-burn and fallowing techniques. Similar practices are used in ancient agricultural methods in north-eastern India, where maize and other leguminous crop seeds are frequently hung over the kitchen to be exposed to the elements according to Chetry and Belbahri (2009). Fallen Pinus needles, twigs, and leaves are used in north-east India's high- and mid-elevation farming. Burning chopped bushes on top of the ground suffocates bugs and infections. This method is used to develop crops like potatoes and ginger that are frequently healthier (Chhetry and Belbahri, 2009). The ethnic Noctes group in India's Arunachal Pradesh region has preserved a long-standing custom of slash-and-burn farming on inclines. Apart from the thermal consequences of a fire, smoke also has a major function in conventional farming systems. South African farmers with little resources keep their maize cobs over a fireplace to conserve seeds are in contact with heat and smoke. It's thought that this approach grain is shielded from fungi and insects during storage (Modi, 2004).

The term "prescribed burning" has been cleverly devised to describe the practice of utilizing fire to eradicate crop residue in both industrialized and developing nations. This also enables contemporary farmers to expedite fieldwork, lower residue management expenses, boost crop production, and enable improved control of illnesses and weeds (Mandal *et al.,* 2004). One benefit of burning is that it produces clarity, the leftovers fast and promotes seed germination and seedling growth of a freshly planted crop. While this approach is practical and economical, it also has numerous drawbacks, including air pollution and the death of beneficial microbes and insects found in soil (Mandal *et al.,* 2004).

All of these reports make it abundantly evident that fire and smoke water are tried-and-true methods in traditional farming. Since De Lange and Boucher (1990) initially reported the phenomenon, there has been a greater focus on smoke stimulated seed germination research in the field of ecology during the past 20 years. (De Lange and Boucher, 1990). Over 1200 species from 80 genera in various ecosystems have been found to have their seed germination stimulated by smoke to date, and the number is growing as research continues. Few species used in horticulture and agriculture are presently under investigation despite the conventional evidence of the important consequences of smoking. When used as a diluted solution, the biologically active compounds in smoke easily dissolve in water, and treated seeds from various species exhibit a noticeable increase in germination. Boucher and De Lange (1990) were the first to document this occurrence. They produced smoke that was placed in a drum and bubbled with compressed air using purified water. Using this technique, a variety of aqueous smoke extract has been prepared using plant materials. In general, any plant material can be used to prepare smoke extracts (Jäger *et al.,* 1996). Hence, Smoke-water is one of the most convenient means of application.

Role of bioactive components and stimulant present in smoke water:

There are various plant species such as *Leucospermum cordifolium, Orothamnus zeyheri, Staavia dodii* and *Serruria forida,* whose seeds germinate only in the presence of smoke and fire**.** Smoke biology is gaining interest all over the world nowadays and much work is being conducted to study and understand the physiology and chemistry of smoke related compounds and its bioactive compounds.

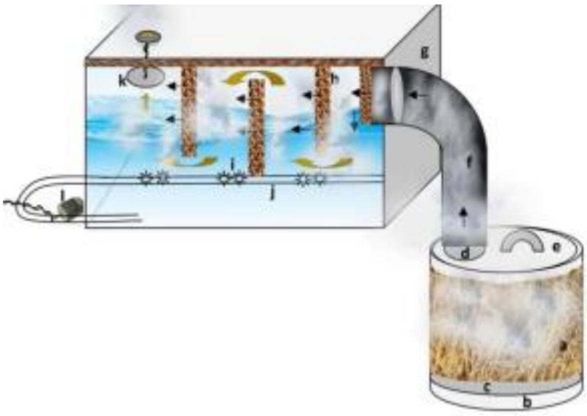
Karrikinolide (KAR1): It is considered as a stimulatory compound which helps in the germination of seeds. It is a butenolide which is identified as 3-methyl-2H-furo[2,3-c]. pyran-2-one, it is a heat stable, water soluble and long lasting compound (Zhou *et al.,* 2014). There is also inhibitory butanolide which is known as trimethylbutenolide (TMB) and is identified as ,4,5-trimethylfuran-2(5H)-one, this compound decreases the activity of Karrikinolide (Gupta *et al.,* 2020). It is observed that KAR1 is able to stimulate growth of root and flowering and it also influence pre and post germination of seeds of *Zea mays*, *Allium cepa*, *Solanum lycopersicum, Abelmoschus esculents* and beans (Kamran *et al.,* 2017). Karrikinolide was considered as the main bioactive component of seed germination but there is some evidence in which species of plant showed seed germination but it was not due to KAR1 and this led to the discovery of new bioactive components (Çatav *et al.,* 2018). There are other five types of KAR1 analogous named as KAR2, KAR3, KAR4, KAR5 and KAR6. Even though KAR1 is considered as an important stimulant, there are other analogues such as KAR2 which is considered as the active stimulant for the germination of *Arabidopsis thaliana* (Ren *et al.,* 2017).

Glyceronitrile: It is another bioactive component of smoke water. It does not show any positive response on its own, rather it requires water in which glyceronitrile hydrolyzes slowly in order to release cyanide, and this cyanide brings about the seed germination activity. It is observed that various cyanohydrins like mandelonitrile, acetone cyanohydrin, 2,3,4-trihydroxybutyronitrile and glycolonitrile brings about seed germination (Baldos *et al.,* 2015). Cyanohydrin glyceronitrile is the active stimulant of *Tersonia cyathiflora* (Ren *et al.,* 2017).

As per the study conducted by Tavşanog˘lu and his colleagues in 2017, it was observed that karrikinolide and mandelonitrile (analogous of cyanohydrin) shows stimulation in germination of seeds by different mechanism (Tavşanog˘ lu *et al.,* 2017). Similarly, smoke produced from different plant materials contains various bioactive components but only few or certain bioactive components can bring about germination of seeds indicating that different types of plants require different bioactive components from the smoke and this may be the reason why some of the bioactive components in the smoke remains unidentified (Ren *et al.,* 2017). Moreover, smoke water can be used for plants to increase the germination activity of useful plants as well it can be used as an herbicide for decreasing the germination activity of seeds of weeds or unwanted plants (Garrido *et al.,* 2023)

Biostimulants are compounds which can improve the nutrient uptake of plants, enhance growth and yield of plants and help alleviation of abiotic stresses. Smoke water has been found to play an important role in enhancing shoot length, fresh weight, leaf initiation and expansion, stem thickness, carbohydrate and protein content and chlorophyll content of a variety of plants (Khatoon *et al.,* 2020). Smoke water has been observed to have a role in the mitigation of heat stress in tomato plants, salinity stress in maize and rice plants, flood stress in soybean, etc indicating its potential as a biostimulant (Khatoon *et al.,* 2020).

Smoke water apparatus



Schematic diagram of smoke water apparatus (Gupta *et al.*, 2020)

A- Stainless steel container for placing the grass and smouldering it

B- Aeration system

C- Wired sieve

D- Smoke travelling into the water tank

E- Lid of the stainless steel container

F- Stainless steel tube- pathway from which the smoke is transferred from container to water tank

G- Water tank

H- Wet wall panel

I- sprinklers

J- water pipes

K- exhaust value

L- motor

The grass is smouldered in the stainless steel container and the smoke produced is transferred to the water tank from the stainless steel tube and also an aeration system is provided so that the smoke produced is able to move towards the water tank. The water tank contains distilled water with wet wall panels present in it in order to saturate the smoke in water.

Sprinklers are also present which helps in the dissolution of the components present in the smoke and motor helps in the circulation of the water (Gupta *et al.,* 2020). Once the preparation is done and smoke water is ready, its standardization is necessary, which is done by testing it against germination of seeds at dark (Gupta *et al.,* 2020).

Scientific evidences and recent developments:

Multiple studies have been conducted in various countries to understand the significance, principle, usage and advantage of smoke water in seed germination. Researcher from China performed an experiment in which 13 plant species were studied and out of which one plant species named *A. debilis* showed positive response whereas other plant species such as *T. magnifica and A. auriculiformis* showed negative effects on seed germination this shows that not every plant species shows positive response or is affected by smoke water (Zhou *et al.,* 2014). Another experiment was performed in amazon forest, where 10 Amazonian tree species were selected for analysis. In which 5 Amazonian tree species showed good germination patterns i.e, *Jacaranda, Ochroma, Cordia, Bellucia* and *Bertholletia* showed positive response where as other 5 amazonian tree species such as *Schizolobium, Tabebuia, Cariniana, Enterolobium* and *Swietenia* showed no much response (Ferraz *et al.,* 2013). Smoke water produced from *Cecropia palmata* can be used for germination of seeds. Similarly sawdust from the Lauraceae family has shown positive activity towards germination of tomato seeds (Ferraz *et al.,* 2013). There were other experiments carried out in which 31 plant species from the Mediterranean Basin were studied in order to determine the bioactive components of the smoke, and it was observed that 21 plant species showed positive response towards smoke water and some of the plant species showed negative effects (Çatav *et al.,* 2018). The negative effect of seed germination by smoke water can be considered as disadvantages but it can be beneficial for inhibiting the germination of seeds of weeds and thus it can be used as herbicide by farmers and thus increasing the productivity of useful crops (Garrido *et al.,* 2023). As per the study done by Iqbal *et al.,* 2016, smoke water has shown good results in pre and post germination of wheat- *Triticum aestivum*. Positive effects of smoke solution like development of seedling, enhancement of vigor, length, mass of seedling and crop yield was observed in studies conducted with plants like okra, celery, acacia, etc (Khatoon *et al.,* 2020).

Conclusion:

Smoke water can be used in the near future for increasing the germination activity of seeds as well as it can be used as herbicide. Production of smoke water is easy and inexpensive. Moreover, various experiments done by researchers have shown that smoke water can be useful and can be a sustainable tool for increasing the yield and benefiting the agricultural sector. Bioactive components like Karrikinolide and cyanohydrin are considered as important active agents which play the main role in germination of seeds. Overall, it can be concluded that some plant species respond positively to smoke water, emphasizing the need for further exploration to understand the specific requirements of different plants which can help in practical application in sustainable agriculture for compatible crops.

References:

1. Alahakoon, A. A. C. B., Perera, G. A. D., Merritt, D. J., Turner, S. R., & Gama-Arachchige, N. S. (2020). Species-specific smoke effects on seed germination of plants from different habitats from Sri Lanka. *Flora*, *263*, 151530.

2. Aremu, A. O., Kulkarni, M. G., Bairu, M. W., Finnie, J. F., & Van Staden, J. (2012). Growth stimulation effects of smoke-water and vermicompost leachate on greenhouse grown-tissue-cultured 'Williams' bananas. *Plant Growth Regulation*, *66*, 111-118.

3. Baldos, O. C., DeFrank, J., & Sakamoto, G. S. (2015). Germination response of dormant tanglehead (*Heteropogon contortus*) seeds to smoke-infused water and the smoke-associated stimulatory compounds, karrikinolide and cyanide. *HortScience*, *50*(3), 421-429.

4. Brown, N.A.C., Botha, P.A., 2004. Smoke seed germination studies and a guide to seed propagation of plants from the major families of the Cape Floristic Region, South Africa. South African Journal of Botany 70, 559–581.

5. Brown, N.A.C., Van Staden, J., 1997. Smoke as a germination cue. A review. Plant Growth Regulation 22, 115–124.

6. Calabrese, E. J., & Agathokleous, E. (2021). Smoke-water commonly induces hormetic dose responses in plants. *Science of The Total Environment*, *765*, 142776.

7. Çatav, Ş. S., Küçükakyüz, K., Tavşanoğlu, Ç., & Pausas, J. G. (2018). Effect of fire-derived chemicals on germination and seedling growth in Mediterranean plant species. *Basic and Applied Ecology*, *30*, 65-75.

8. Chhetry, G.K.N., Belbahri, L., 2009. Indigenous pest and disease management practices in traditional farming systems in north east India. A review. Journal of Plant Breeding and Crop Science 1, 28–38.

9. Chou, Y. F., Cox, R. D., & Wester, D. B. (2012). Smoke water and heat shock influence germination of shortgrass prairie species. *Rangeland Ecology & Management*, *65*(3), 260-267.

10. De Lange, J.H., Boucher, C., (1990). Autecological studies on Audouinia capi[1].tata (Bruniaceae). I. Plant-derived smoke as a seed germination cue. South African Journal of Botany 56, 700–703.

11. Ferraz, I. D. K., Arruda, Y. M. B., & Van Staden, J. (2013). Smoke-water effect on the germination of Amazonian tree species. *South African Journal of Botany*, *87*, 122-128.

12. Garrido, R. M., Dayan, F. E., & Kolb, R. M. (2023). Herbicidal Activity of Smoke Water. *Agronomy*, *13*(4), 975.
13. Gupta, S., Hrdlicka, J., Ngoroyemoto, N., Nemahunguni, N., Gucký, T., Novak, O., Kulkarni, M., Doležal, and K., Van Staden, J., (2020). Preparation and Standardisation of Smoke-Water for Seed Germination and Plant Growth Stimulation. Journal of Plant Growth Regulation. 39. 10.1007/s00344-019-09985-y.
14. Hallam, S. J. (2014). Plant usage and management in Southwest Australian Aboriginal societies. In *Foraging and farming* (pp. 136-151). Routledge.
15. Holley, R. A., and Patel, D. (2005). Improvement in shelf-life and safety of perishable foods by plant essential oils and smoke antimicrobials. *Food microbiology*, *22*(4), 273-292.
16. Iqbal, M., Asif, S., Ilyas, N., Raja, N. I., Hussain, M., Shabir, S., Muhammad, N. A. F., and Rauf, A. (2016). Effect of plant derived smoke on germination and post germination expression of wheat (*Triticum aestivum* L.). *American Journal of Plant Sciences*, *7*(6), 806-813.
17. Janković, V. (2013). A historical review of urban climatology and the atmospheres of the industrialized world. *Wiley Interdisciplinary Reviews: Climate Change*, *4*(6), 539-553.
18. Kamran, M., Khan, A. L., Ali, L., Hussain, J., Waqas, M., Al-Harrasi, A., Qari,M, I., Yoon-Ha, K., Sang-Mo, K., Byung-Wook, Y., and Lee, I. J. (2017). Hydroquinone; a novel bioactive compound from plant-derived smoke can cue seed germination of lettuce. *Frontiers in chemistry*, *5*, 30.
19. Khatoon, A., Rehman, S. U., Aslam, M. M., Jamil, M., & Komatsu, S. (2020). Plant-Derived Smoke Affects Biochemical Mechanism on Plant Growth and Seed Germination. *International Journal of Molecular Sciences*, *21*(20), Article 20. https://doi.org/10.3390/ijms21207760
20. Mandal, K.G., Misra, A.K., Hati, K.M., Bandyopadhyay, K.K., Ghosh, P.K., Mohanty, M., 2004. Rice residue-management options and effects on soil Properties and Crop Productivity. Food, Agriculture and Environment, 2, 224-231.
21. Modi, A.T., 2004. Short-term preservation of maize landrace seed and taro propagules using indigenous storage methods. South African Journal of Botany 70, 16–23.
22. Ren, L., Bai, Y., & Reaney, M. (2017). Evidence of different compounds in smoke derived from legumes and grasses acting on seed germination and seedling emergence. *Seed Science Research*, *27*(2), 154-164.
23. Simorangkir, D. (2007). Fire use: is it really the cheaper land preparation method for large-scale plantations?. *Mitigation and adaptation strategies for global change*, *12*(1), 147-164.

24. Sreekissoon, A., Finnie, J. F., & Van Staden, J. (2021). Effects of smoke water on germination, seedling vigour and growth of *Sceletium tortuosum*. *South African Journal of Botany*, *139*, 427-431.
25. Tangjang, S. (2009). Traditional slash and burn agriculture as a historic land use practice: A case study from the ethnic noctes in Arunachal Pradesh, India. *World Journal of Agricultural Sciences*, *5*(1), 70-73.
26. Tavşanoğlu, Ç., Ergan, G., Çatav, Ş. S., Zare, G., Küçükakyüz, K., & Özüdoğru, B. (2017). Multiple fire-related cues stimulate germination in *Chaenorhinum rubrifolium* (Plantaginaceae), a rare annual in the Mediterranean Basin. *Seed Science Research*, *27*(1), 26-38.
27. Tikai, P., & Kama, A. (2004). A study of indigenous knowledge and its role in sustainable agriculture. In *Proceedings of the 2003 National Environment Forum, Samoa. Retrieved April* (Vol. 30, p. 2015)
28. Wibowo, S., Syafii, W., Pari, G., & Herliyana, E. N. (2023). Utilization of Lignocellulosic waste as a source of liquid smoke: A literature. *Journal of Environmental Health*, *15*(3).
29. Zhou, J., Teixeira da Silva, J. A., & Ma, G. 1(2014). Effects of smoke water and karrikin on seed germination of 13 species growing in China. *Central European Journal of Biology*, *9*, 1108-1116.

MARINE MICROALGAE AS A SOURCE OF BIOFERTILIZERS DEVELOPMENT FOR SUSTAINABLE AGRICULTURE

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Currently in quick-paced society, the rising number of world population brings about a massive energy consumption described by the reduction of oil assets which are thought to be the principle prerequisites for using sustainable energies. The utilization of biomass as an economical source for energy production represents to in this way a promising alternative for the substitution, at any rate partially, of fossil fuels consumption (Yahmed *et al.*, 2017). Seaweeds are also the world's leading primary producers with above 200,000 kinds of species available. Microalgae production entails bulk of cultivation, biomass recovery and downstream set-ups to ensure a stable harvest for food, compounds, feed, biofuel and bio fertilizers (Balasubramaniam *et al.,* 2021). The Gulf of Mannar coastal region of India bears flourishing evolution of seaweeds. The south shore harbours around the more than 200 species of seaweeds. Their growth in coastal waters be like like grass in large regions, stretching out and distribution to more than meters. Seaweeds develop bounteously along the Indian coastline especially in rough shore areas (Kumar and Sahoo, 2011). Around 841 taxa of marine algae were found in both between tidal and profound water areas Indian seashore (Oza nd Zaidi, 2001).

In addition to improving soil potency and superiority microalgae can generate plant growth polysaccharides, hormones, antibacterial compounds and other metabolites substance like the *Chlorella* sp., *Spirulina* sp., *Cyanobacteria* (blue-green algae) (Ronga *et al.,* 2019). Since they contribute directly into the absorption of atmospheric carbon dioxide into organic algal biomass by photosynthesis, cyanobacteria and green microalgae are major organic matter sources of the agro-ecosystem (Guo *et al.*, 2020a).

Seaweeds are generally secured to the ocean depths or other stable structures by root like “holdfasts,” which helps play out the individual aptitude of connection but unlike the origins of higher plants, seaweeds do not a source of enhancements from their host (Wyles *et al.*, 2014). A specific seaweed arrangement of these collections is resolute the photosynthetic colorants at the end its reformative mode at the point of the micro and macro morphologies and finally by photopolymers (Ryan Drum, 2018). Ulva species is the thin flat green algae mounting a small discoid holdfast that might reach 18 cm or more than an in length, conversely for the most part of the substantially less and up to 30 cm crosswise. Thalli are one cell dense, lenient and luminous (Guiry and Guiry, 2017).

Diverse strategies for biomass treatment were utilized for extraction of conceivable inhibitors and residual biomass was assessed for methane yields. In this study also includes strategizing the treatment process for proficient extraction of individual components of biomass with that goal that every fraction offers value-addition and thus supports bio-based economy approach. The exploring approaches are enriched biogas production from U. lactuca (Mhatre and Gupta, 2018). Still an important portion of the Ulva species biomass remnants unutilized making an organic waste (Briand and Morand, 1997; Morand *et al.*, 2006). It is a rich source of proteins (16–30%) and carbohydrates (60–65%) consisting of high-value sulfated polymer ulvan along with cellulose and hemicellulose and 4–5% lipids (Lahaye and Robic, 2007; Msuya and Neori, 2008). The supreme energy efficient method to obtaining biofuel from macroalgae is engaging anaerobic digestion (AD) to biogas (Hughes *et al.*, 2012). The making of the biogas through AD provides significant benefits above the different types of bioenergy production. It has remained one of the most energy-efficient and biologically valuable innovations for bioenergy production (Olabi, 2012; Karray *et al.*, 2017). In consistent organic substrates need to hydrolysis, acidogenesis, acetogenesis and methanogenesis for the implementation of the AD reactions. Biogas the end product one of the AD include major methane substance of the 60–70% and can be used for heat and electrical energy generation (Kim *et al.*, 2014).

Table 1: Commercial seaweed products are used in agriculture (Nabti *et al.*, 2016b)

Sr. No.	Application	Seaweed name	Product name
1.	Plant growth stimulant	*Ascophyllum nodosum Ascophyllum*	Acadian
2.	Plant growth stimulant	*Ascophyllum nodosum*	AgroKelp
3.	Plant growth stimulant	*Nodosum Macrocystis pyrifera*	Agri-Gro Ultra
4.	Plant growth Stimulant	*Unspecified*	Bio-GenesisTM High TideTM
5.	Bio fertilizer	*Ecklonia maxima*	Fartum
6.	Plant growth stimulant	*Durvillea antarctica unspecified*	Kelpak
7.	Plant biostimulant	*Unspecified*	Profert
8.	Plant biostimulant	*Durvillea potatorum*	Sea Winner

The alteration of the aquatic biomass to methane is possible involving few complications that need to be tackled carefully. Competent cultivation, harvesting and change technologies are effective and efficient to use macroalgae as a supreme capacity (Montingelli *et al.*, 2016). The exploitation of marine biomass as an innovative and alternative feedstock for biogas invention could also reduce the sustainable and the waste sludge can be used as a biomanure.

Use of various inorganic fertilizers, pesticides, bug sprays has harmed the soil ecosystem widely. The different type of practice makes the soil environment unsuitable for crop development in the future (Uthirapandi *et al.*, 2018). The suitability of Ulva sp as biofertilizer has not yet been examined sufficiently and there are no examinations on the impacts on Ulva sp to produce seaweed extract (Castellanos-Barriga *et al.*, 2017). The utilization of algal biomass as manure for the improvement of soil quality for agricultural crop production has been intensively studied in recent existences (Wosnitza and Barrantes, 2006; Cole *et al.*, 2016). The most important advantage is that the algal biomass is a readily biodegradable material and has a high content of organic matter and macronutrients like nitrogen, phosphorus, potassium and calcium (N, P, K & Ca) which makes them useful for the improving the quality of soil (Tabarsa *et al.*, 2012). Natural manures can be used to create essences that help increase organic activities in soils.

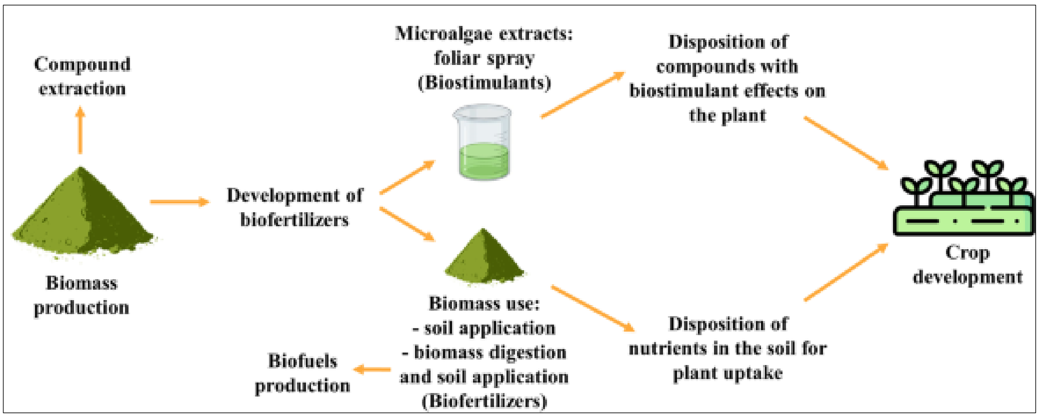

Fig. 1: Marine Microalgae for the Development of Biofertilizers

The green macroalgae Ulva sp. has great abundant of potentially important species. In Tamil Nadu is the reach source of marine seaweeds originate in gulf of manner in India and some of the countries the suitability of Ulva sp. as used as a biomethanation and bioconversion takes not yet been examined sufficiently and there is no studies on the end product used as an organic fertilizers. However, the mixtures of cow manure and Ulva sp. has produced more methane which is used for domestic and marketable activities. The bioconversion of organic manure develops the soil fertility and increases the plant growth. This research work was used to initiate with large scale biogas production and increase the agricultural crop yield in future. One of the major important roles in the Ulva sp. used to zero waste management without any effects of environment and soil.

Nowadays the increasing prices of petroleum-based fuels have persistently focused on the development of alternative energy sources, whereas the solid residue can be used as an organic fertilizer which can be one of the solutions from depending on conventional synthetic fertilizer. Microalgae is recommended was used in eco-friendly and zero waste management process that composites are to improve sustainable crop growth and yield and used as a supernumerary for synthetic fertilizers. Marine microalgae is effectively used as an eco-friendly approach to biogas production and organic farming. Microalgae are the innovative biomass resource for the next decades and production of biodiesel. Under this situation, biofertilizers may work as a good inducer for sustainability to improve the agricultural crop production and also enhances the soil fertility and spotless environment.

Conclusion:

Marine microalgae used as a bio-fertilizer is the future of agriculture in the world, where it is expected to replace chemical fertilizer. Because it is safer on the soil and also facilitates the process of biodegradation carried out by microorganisms, thus leads to an increase in soil fertility in a safe way without leaving chemical residues. The soil should be fertile enough to give high production and plants require critical nutrients from fertile soil which also supports a diversified and dynamic biotic population that helps the soil sustainable agricultural practice that includes using bio-fertilizer to expansion into the nutrient content of the soil and organic matters subsequent into higher yield and resist eco-friendly degradation.

References:

1. Balasubramaniam V., Gunasegavan R.D.N., Mustar S., et al. (2021). Isolation of Industrial Important Bioactive Compounds from Microalgae. *Molecules, 26.*
2. Briand, X., & Morand, P. (1997). Anaerobic digestion of Ulva sp. 1. Relationship between Ulva composition and methanisation. *J. Appl. Phycol., 9,* 511.
3. Castellanos-Barriga, L.G., Santacruz-Ruvalcaba, F., Hernández-Carmona, G., Ramírez Briones, E., & Hernández-Herrera, R.M. (2017). Effect of seaweed liquid extracts from Ulva lactuca on seedling growth of mung bean (Vigna radiata). *J. Appl. Phycol., 29,* 2479–2488.
4. Cole, A.J., Roberts, D.A., Garside, A.L., de Nys, R., & Paul, N.A. (2016). Seaweed compost for agricultural crop production. *J. Appl. Phycol., 28,* 629–642.
5. Guiry, M.D., & Guiry, G.M. (2017). AlgaeBase. World-wide electronic publication, National University of Ireland, Galway 2015, URL. http://www.algaebase.org.
6. Guo S., Wang P., Wang X., et al. (2020). Microalgae as Biofertilizer in Modern Agriculture. *Microalgae Biotechnol Food, Heal High Value Prod.,* 397–411.
7. Hughes, A.D., Kelly, M.S., Black, K.D., & Stanley, M.S. (2012). Biogas from Macroalgae: is it time to revisit the idea? *Biotechnol. Biofuels, 5,* 86.

8. Karray, R., Karray, F., Loukil, S., Mhiri, N., & Sayadi, S. (2017). Anaerobic co-digestion of Tunisian green macroalgae Ulva rigida with sugar industry wastewater for biogas and methane production enhancement. *Waste Manag., 61,* 171–178.
9. Kim, J., Jung, H., & Lee, C. (2014). Shifts in bacterial and archaeal community structures during the batch biomethanation of Ulva biomass under mesophilic conditions. *Bioresour. Technol., 169,* 502–509.
10. Kumar, G., & Sahoo, D. (2011). Effect of seaweed liquid extract on growth and yield of Triticum aestivum var. Pusa Gold. *J. Appl. Phycol., 23,* 251–255.
11. Lahaye, M., & Robic, A. (2007). Structure and functional properties of ulvan, a polysaccharide from green seaweeds. *Biomacromolecules, 8,* 1765–1774.
12. Mhatre, V., & Gupta, G. (2018). Adaptable Push-Notification State. *U.S. Patent No. 9,992,293.* Washington, DC: U.S. Patent and Trademark Office.
13. Montingelli, M.E., Benyounis, K.Y., Stokes, J., & Olabi, A.G. (2016). Pretreatment of macroalgal biomass for biogas production. *Energy Convers. Manag., 108,* 202–209.
14. Morand, P., Briand, X., & Charlier, R.H. (2006). Anaerobic digestion of Ulva sp. 3. Liquefaction juices extraction by pressing and a technico-economic budget. *J. Appl. Phycol., 18,* 741–755.
15. Msuya, F.E., & Neori, A. (2008). Effect of water aeration and nutrient load level on biomass yield, N uptake and protein content of the seaweed Ulva lactuca cultured in seawater tanks. *J. Appl. Phycol., 20,* 1021–1031.
16. Nabti E., Jha B., & Hartmann A. (2016). Impact of seaweeds on agricultural crop production as biofertilizer. *Int. J Environ. Sci Technol., 145(14),* 1119–1134.
17. Olabi, A.G. (2012). *Developments in Sustainable Energy and Environmental Protection.* pp. 2–5.
18. Oza, R.M., & Zaidi, S.H. (2001). A Revised Checklist of Indian Marine Algae, vol 296 CSMCRI, Bhavnagar. Parmar, A., Singh, N.K., Pandey, A., Gnansounou, E., & Madamwar, D. (2011). Cyanobacteria and microalgae: a positive prospect for biofuels. *Bioresour. Technol., 102,* 10163–10172.
19. Ronga D, Biazzi E, Parati K, et al (2019). Microalgal Biostimulants and Biofertilisers in Crop Productions. *Agron 2019, Vol 9, Page 192,* 9:192.
20. Ryan, Drum. (2018). Medicinal Uses of Seaweeds, Island Herbs. http://www.ryandrum.com/seaweeds.htm. Sarı, A., & Tuzen, M. (2008). Biosorption of cadmium (II) from aqueous solution by red algae (Ceramium virgatum): equilibrium, kinetic and thermodynamic studies. *J. Hazard Mater., 157,* 448–454.

21. Tabarsa, M., Rezaei, M., Ramezanpour, Z., & Waaland, J.R. (2012). Chemical compositions of the marine algae Gracilaria salicornia (Rhodophyta) and Ulva lactuca (Chlorophyta) as a potential food source. *J. Sci. Food Agric.*, *92,* 2500–2506.
22. Uthirapandi, V., Suriya, S., Boomibalagan, P., Eswaran, S., Ramya, S.S., & Vijayanand, N. (2018). Bio-fertilizer potential of seaweed liquid extracts of marine macro algae on growth and biochemical parameters of Ocimum sanctum. *J. Pharmacogn. Phytochem., 7,* 3528–3532.
23. Wosnitza, T.M.A., & Barrantes, J.G. (2006). Utilization of seaweed Ulva sp. in paracas bay (Peru): experimenting with compost. *J. Appl. Phycol., 18,* 27.
24. Wyles, K.J., Pahl, S., & Thompson, R.C. (2014). Perceived risks and benefits of recreational visits to the marine environment: integrating impacts on the environment and impacts on the visitor. *Ocean Coast Manag.*, *88,* 53–63.
25. Yahmed, N. Ben, Carrere, H., Marzouki, M.N., & Smaali, I. (2017). Enhancement of biogas production from Ulva sp. by using solid-state fermentation as biological pretreatment. *Algal Res., 27,* 206–214.

A SYNOPTIC STUDY OF THE MECHANISM AND CONCEPT OF MOLECULAR PLANT BREEDING

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Abstract:

The abstract highlights molecular plant breeding, emphasizing the integration of advanced genetic techniques to enhance crop development. This approach involves leveraging molecular markers, genetic mapping, and biotechnological tools to accelerate the breeding process, resulting in improved plant traits, increased yield, and enhanced resistance to environmental stressors. The abstract underscores the significance of molecular methods in revolutionizing plant breeding strategies for sustainable agriculture.

Keywords: DNA, Hybrid, Genotypes, Breeding, Heterosis, Markers

Introduction:

Between the 1980s and 1990s, there was a rapid development of new molecular genetics methods that allowed for the identification of genetic variation at the molecular level and the understanding of the effects of genetic variants on phenotype. Major sequencing projects have been completed in the last ten years thanks to increased output (measured in kilo base pairs created) as a result of improvements in sequencing device capacity over time.

Instrument capacity variations and NGS developments

Over the past 20 years or more, sequencing technology has greatly improved, resulting in lower sequencing costs and a higher volume of sequenced species. Additionally, the quantity of (re-) sequenced genomes in databases has grown quickly.

Cost of DNA sequencing

The cost of sequencing has been affected by advancements in DNA sequencing technology, which over time has led to a sharp decline in sequencing costs per genome. Because the relative costs of genotyping versus phenotyping have significantly decreased and knowledge about genes, markers linked to genes, and QTL has accumulated, DNA and other genomic technologies will become more and more important in plant breeding. Together, these findings suggest that switching to DNA assays will become increasingly advantageous if breeding materials can be evaluated at the DNA level in a manner that is comparable to agronomic evaluation. For the purpose of enhancing crop plants, molecular plant breeding blends traditional plant breeding techniques with molecular procedures.

Traditional plant breeding

Genetic structure of variety types

The genetic makeup of variety types influences whether or not molecular techniques can be used to enhance breeding stock. For instance, because clonal types are highly heterozygous, marker-assisted backcrossing, which requires a homozygous recurrent parent, is not relevant to clone breeding. Therefore, it will be unable to replicate the recurrent parent in BC generations due to segregation.

Reproduction systems, propagation, and types of varieties

Asexually, sexually and either method can be used to propagate certain plant species. The nucleus of a pollen grain fuses with an egg cell in the ovary to create the kernel's embryo during sexual reproduction. A person is spread by asexual reproduction using vegetative tissue.

Genetic variation within a variety

The phrases homogeneity and heterogeneity describe how each plant in a cultivar is related genetically. When the plants that make up a cultivar are genetically the same, the cultivar is homogenous; when they are genetically diverse, the cultivar is heterogeneous.

Genotype structures of varieties

A cultivar's individual plants are described by their genetic make-up using the words homozygosity and heterozygosity. When alleles at a locus are the same, the locus is homozygous. When there are different alleles at the locus, it is said to be heterozygous. A plant's homozygosity level is an indicator of the proportion of its genome's loci that are identical. Self-pollination of individuals is the main strategy for reaching homozygosity, and it is frequently employed to create pure-line cultivars or inbred lines that are used to create hybrids. Crossing plants with various alleles at some or all loci results in heterozygosity. Crosses are capable of being made by hand or by allowing the wind or insects to freely pollinate the plant. The heterozygosity of plants in clonal, synthetic or hybrid cultivars is very high. A pure-line cultivar comprises homozygous plants.

Breeding categories

Table 1: Breeding categories, modes of propagation and genetic structures of varieties.

	Clone breeding	**Line breeding**	**Population breeding**	**Hybrid breeding**
Mode of propagation	asexual	sexual	sexual	sexual
Heterozygosity of plants	heterozygous	homozygous	heterozygous	heterozygous
Genetic variation within a variety	uniform	uniform	heterogeneous	uniform
Reproduction	possible	possible	possible	undesirable

In Table 1 list of the various breeding categories and the ways in which they are propagated. A pure-line variety's seed is created through self-pollination. The individual plants are hence regarded as homogenous (genetically comparable to other members of the variety) and homozygous (having identical alleles at most or all loci).

Seeds of hybrid varieties

A hybrid variety's seed for commercial planting is created by mating two parents that are genetically unrelated. The hybrid is hence heterozygous. Hybrids can be classified as single-crosses, modified single-crosses, three-way crosses, or double-crosses, among other things. The quantity of inbred lines utilized to create commercial seed varies between them. The plants in a three-way or double-cross hybrid are genetically distinct or heterogeneous, in contrast to the F1 (hybrid) plants produced from a single-cross, which are genetically identical or homogenous.

Open pollination results in the sexual reproduction of synthetic and open-pollinated types. The plants in a commercial field of synthetic and open-pollinated types are heterozygous and diverse as a result of open pollination.

Clonal varieties are created from a single plant that the breeder has chosen in an asexual manner. As a result, every plant in a clonal variety has the same genetic makeup, or is homogeneous. Due to the fact that selection is used in the F1 generation, clonal varieties are also heterozygous.

Alternatives in genetic structure

According to the two genetic characteristics of any type of variety—the degree of heterozygosity of people within varieties and the degree of heterogeneity of varieties.

Heterosis

There are numerous ways that heterosis, also known as hybrid vigor, might manifest itself. Mid-parent heterosis and high-parent heterosis are two of the most prevalent. The performance of the hybrid is compared to the mean performance of its parents to determine mid-parent heterosis. The performance of the hybrid as compared to the best performing parent is how high-parent heterosis is measured. In general, there is little correlation between heterosis and hybrid performance.

Formation of heterotic groups

For hybrid crops to perform at their best, heterotic group formation is crucial. When grown in hybrid combination with an individual from a complementary heterotic group, a group of individuals known as a heterotic group typically performs well. Stiff Stalk is a significant heterotic group in elite U.S. maize that primarily descends from lines created from the Iowa Stiff Stalk Synthetic (BSSS), a population created by G.F. Sprague in 1933–1934. Other heterotic groupings are typically referred to as non-Stiff Stalk in elite maize breeding in the United States. Breeders in the United States have discovered that inbreds from the Stiff Stalks are typically crossed with inbreds from one of the other heterotic groups to provide the best hybrid performance.

Table 2: Advantages and disadvantages of types of varieties.

Variety type	Advantages	Disadvantages
Line	Breeding and multiplication are relatively easy	Hetrosis is not exploited; Genetic vulnerability high, especially in diploids
Population	Heterosis is exploited; More stable, low genetic vulnerability	Genetic heterogeneity may result in presence of undesirable genotypes
Hybrid	Optimum exploitation of heterosis; Built-in penalty for reproduction and seed multiplication in farmers field; Product uniform in maturity, quality	Breeding and see multiplication; Genetically vulnerable
Clonal	Heterosis is exploited; Breeding relatively easy	High cost of vegetative propagation; Easy transmission of diseases, especially viral diseases

Basic steps in traditional breeding

An activity cycle is used in traditional plant breeding. There are several fundamental breeding strategies that can be modified in various ways. The strategy adopted is mostly determined by a crop species' reproductive biology.

When choosing the best course of action, economic, environmental and resource issues are crucial. As a result, each breeding program and breeding category has a separate set of details for stages 2, 3, and 4. However, the fundamental procedures for creating any cultivar are universal and they will be used to organize the second part of this course.

Integration of molecular genetics and biotechnology with plant breeding

New technology

In the fields of molecular genetics and genomics, there has been an explosion of new technology and data during the last several years. Efficiency gains in plant breeding will be made possible by new scientific knowledge and data gleaned from analysis of massively produced genomic sequence data. Research on gene function, the creation of markers, and the generation of transgenic varieties can all benefit from the integration of genomics and plant breeding (Fig. 8).

Sequencing data can be used to identify homology and syntenic traits, as well as patterns of gene expression. In mapping experiments, gene sequence data can be utilized to isolate interesting loci. Gene function is established through plant transformation using biolistic techniques, Agrobacterium, and virus-induced gene silencing (VIGS) techniques. Transgenic types can be engineered with unique features by using genes of interest discovered through genomics investigations. Information on gene function is also helpful for targeted mutagenesis (targeted induced local lesions in genomes, or TILLING) for crop improvement, association studies, and reverse genetics procedures to replace genes.

Application of markers in plant breeding

In general, marker-assisted plant breeding involves (1) marker-assisted selection (MAS), where a marker is associated with a trait of interest; (2) marker-assisted backcrossing (MABC) to recover the recurrent parent with a trait of interest; (3) marker-assisted recurrent selection (MARS) for quantitative trait loci (QTL) using a panel of polymorphic markers that are linked to the QTL of interest, and (4) genomic prediction of line, more generally performance of the population or genotype. Additionally, markers can be employed in research initiatives to uncover new marker-trait relationships, identify germplasm to aid in the selection of parental lines, and understand germplasm structure, among other things.

Table 3: Application of molecular markers in plant breeding

Basic steps in plant breeding	Tasks that can be addressed with genomic tools
Genetic resources	Biodiversity monitoring Registration and maintenance
Phase I: Production of genetic variation	Selection of complementing parents Targeted gene introgression Controlled recurrent selection
Phase II: Development of variety parents	Genomic prediction of genetic potential Pyramidization (stacking) Prediction of best hybrids
Phase III: Testing of experimental varieties	Reduced testing (costs)
Registration	Variety protection (UPOV) Patenting

Diagnostics in plant breeding

Diagnosis

"Apart" is denoted by the Greek letters dia and gno, which both imply "to know or discern things." The term "diagnosis" is used in the medical field to denote the procedure of identifying and determining the nature and cause of symptoms through evaluation of pre-existing data (such as patient history), examination of patients using conventional or laboratory methods, and ultimately interpretation of those various sources of information. In a biological sense, diagnosis is identifying distinctive traits of, for instance, an organism in a taxonomic context. Diagnostics, in its broadest meaning, refers to the use of quantitative methods for the analysis of data.

Tremendous tasks

In plant breeding, the important tasks are:

1. generation of genetic variation as a source for
2. developing components of varieties, and
3. testing of experimental varieties (Lubberstedt 2013).

All three of these key tasks can be performed intuitively based on the experiences of plant breeders, but they increasingly benefit from diagnostic procedures.

Central questions in plant breeding revolve around:

- ❖ Identification of the best founder genotypes at the outset of breeding programs to generate genetic diversity, which relates to the usefulness concept in plant breeding,
- ❖ Identification of the best variety components (such as inbred lines) or varieties, and evaluation of the performance of combinations of variety components such as experimental hybrids.

In marker-aided methods, DNA-based markers are utilized to supplement or replace field trial-based evaluation. Non-DNA based "biomarkers" are used in plant breeding, albeit to a lesser extent than in medicine. However, the goal of each test process is to accurately forecast the best genotypes or genotype combinations. The challenge is if novel processes offer these predictions more reliably, in less time, and/or at a cheaper cost compared to established procedures as a result of technological advancement in the field of genomics.

Classification of diagnostic techniques

Diagnostic tools can be divided into various categories. Diagnostics may be based on molecular characteristics or phenotypic traits. Spectral characterisation or seed color markers are examples of non-destructive phenotypic characterization techniques that can be used after harvesting plant materials and undergoing any type of treatment. The benefit of non-destructive techniques is that they don't impede the organism's regular growth and development. Before planting, for instance, seed can be categorized and separated into good and unattractive batches based on factors like oil content. However, there are some qualities for which there are no such non-destructive techniques. Inducible resistance in the absence of a pathogen could serve as an illustration.

Using molecular techniques

Utilizing molecular methods allows researchers to track or forecast a desired feature before it manifests phenotypically. Most likely, human diseases are the finest examples. It is feasible to estimate an individual's risk of contracting a specific disease using molecular markers (based on DNA markers), as well as to predict the development of a disease like cancer using non-DNA expression markers. The timing and style of therapy may be heavily influenced by the ability to predict the beginning of a disease. In order to choose kernels based on DNA markers prior to sowing, seed chipping has been created in plant breeding. This efficiently lowers the expense of cultivation and the evaluation of undesired genotypes.

It is useful to differentiate between DNA-based and non-DNA-based molecular markers. DNA-based information remains constant throughout plant organs, developmental stages, habitats, and treatments since DNA is present in every cell and is unaffected by the environment. In terms of the reliability of the information, this could be advantageous. The drawback of DNA-based markers is that they cannot detect alterations in plant development or responses to the environment. Therefore, DNA markers make it possible to evaluate the likelihood that a specific genotype would result in a particular phenotype. However, they don't offer any details on the actual metabolic processes that non-DNA molecular markers can track. Different technological and financial standards apply to both DNA and non-DNA indicators.

Table 4: Classification of diagnostic techniques

Classification of diagnostic techniques	Distinguishing features
Destructive vs. non-destructive	Samples get destroyed with destructive methods, thus, non-destructive methods are preferable. A recent example is seed chipping, allowing characterization of seed fractions, without interfering with seed germination.
Phenotypic vs. molecular	Phenotypes can be strongly affected by non-inherited environmental factors. DNA-based methods exhibit much greater heritabilities, i.e., they are not as strongly influenced by environmental factors.
DNA vs. non-DNA biomarkers	DNA-markers report the potential or risk for target trait expression, whereas non-DNA biomarkers have the capability of reporting the onset or expression of a target trait (such as medical biomarkers for disease onset)
Functional vs. random DNA-markers	Functional markers are derived from polymorphisms causally affecting target target trait expression; in contrast, most random DNA-markers are effective by linkage with respective causal polymorphisms.
Technical classification biomarkers	Depending on the molecular class: DNA, RNA, Proteins, metabolites
Technical classification DNA-markers	Can be depending on the underlying DNA polymorphism (SNP, INDEL, SSR) or detection technology.

Diagnostic procedures

Another way to differentiate between different diagnostic approaches is to consider whether they report on the elements that cause phenotypic changes or whether association is the basis of their predictive value. Supposedly "ideal," "perfect," or "functional" DNA markers have been described (Andersen and Lübberstedt, 2003) (FMs: will be used in the following for simplification). These FMs come from gene polymorphisms, which result in phenotypic variation.

Therefore, it is possible to anticipate that a particular genotype will be resistant to a specific disease (isolate) in the case of the presence of a specific allele at a polymorphic site within a resistance gene (as an example). Plant resistance tests are no longer necessary for this specific disease after it has been established. In contrast, if a DNA marker is connected to a resistance gene, the breeding population's linkage disequilibrium determines how informative the marker will be.

In comparison to genomic selection tactics, other methods based on random DNA markers are drawing more and more interest in the field of plant breeding (Heffner *et al.*, 2010). This is largely a result of advancements in DNA marker and sequencing technologies, which make it possible to genotype breeding populations at low cost with thousands of markers per genotype. Genomic selection has lately been used in the context of plant breeding after initially proving successful in animal breeding. In the long run, combination techniques based on FMs and genomic selection for unexplained genetic variation will be developed as knowledge about the genes impacting traits of interest and knowledge about causal polymorphisms grows.

Perspectives

Although genomic selection won't likely stop being a significant area of study in plant breeding in the foreseeable future, neither gene nor quantitative trait polymorphism (QTP) identification is one of its goals. Nevertheless, it is anticipated that advancements in agronomic trait genetic studies, fueled by advances in sequencing technology and based on methods such as genome-wide association studies and map-based gene isolation, among others, will result in a sharp rise in the number of genes and QTP identified in the coming decades that have an impact on agronomic traits. Long-term, it is then debatable whether more focused methods of choosing the best haplotypes and genotypes are necessary.

In contrast to plants, non-DNA indicators are far more important in the field of medicine. While knowing whether a specific ailment has happened that necessitates treatment is more important than knowing the risk as determined by DNA markers in the medical sciences (which is analogous to the phrase "potential" in plants). This is also true because gene therapy is typically not a viable option for treating hereditary conditions.

Developing a suitable treatment may benefit from knowledge of the molecular mechanism(s) underlying a certain disease. In the long run, crop sciences might find this idea interesting as well. If substances that assist combat specific types of stress were to become available, their application by seed coating or spraying may replace or supplement the corresponding breeding efforts for enhancing agronomic performance.

References:

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2442525/
2. https://iastate.pressbooks.pub/molecularplantbreeding/chapter/molecular-plant-breeding-concepts/
3. https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/molecular-breeding
4. https://www.intechopen.com/chapters/40178
5. https://www.sciencedirect.com/science/article/pii/S2405844021021964

RECENT DEVELOPMENTS OF HORTICULTURE IN INDIA

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Abstract:

Currently, global climate change is projected to increase the risk of frequent droughts. Horticulture is in a period of great change a worldwide and faces serious problems. Traditional agriculture won't be able to feed a population that is expanding quickly with fresh, wholesome food in the future. In such cases, soilless culture is an alternative technology for effective adaption. The above ground system links to hydroponics and aeroponics systems. In an aeroponic system, plant roots are suspended in artificially supplied plastic supports and porous materials displace the soil under controlled conditions. The roots are given room to spread out and hang open in the atmosphere. Atomizing nozzles are included with water that is nutrient rich, though. Occasionally, the nozzles emit a fine mist with varying droplet sizes. Aeroponics systems are the most sustainable and reliable growing technique, according to this review's findings. It is recommended to use this system because it creates the most efficient, practical, sensible, economical and practical system of growing crops followed by cultivation and not using any other soil.

Introduction:

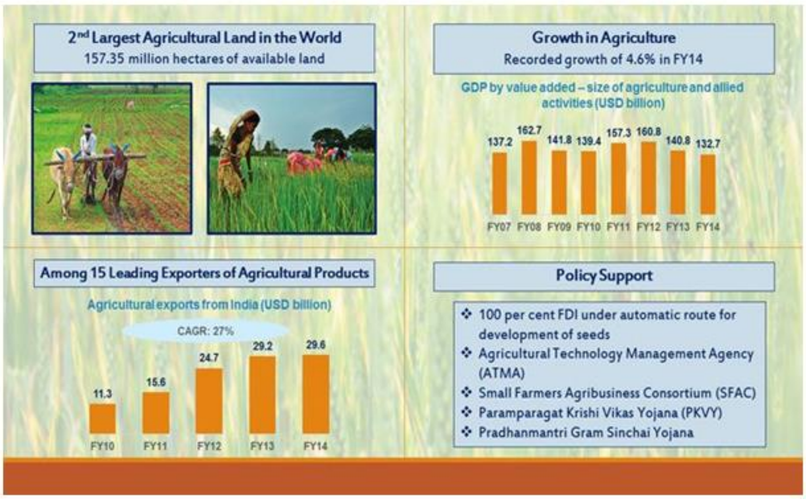
The practise of cultivating plants for human consumption, non-food uses, and social purposes is known as horticulture. India is home to a number of commercially important horticultural crops. Horticulture accounts for 30% of India's GDP and provides about 37.1% of total agricultural exports. Production in 2017-2018 was estimated at around 306.8 million tonnes (Ministry of Agriculture, India). However, horticulture in India is facing a number of challenges such as: lack of planting material complete fodder horticulture lack of market facilities post-harvest management lack of processing facilities lacks of skilled labor varieties of other crops and model crops varieties of horticulture varieties of annuals varieties of perennials grown primarily for fresh consumption. In other words, their cultivation and reproduction methods are significantly different from other crops, especially in terms of somatic mutations or budding, grafting. Regulation of flowering, development of organogenesis and postharvest storage systems. Horticultural research focuses mainly on biological issues related to reproduction, cultivation and post-harvest production, which provide useful information in breeding to improve quality and annual production. Due to a long young phase, polyembryonicity (e.g. citrus) and a large canopy of horticultural perennials, especially fruit plants.

According to Chassy *et al.* (2014), perceived health benefits, safety worries about pesticides, hormones, antibiotics, and genetically modified organisms (GMO's) as well as environmental worries related to benefits to and concerns about fairness are all factors that are driving the growing popularity of organic fruits and vegetables. Superior ecosystem services and social advantages are provided by organic farming systems in comparison to conventional agriculture (Regnalod and Wachter, 2016). The farms should be run in amazing ways, mainly due to advances in sensors, devices, machinery information development such as advances in robotics, temperature ad humidity sensors, aerial imagery and GPS. In this content, horticultural crops are more productive than any other crop group and can therefore play an important role in meeting the needs of the population is almost 5.4 times higher (Tiwari et.al.,2015). A wide range of horticultural crops such as fruit, trees, vegetables, flowers, aromatic plants, Medicinal plants, spices and plantation crops. These common precision farming and machine constructive make farms, more profitable, safer and less harmful to the environment.

Origin and evolution of horticulture

The history of horticulture overlaps with the history of agriculture. Horticulture has its roots in the transition of human communities from a nomadic hunter-gatherer lifestyle to a local or semi-local horticultural community. In the pre-Columbian Amazon rainforest, indigenous peoples used biofuel to improve soil productivity by burning plant debris. European settlers called this soil "Terra Preta de Indio". In forest areas this type of gardening was often practiced and burn. In pre-contact North America, the semi-sedimentary horticultural communities of the eastern forest growing corn, squash, and sunflowers were distinctly different from the nomadic hunter-gatherer communities of the Plains.

Horticulture in India



In India, the major part of horticulture production comprises fruits and vegetables. India has a highly favourable climate for agro products such as fruits, vegetables, spices, and aromatic plants. The Indian horticulture sector produces about 320 million tonnes of produce and accounts for about 33% of the Gross Value Added (GDA). It is a labor-intensive industry and therefore offers many job opportunities, especially for rural residents. Innovative and advanced technologies introduced in horticulture have increased production and export opportunities thereby increasing growth. In India, 10% of the area under horticulture accounts for 33% of the value of agriculture. Over the years, the horticultural sector has become an important factor in the overall economic development. India has favorable geographical features that contribute to the growth of several vegetables. More than 40 different vegetables are grown in different regions of India. India is the second largest producer of vegetables in the world. India's fruit production accounts for more than 10 percent of world production. Indian states like Uttar Pradesh, Odisha, Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra and Karnataka produce the majority of the fruit production. Favorable climatic conditions allow the production of various flowers throughout the year in selected regions of the country. The growing demand for flowers for upper- and middle-class beauty purposes contributed to the growth of floriculture as a sophisticated business.

Types of horticulture practices in India

There are several major areas of focus within the science of horticulture. They include:

1. Oleculture: the growing of vegetables.

2. **Pomology,** or fruticulture, is the study and practice of growing fruits and nuts.

3. **Viticulture**: the process of growing grapes, mostly for winemaking.

4. **Floriculture**: the cultivation of decorative and flowering plants.

5. **Turf management** is the process of growing and caring for turf grass for recreational, sporting, and other uses.

6. **Arboriculture**: the practice of growing and maintaining single trees, shrubs, vines, and other woody perennials, usually for landscape and recreational uses.

7. **Landscape horticulture**: the choice, cultivation, and maintenance of plants utilized in landscape design.

8. **Postharvest physiology**: the handling of horticultural crops to delay deterioration during transportation or storage.

Present situation- Growth of horticulture in India

The Department of Agriculture, Cooperation and Farmers' Welfare has just released the third preliminary estimate (2018-19) of area and production of various horticultural crops. According to the report, the country's total horticultural production is estimated at 313.85 million tonnes, which is 0.69% more than the 2017-18 horticultural production of 311.71 million tonnes.

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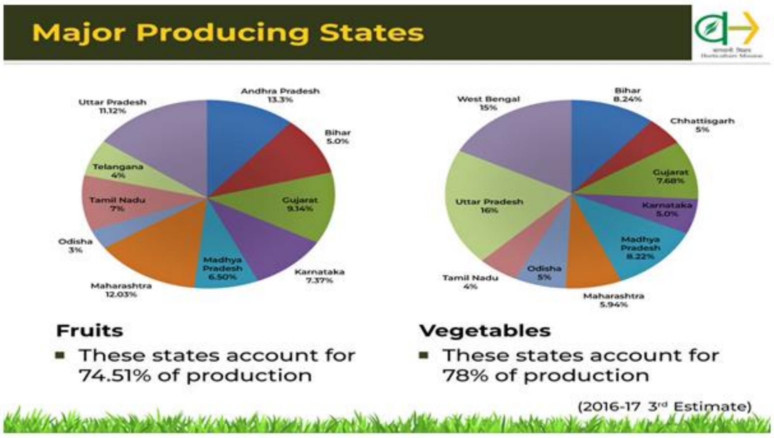
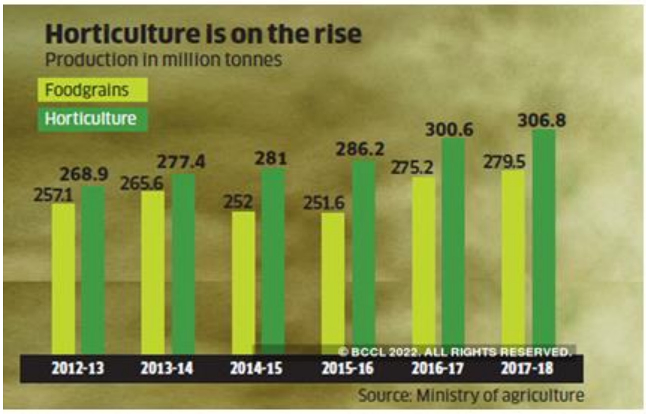
The cultivated area of horticultural crops increased from 25.43 million hectares in 2017-2018 to 25.49 million hectares in 2018-2019. The Department of Agriculture, Cooperation and Farmers' Welfare (DACandFW) is one of three subdivisions of the Ministry of Agriculture and Rural Affairs, the other two being the Department of Animal Husbandry, Dairying and Fisheries (DAHD and F) and the Department. of Agricultural Research. and Education (DARE)





Benefits of horticulture for India

Horticulture contributes as the major source of Food and Nutrients. Sector provides large employment opportunities for such a large population in India. Horticultural products are mainly exported to the foreign countries and become an identity for India in foreign market. Contribution to GDP: It also adds foreign bullion the Economy. For Environmental sustainability, the production **of** inter-crop production or mixed cropping has proved to be beneficial for soil health. Source of herbal medicines- They are source of medicines obtained from the medicinal plants.

Recent trends in horticulture growth technology

Indoor vertical farming:

Vertical farming is the cultivation and production of crops/plants in vertically stacked layers and vertically sloping areas. The whole world is one the verge of a population explosion, and faces the greatest challenges. The previously explored the development of hybrid/enhanced high-yielding varieties, improved techniques, improved tools and equipment, integrated water nutritional management practices. The extended greenhouse technology and genetically modified crops (Suparwoko et.al.,2017, Wortman et.al.,2016). Today the landscape of vertical farming has completed farming has completed changed, whether urban or rural, to produce the maximin amount of food for the hungry. I t is now a new agricultural technology worldwide. Vertical farming is also gaining ground in India.

Vertical farms in shipping containers:

They are becoming more popular. 40-foot shipping containers are used in these vertical farms to ship their goods around the world. . The shipping container was converted into an independent vertical space with a drip irrigation system. LED lights to start and grow different plants. This growth management system allows users to control all systems remotely from their smartphone or computer. There are empty buildings in urban areas where vertical farms can be placed. Vertical farms also use a completely new construction. A new way to grow crops artificially by stacking plants vertically using its 3D rendering of sky views and rooms.

Types of vertical fars:

From small two-story or wall-mounted systems to huge multi-story warehouses, vertical farms come in a variety of sizes and shapes. All vertical farms use three soilless techniques: hydroponics, aeroponics or aquaponics to provide nutrients to the plants.

- **Hydroponics**: Hydroponics means growing plants without soil in a nutrient solution. Plant roots are immersed in a nutrient solution that is regularly tested and dosed to ensure that the correct chemical composition is maintained.
- **Aeroponics**: The National Aeronautics and Space Administration (NASA) created this innovative indoor growing method. NASA first used the term "aeroponics" in the 1990s when they became interested in finding efficient ways to grow plants in space, explaining "plant growth in the Earth's atmosphere/nebula with very little water." An aeroponic system uses up to 90% less water than the most efficient hydroponic systems. It absorbs more vitamins and minerals, making them healthier and more nutritious.
- **Aquaponics**: Aquaponics systems combine fish and plants into a single ecosystem. In vertical farms, plants are fed with waste produced by fish grown in inland ponds, which contain many nutrients. Waste water after plant filtration and cleaning into fish ponds. This simplifies economics and production and maximizes efficiency. Aquaponic systems help make this closed-loop system more common.

Remote sensing in horticulture:

A remote sensing system provides four basic components for measuring and recording data about a remote area. These components include power source, transmission line, target and satellite sensor (Singh et.al., 2014). Remote sensing has great utility in area cover, mapping such as vegetation, oil, water, forests and human activities. The first case of using remote sensing techniques in India was recorded in a coconut wilt experiment in 1970 (Ray, 2016). Some applications include agricultural development, crop area and yield assessment, precision farming, cropping system analyses, agricultural water management, drought assessment and monitoring, watershed development, land resource mapping, forecasting of potential fishing areas, climate impacts on agriculture (Navalgund and Ray, 2000, Panigrahy and Ray, 2006, Navalgund *et al.*, 2007).

Crop insurance: Crop insurance can benefit farmers who lose their crops due to sudden changes in weather conditions. They also cases of insurance fraud. To verify this, insurers can use the red and infrared bands of satellite images in conjunction with the NDVI (Normalized Differential Vegetation Index) and crop testing to detect timescales. Soil moisture: remote sensing techniques can be useful for determining soil moisture using active and passive sensors from space. Active sensors illuminate their target and record backscatter, resulting in high spatial resolution but low accuracy, while passive sensors measure naturally emitted electromagnetic waves with high accuracy but low resolution. Crop stands: Remote sensing is useful to identify the cultivated stands and thus the total area of the cultivated stands and its production. Yield estimation: Remote sensing is a very useful toll for estimating yields of different annual crops (Maja and Ehsani,2010, Usha *et al.*, 2013). It has been performed such as predicting tomato processing yield using crops growth models. Modified chemistry and leaf area index for tomato processing (Yang *et al.*, 2008) estimated the physical parameters of cabbage and estimated cabbage yield using aerial photography and reflectance spectroscopy.

Detect the presence of pest and diseases:

Pests and diseases are the two main causes of production loss and economic loss in the crop industry. It can be a useful tool for early decision and identification of diseases and management of pests and by detecting changes in plant pigments, variation in Pest induced leaf bones and identification of susceptible areas of plants (Usha *et al.*, 2013). Johnson *et al.*, 1996 developed in airborne multi-faceted digital imaging system related to reflectance. Seasonal development of the soil fungus complex and the southern root know nematode in kenaf (Hibiscus cannabinus) was monitored using multiregional NIR and *et al.*, 1999 (Borengasser *et al.*, 2001) demonstrated that when citrus foliar lesions develop on citrus leaves, the spectral reflectance of the leaves changes over the wavelength range of 600-700nm.

Role of GPS in precision vegetable farming:

The GPS component in precision vegetable farming performs the most factor (Hildreth JC 2003). The perfect score starts with good supervisors and new operators resources like planters, fertilizer spreader, qharvesters is needed (Matolcsi *et al.*, 2008, Rovelli, 2002). Precision farming is an integrated crop management approach that seeks to the actual needs of crops for small areas of an agricultural region. Data collected in the field, such as weed location, area boundaries and reported crop quality is easily transferred to others. Applications for GPS-based precision farming has been used for tractor guidance, area mapping, soil sampling and farm preparation, crop reconnaissance, flexible scale programs and mapping productivity map. GPS allows to operate in low visibility terrain issues, such as rainfall, grain, fog and darkness. Growers can gain additional benefits by combining use of several other soil improvers and fertilizers, determining economic thresholds for pest and weed control and protecting organic energy source for future use. It also allows pilots to providers, can anticipate further changes as GPS is steadily upgraded. With the current civilian service provided by GPS, the country is focusing on using second and third city signals on GPS satellites.

Nuclear technology in horticulture:

Most people are aware of the contribution of nuclear technology in power generation and its diversification. The impact of this technology is even greater for non-energy applications (Bagher *et al.*, 2014). A large amount of energy involved in the cleavage of the atom can be used for various peaceful applications (Charles, 2016). Cultivation is one of the important sectors in the framework of activities using atomic energy for peaceful purposes with great social impact. Ionizing radiation provides an effective to many unstainable productivity-enhancing technologies i.e., the use of hazardous chemicals. Ionizing radiation involves the controlled application of energy from gamma rays, electrons and X-rays to enhance the production and preservation of various crop products. In the field of horticulture, recent research has shed light on the potential application of new nuclear energy for mutagenicity, pest control, increased agricultural yields and improved post-harvest product quality.

Table 1: Dose limits for radiation processing of horticultural produce (Extract from the gazette of India, 2012)

Class	**Commodities**	**Purpose**	**Dose limit (kGy)**
Class I	Underground vegetables	Inhibits sprouting	0.02-0.2
Class II	Fresh fruits and vegetables	Delay ripening	0.2-0.2
Class III	Dried fruits	Reduction of microbes	1.5-5.0
Class VI	Dried vegetables, dried herbs, coffee, tea and cocoa.	Microbial decontamination	6.0-14.0

Irradiation process:

During irradiation, the implant material is intentionally irradiated to change or improve its properties. This process is achieved by placing the material near a radiation source, such as cobalt-60, for a fixed period of time during which the product is exposed to the radiation emitted by the radiation source (Vose, 2013). Radiant energy arriving at the product is absorbed into the tissues of the material; amount depending on its mass and composition and exposure time. A certain amount of radiation energy is required to achieve the desired effect in the product; the exact value is determined by research (Iaeorg, 2017). The optimal dose of ionizing radiation from the point of view of mutagenicity depends on the genotype, the radiation and the treatment device. Gamma radiation was necessary in the early days of horticultural plant nuclear technology, but today gamma radiation is often used as mutagens.

Table 2: Optimum dose of gamma irradiation for mutagenesis in ornamental plants

Crop	Treated part	Optimum dose (krad)
Amaryllis	Bulb	0.25-5.0
Bougainvillea	Stem cutting	0.25-1.25
Canna	Rhizome	2.0-4.0
Chrysanthemum	Rooted cuttings and suckers	1.0-3.5
Gerbera	Rooted plantlets	1.0-2.0
Gladiolus	Corns	0.25-5.0
Hibiscus	Stem cutting	1.0-4.0
Rose	Stem with budding eyes	2.0-6.0
Marigold	Rooted cuttings and seeds	0.5-2.0
Lantana	Stem cuttings	1.0-4.0
Tuberose	Bulb	0.25-8.0
Poitulaca	Stem cuttings	0.25-1.25

(Source: Dutta, 2009)

Conclusion:

The horticulture industry as a diversified agricultural function has emerged as a potential source of employment. It contributes to the long-term growth of the sector and the economy. India has emerged as a leading producer of horticultural goods and has established itself as a reliable source of job creation, income generation, and export support. With the help of better allocation of resources, infrastructure development, technological innovation, and better implementation of policies for the development of horticulture sector, India is expected to gain a prominent position in the global arena. A conscious effort to implement specific strategies will enable the horticulture sector to grow and prosper in the future.

References:

1. Tiwari, A., Singh, A.K., Singh, S., Singh, B., & Pal, A.K. (2015). University-Industry based partnership for horticultural development in India- needs and challenges. *Abst: International Conference on Issues and Challenges in Doctoral Research, 25 August, B.H.U., under the aegis of global networks of doctorates, Varanasi*, p.21.

2. Suparworko, & Taufani, B. (2017). Urban farming construction model on the vertical building envelope to support the green buildings development in Sleman, Indonesia. *Procedia Engineering, 171*, 258-264.
3. Singh J.P., D. Deb, & R.S. Chaurasia (2014). Use of Geo-spatial technology as an evolving technology of 21st century for natural resource management in different region of India. In *Emerging Technology of 21st century, New India Publishing Agency (11May 2015).*
4. Ray, S.S. (2016). Remote sensing for agricultural applications. *GeoSmaart India, Geomatics for Digital India, March 2, 2016.*
5. Navalgund, R.R., Jayaraman, V., & Roy, P.S. (2007). Remote sensing applications: An overview. *Current Science, 93(12),* 1747-1766.
6. Maja, J.M., & Ehsani, R. (2010). Development of a yield monitoring system for citrus mechanical harvesting machines. *Precision Agric. J., 11(5),* 475-487.
7. Usha, K., & Singh, B. (2013). Potential applications of remote sensing in horticulture. A review. *Scientia Horticulturae, 153,* 71-83.
8. Yanga, C., Liu, T.X., & Everitt, J.H. (2008). Estimating cabbage physical parameters using remote sensing technology. *Crop Protect., 27,* 25-35.
9. Borengasser, M., Gottwald, T.R., & Riley, T. (2001). Spectral reflectance of citrus canker. *In: Proceedings of the Florida State Horticultural Society, vol, 114,* 77-79.
10. Hildreth JC (2003). The Use of Short-interval GPS Data for Construction Operations Analysis. *PhD Thesis, Virginia Tech.*
11. Matolcsi T, Matolcsi M (2008). Coordinate time and proper time in the GPS. *European journal of physics, 29,* 1147.
12. Rovelli C (2002). GPS observables in general relativity. *Physical Review D, 65,* 044017.
13. Bagher, A.M., Nahid, A., Mohsen, M., & Vahid, M. (2014). Nuclear techniques in agriculture and genetics. *American Journal of Bioscience, 2(3),* 102-105.
14. Vose, P.B. (2013). *Introduction to Nuclear Techniques in Agronomy and Plant Biology: Pergamon International Library of Science, Technology, Engineering and Social Studies.* Elsevier.
15. Iaeaorg. (2017). http://www.naweb.iaea.org/nafa/news/food-irradtool0807.pdf.
16. Wortman, S.E., Douglass, M.S., & Kindhart, J.D. (2016). Cultivar, growing media, and nutrient source influene strawberry yield in a vertical, hydroponic, high tunnel system. *HortTechnology, 26(4),* 466-473.

THE SIGNIFICANCE OF PLANT PATHOLOGY IN COMPREHENSIVE PEST CONTROL STRATEGIES

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Abstract:

Entomopathogens are microorganisms that infiltrate and replicate within arthropods, such as insects, mites, and ticks, playing a crucial role in integrated pest management (IPM) strategies. They encompass a diverse range of organisms, including viruses, bacteria, fungi, protists, and multicellular animals like nematodes. These entomopathogens serve as biopesticides and employ unique mechanisms of action. Some entomopathogens enter the host insect through its mouth (per os), while others penetrate the insect's protective cuticle. Once inside, they infect the insect's midgut cells and spread throughout its body. For instance, *Bacillus thuringiensis* (Bt) bacteria produce Cry toxins, which are activated in the insect's midgut, leading to larval death. Entomopathogenic fungi like *Beauveria* and *Metarhizium* employ physical or enzymatic means to penetrate the insect's cuticle, ultimately causing the host's death. Baculoviruses, common among insects, enter through ingestion and infect various tissues, leading to host death. Entomopathogenic nematodes (EPN) form symbiotic relationships with bacteria and parasitize insects by infiltrating their body cavities. These nematodes release bacteria that aid in host degradation. Entomopathogenic protozoa, such as microsporidians, slowly weaken host insects by reducing feeding, vitality, reproduction, and lifespan when consumed. Entomopathogens are vital tools in IPM, offering specificity and environmentally friendly pest control. Their precise targeting of pests makes them essential for sustainable pest management in agriculture.

Keywords: Entomopathogen, IPM, Bacteria, Fungi, Virus, Nematode, Protozoa

Introduction:

Integrated Pest Management (IPM) stands as a widely accepted strategy in modern pest control, driven by the aim to select and employ highly effective pest management tactics while simultaneously reducing the indiscriminate use of chemical insecticides and their potential negative environmental impacts. Within the framework of IPM, biological control emerges as a pivotal component, emphasizing the utilization of natural adversaries like predators, parasitoids, and microbial pathogens, particularly entomopathogens (Jacbson, 1997).

Entomopathogens are a category of microorganisms with the capacity to infect arthropods, including insects, mites, and ticks. These microorganisms, often referred to as "entomopathogens," infiltrate their arthropod hosts, replicate within them, and subsequently spread to infect other susceptible insects. The entomopathogens encompass a wide array of organisms, encompassing noncellular agents such as viruses, prokaryotes like bacteria, eukaryotes including fungi and protists, as well as multicellular animals exemplified by nematodes. The utilization of entomopathogens as biopesticides for pest management is commonly known as microbial control and assumes a crucial role in integrated pest management (IPM) strategies directed at addressing various pest issues (Vega and Kaya, 2012).

Pathogens can be categorized into four broad groups based on their characteristics and behavior: These categories help us understand the various ways pathogens interact with hosts and their potential to cause diseases under different conditions.

A. Facultative pathogen: These are pathogens that have the ability to infect and multiply within host animals but can also reproduce in the external environment. Facultative pathogens are typically easy to culture in laboratory settings. Examples include *Bacillus thuringiensis* and *Beauveria bassiana.*

B. Opportunistic pathogen: Opportunistic pathogens are microorganisms that typically do not cause diseases but can become pathogenic under certain conditions, especially when the host's immune system is compromised. An example is *Aspergillus flavus*.

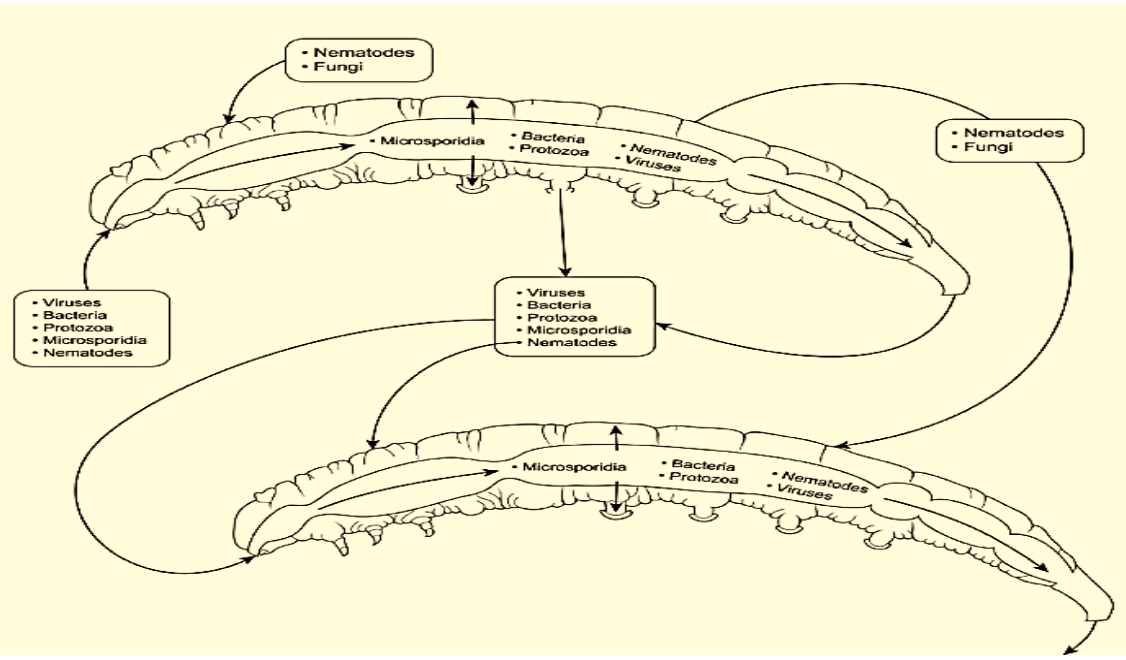
C. Obligate pathogen: Obligate pathogens are microorganisms that can only multiply within the bodies of specific hosts, causing specific diseases. They usually have a limited host range and are challenging to culture in vitro. Examples include *Paenibacillus popilliae,* microsporidia, and baculoviruses.

D. Potential pathogen: This category includes microorganisms that lack inherent mechanisms to invade or infect a host but can multiply and cause disease if they gain entry, often through wounds or other openings. Potential pathogens are typically easy to culture and do not cause specific diseases in specific hosts. They are sometimes referred to as "secondary invaders." An example is *Serratia marcescens*.

The primary portal of entry for most entomopathogens

The primary route of entry for most entomopathogens, including viruses, bacteria, protists, microsporidia, and certain nematodes, is typically through the insect's mouth (per os). Conversely, fungi and some nematodes primarily enter through the insect's protective cuticle. Entomopathogens that utilize the oral route can infect the insect's midgut cells and potentially penetrate the hemocoel, leading to a systemic infection. Similarly, those that breach the integument, such as fungi, may initiate infection on the insect's outer surface (cuticle) and subsequently penetrate into the hemocoel. Some protists and nematodes can also penetrate directly into the hemocoel through the cuticle.

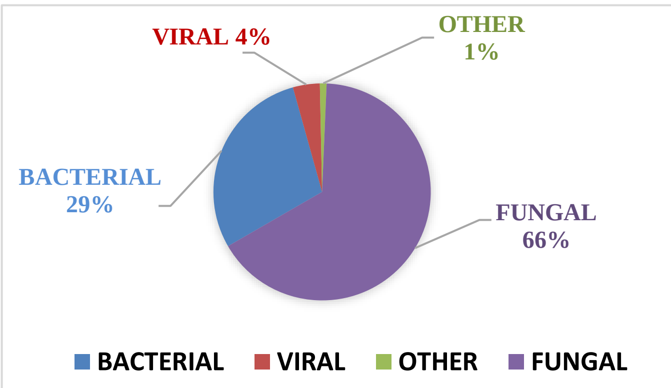
In certain instances, a few fungal species may enter the host through the mouth, or nematodes may gain entry through the anus or spiracles (although not depicted in the figure). Once these entomopathogens complete their life cycle and reproduce within the initial host, infective propagules are released, either from a living or deceased host. These propagules can then initiate new infections in other susceptible hosts, perpetuating the cycle of infection and transmission.



Source: Vega and Kaya, 2012

List of entomopathogen which are uses in ipm as biopesticides

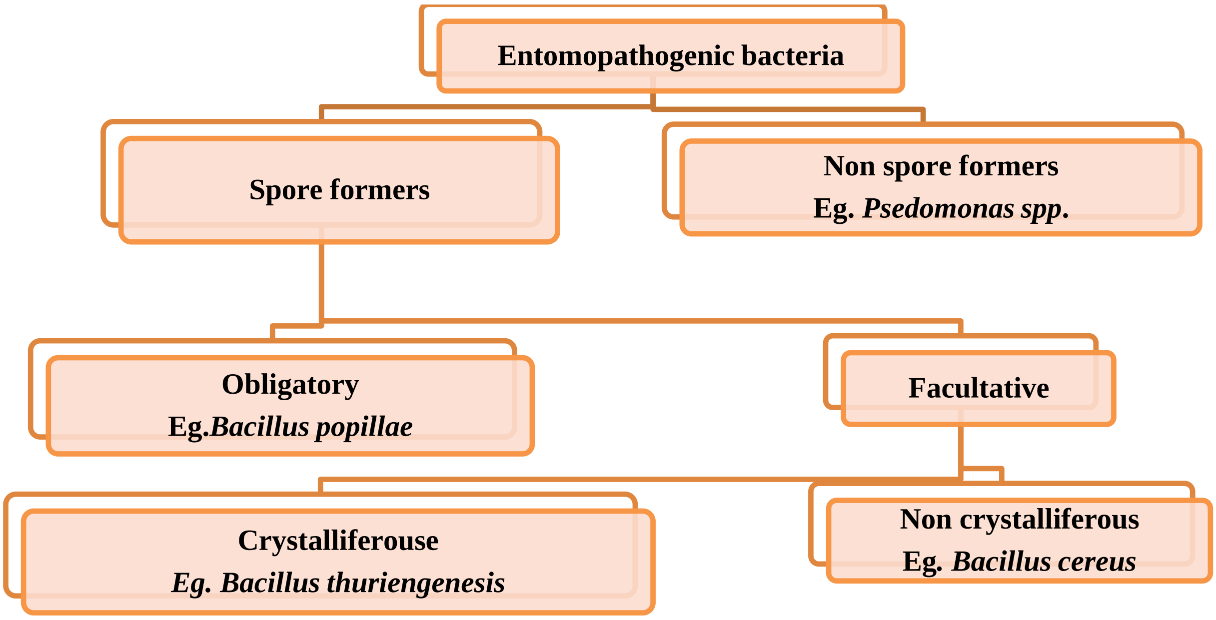
1. Entomopathogenic bacteria
2. Entomopathogenic fungi
3. Entomopathogenic virus
4. Entomopathogenic nematode
5. Entomopathogenic protozoa



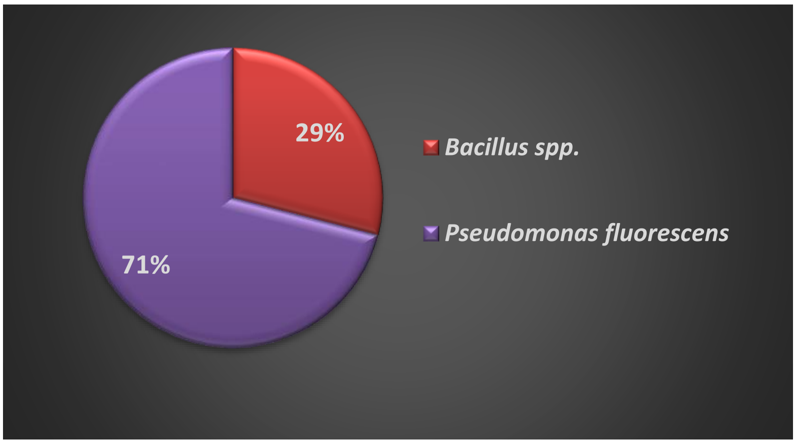
(Source: Mishra *et al.*, 2020)

1. Entomopathogenic bacteria: Entomopathogenic bacteria are unicellular prokaryotic organisms having size ranging from less than 1 µm to several µm in length. Bacteria with rigid cell wallsare cocci, rod-shaped and spiral. Entomopathogenic bacteria and their toxins are the most commercially successful microbial insecticides. Bacteria in Bio-controls of pest: *Bacillus thuringiensis, Bacillus papillae, Serratia entomophila.*

Classification of Entomopathogenic bacteria



Bacterial biopesticide used in India



(Source: Mishra *et al.*, 2020)

A. *Bacillus thuringiensis*

Bacillus thuringiensis (*Bt*), a rod-shaped, +ve positive or facultative aerobic spore-forming soil bacterium which produces parasporal inclusions upon sporulation. *Bacillus thuringiensis* (Bt) is ubiquitously present in various ecological niches, including soil, rhizosphere, freshwater, plants, insects, and stored products in warehouses. While commonly referred to as a 'soil bacterium,' its presence is not limited to soil; it is also found in diverse environments such as dead insects, forest ecosystems, and grain dust. The insecticidal properties of Bt were first identified in 1901 by Japanese bacteriologist Shigetane Ishiwata, who initially named it Bacillus sotto after isolating it from diseased silkworm larvae (*Bombyx mori*). Subsequently, in 1911, German biologist Ernst Berliner independently isolated Bt from the deceased Mediterranean Flour Moth (*Ephestia kuchniella*) in the Thuringia region. Unaware of Ishiwata's earlier work, Berliner provided a detailed scientific description and renamed it Bacillus thuringiensis. This became a valid name. Moret han 80 varieties or sub-species of *Bt* have been described so far. Bacillus thuringiensis is a gram-positive, endospore-forming bacterium that has a unique ability to produce insoluble crystal-like bodies in the cytoplasm during sporulation. These bodies are physical aggregations of many insecticidal 'Cry' (acronym. for 'crystal') proteins. Different sub-species of Bt produce distinct insecticidal proteins. Expression of Bt genes in tobacco and tomato provided the first example of genetically modified plants.

Bioinsecticide activity of *bacillus thuringiensis* proteins

Bt strains synthesize parasporal inclusion crystal proteins (Cry) and cytolytic (Cyt) toxins known as δ-endotoxins, During the sporulation process of stationary growth phase. These parasporal crystals are pathogenic to insect larvae of different order, mostly Lepidoptera, Diptera, Coleoptera etc. By synthesizing parasporal crystalline inclusion during sporulation, the bacterium can ensure its survival, since a dead insect can provide sufficient nutrients that allow the spores to germinate**,** Additionally, Bt can also synthesize other insecticidal proteins during the vegetative growth phase:- Vegetative insecticidal proteins (Vip)**,** Secreted insecticidal proteins (Sip).

Mode of action of Bt

The concerned *Bt* protein has to be ingested by the susceptible larvae as it has no contact effect.This is so because the native Bt protein is a 'protoxin' and has to be activated toxic protein (delta-endotoxin) which occurs in the midgut of only the susceptible larvae, The insect gut should be alkaline (pH 9.5 and above for Lepidoptera) and also contain a proteolytic enzyme (Trypsin) for activating the Bt protein. Once activated, the Bt protein binds to specific receptors in the midgut, creating pores in midgut cells. This process disrupts osmoregulation, leading to midgut paralysis and cell lysis. Consequently, the gut contents leak into the insect's body cavity (hemocoel), and the insect's blood (hemolymph) enters the gut, further disturbing the pH balance. Bacteria that enter the body cavity cause septicemia, ultimately resulting in the death of the host insect.

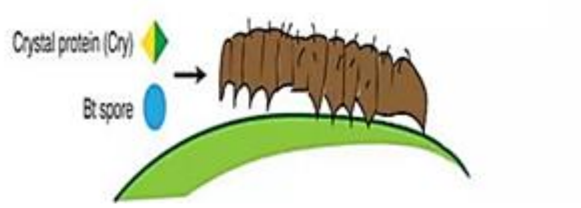
Different insects exhibit various responses to Bt toxins, depending on factors like crystal proteins (delta-endotoxin), receptor sites, production of other toxins (exotoxins), and the requirement of spores:

Type I response: Insects experience midgut paralysis shortly after ingesting delta-endotoxin. Symptoms include feeding cessation, increased hemolymph pH, vomiting, diarrhea, and sluggishness. General paralysis and septicemia develop within 24-48 hours, leading to the insect's death. Examples of insects with Type I responses include silkworms, tomato hornworms, and tobacco hornworms.

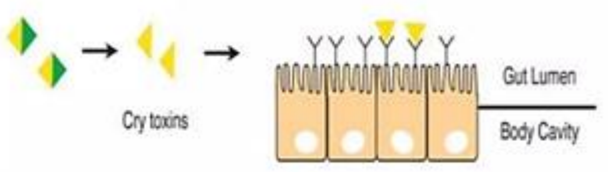
Type II response: Similar to Type I, midgut paralysis occurs rapidly, but there is no general paralysis. Septicemia sets in within 24-72 hours. Insects like inchworms, alfalfa caterpillars, and cabbage butterflies exhibit Type II responses.

Type III response: Midgut paralysis occurs, followed by feeding cessation. Insects may remain active with no general paralysis. Mortality typically occurs within 48-96 hours, and it increases if spores are ingested. Examples include Mediterranean flour moths, corn earworms, and gypsy moths.

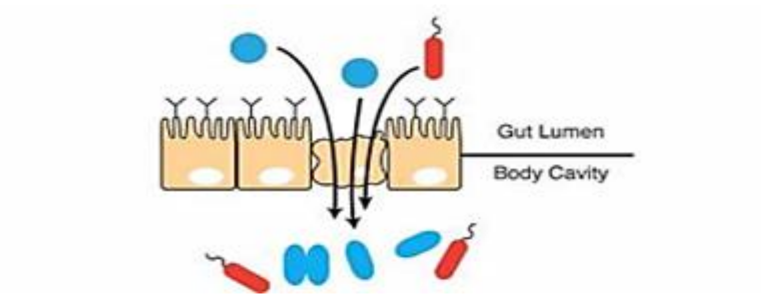
Type IV response: Insects are naturally resistant, with older instars being less susceptible than younger ones. Midgut paralysis happens, followed by feeding cessation, and insects may remain active. Mortality usually occurs within 72-96 hours or more, with higher mortality if spores are ingested. Cutworms and armyworms belong to this category (Dara., 2017).



(A) Larve ingest Bt spore and Cry proteins



(B) In Larve midgut, proteolytic digest of protein release Cry toxin, which bind to epithelial receptors



(C) Toxin binding cause cell lysis destroying barrier to body cavity

Pathological Symptoms

- Larvae becomes inactive, stops feeding
- The head capsule becomes large compared to body size

- The larvae become flaccid and dies, usually within days or a week
- The body contents turn brownish-black as they decompose.

Classification of Cry toxins according to their insect host specificities

Main class	Order	Cry toxin
Group 1	Lepidoptera	Cry1, Cry9, and Cry15
Group 2	Lepidopteran and dipterous	Cry2
Group 3	Coleoptera	Cry3, Cry7, and Cry8
Group 4	Diptera	Cry4, Cry10, Cry11, Cry16, Cry17, Cry19, and Cry20
Group 5	Lepidoptera and Coleoptera	Cry11
Group 6	Nematodes	Cry6

Bioinsecticides based on *Bt*

- About 90% of microbial biopesticides are derived from a single entomopathogenic species *Bacillus thuringiensis*
- The varieties of Bt used commercially for the production of bioinsecticides for thecontrol of insect of different order.

Bt variety	Susceptible insects	Cry toxin
Bt. var. *kurstaki*	Lepidoptera	Cry1Aa, Cry1Ab, Cry1Ac,Cry2Aa, and Cry2Ab
Bt. var. *aizawai*	Lepidopteran	Cry1Aa, Cry1Ab, Cry1Ba,Cry1Ca, and Cry1Da
Bt. var.*sandiego*	Coleoptera	Cry3Aa
Bt. var.tenebrionis	Coleoptera	Cry3Aa
Bt. var.*israelensis*	Diptera	Cry4A, Cry4B, Cry11A, andCyt1Aa

B. *Bacillus papillae*

Bacillus papillae is a naturally occurring bacterium that has been extensively manufactured for the management of various insect pests. It holds the distinction of being the first insect pathogen to be officially registered in the U.S. as a microbial control agent. In pesticide applications, it is commonly dispersed onto turf, allowing it to permeate the underlying soils. *Bacillus papillae* specifically targets the Japanese beetle (*Popillia japonica*). Other varieties of *Bacillus papillae* have been found to work on other beetles in the family

Scarabeaidae, which include the Japanese beetle, the chafers (a pasture pest) and the beneficial dung beetles.

***Serratia entomophila*:**

Serratia entomophila is frequently encountered in New Zealand pastures but has been infrequently isolated in other parts of the world. Both pathogenic and non-pathogenic strains of *S. entomophila* and *S. proteamaculans* coexist in mixed populations in soil where larvae are present. Certain strains of *S. entomophila* have undergone rigorous testing for safety concerning mammals, non-target organisms, and the environment. Consequently, they have been registered as New Zealand's inaugural indigenous microbial control agent for insects.

- Pest controlled includes beetles, grass grub (*Costelystra zealandica*).

Commercially available *Bacillus thuringiensis*-based pesticides to control various pests

Bacteria used	**Target pests**	**Trade name**
Bacillus popilliae	Japanese beetle grubs	Doom, Japidemic, Milky Spore Disease, Grub Attack
B. sphaericus	Mosquito larvae	Sphericide, VectoLex
B. thuringiensis subsp. aizawai	Lepidopterans	Certan
B. thuringiensis subsp. israelensis	Mosquito, blackflies and fungus gnats	Bacticide, Summit Bactimos, Bacto Power-Bti, Biodart M, Larvect50, Deltafix, Biovectra Spicbiob, VectoBac, Vectocid
B. thuringiensis subsp. kurstaki	Lepidopteran larvae	Abtec Btk, Agni, Bioasp, BioDart, Bactur, Biobit, Bioworm, Biolep, B.T.Killer, Caterpilin, Cezar, CID, Deflin, DiPel, Dipole, Gold Btk, Halt, JasBT, KavachBt, KrishiBio, Prasar, Lipel, Mahastra, Minchu, Neelstaki
B. thuringiensis subsp. tenebrionis	Colorado potato beetle, stored pests, coleopteran adults and larvae	Foil, M-one, M-track, Novardo, Trident
B. thuringiensis subsp. Galleriae	Lepidopteran larvae, bollworms, Diamondback moth	Spicturin

Usta (2013)

Advantages of bacterial biopesticides:

i. **Safe to use:** Bacterial biopesticides pose no harm to wildlife, humans, or other non-target organisms. They are environmentally friendly and do not leave harmful residues.

ii. **Specific:** Bacterial biopesticides exhibit specificity towards their target organisms, meaning they target the pests without affecting beneficial insects or organisms.

iii. **Compatibility**: Bacterial insecticides can be used alongside synthetic chemical biopesticides, allowing for integrated pest management strategies.

iv. **Non-hazardous residues:** Bacterial biopesticides leave no harmful residues on crops, making them suitable for use even during the harvesting stage.

v. **Natural establishment**: Bacterial biopesticides are self-sustaining and can persist in the environment. They remain effective throughout subsequent crop growth seasons.

Disadvantages of microbial insecticides

i. **Limited pest control:** Microbial insecticides are typically effective against specific species or groups of insects. They may not control all pests, allowing some to survive and cause damage.

ii. **Impact on beneficial organisms:** In pest management programs using predators and parasitoids, the use of synthetic pesticides can harm beneficial organisms. Careful selection of chemical pesticides is essential to avoid this harm.

iii. **Environmental sensitivity**: The effectiveness of microbial insecticides can be affected by environmental factors such as ultraviolet radiation and heat. They are often recommended for application during specific times, like morning hours.

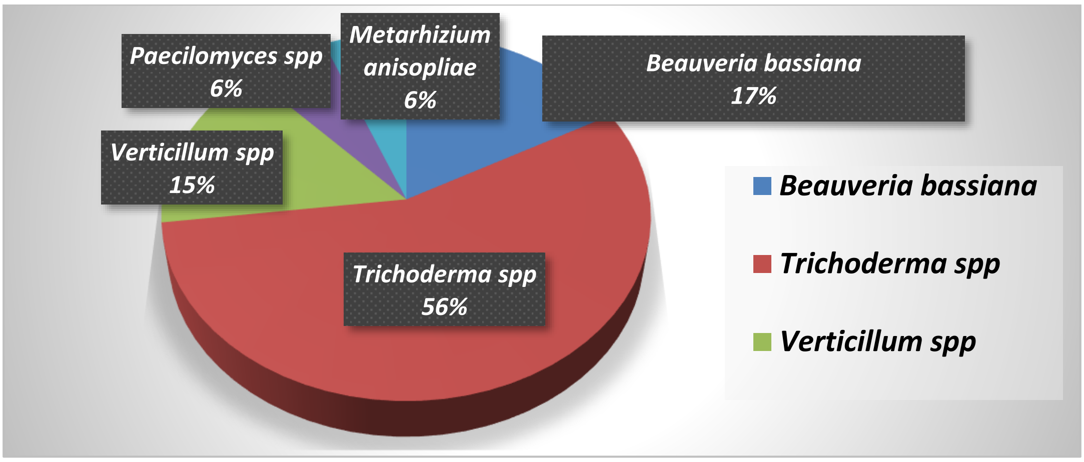
iv. **Special formulation and storage**: Microbial pesticides require specific formulation and storage procedures to maintain their virulence. Proper storage is crucial to preserve their effectiveness.

v. **Limited availability:** Mass production of natural enemies throughout the year can be challenging, limiting their availability in the market. Product registration processes and limited availability can restrict the use of biopesticides compared to chemical pesticides.

vi. **Environmental dependency:** The effectiveness of biopesticides relies heavily on external environmental conditions, including temperature, relative humidity, and rainfall. Suitable weather conditions are essential for the multiplication and survival of biocontrol agents in the field.

Entomopathogenic fungi: - The term "entomopathogenic fungi" (EPF) designates a group of fungi that serve as natural pathogens for a diverse range of insects and other arthropods. Fungi were the initial microorganisms discovered to induce diseases in insects due to their development on the surfaces of their hosts. Many EPF are either obligate or facultative pathogens, with some engaging in symbiotic relationships. Their growth and progression are primarily constrained by external environmental conditions, particularly high humidity or moisture, and suitable temperatures for sporulation and spore germination. The illnesses inflicted by fungi on insects are referred to as "mycoses."

Type of fungal biopesticides used in india



(Source: Mishra *et al.*, 2020)

Mode of action of EPF

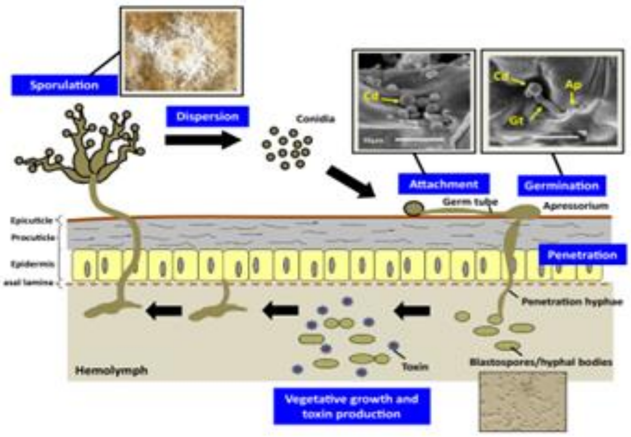
The mode of action of entomopathogenic fungi (EPF) varies, leading to the demise of insects through diverse mechanisms such as inducing starvation or producing toxins. These fungi, which are pathogenic to insects, generate a range of toxins and extracellular enzymes, including proteases and chitinases, that assist in overcoming the host's physical defenses. The primary barrier to infection in insects is the cuticle, requiring physical or enzymatic means to breach its tough structure. The infectious unit in most fungi is a spore, typically a conidium. In many instances, conidia adhere to the cuticle or secrete adhesive mucus as they swell during pregermination. Under favorable conditions, the conidium germinates into a short germ tube, forming small swellings known as appressoria. The appressorium attaches itself to the cuticle and extends an infection peg, establishing a secure attachment necessary for the fungus to penetrate the host physically. Hyphae then infiltrate the integument layers through enzymatic dissolution of chitin and protein, initially ramifying within the cuticle before reaching the hemocoel and internal organs. The invasion by the fungal mycelium progresses until the insect is essentially filled with the fungus, resulting in a firm texture. Conidiophores are subsequently produced, erupting through the cuticle and generating spores on the exterior of the insect, thereby infecting nearby healthy insects as well. The host's demise occurs through tissue obliteration (choking) and the toxins produced by the fungus.

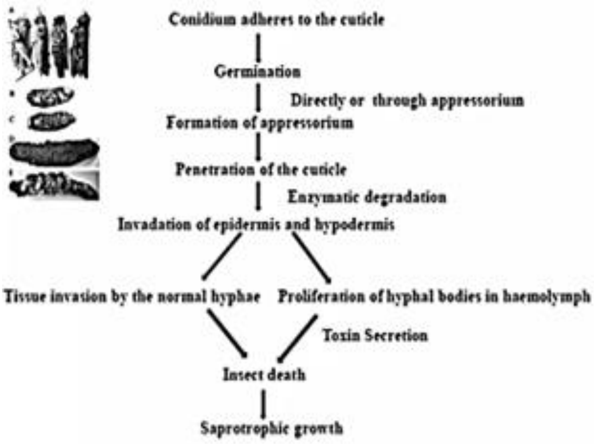
Symptoms

The early symptoms of the fungal disease include a loss of appetite and attempts to climb higher. Subsequently, there is a decrease in irritability, leading to general or partial paralysis, discolored patches on the integument, and an increase in blood acidity. As the disease progresses, the body hardens, and the insect stands upright on its legs at the time of death. The demise occurs within a week, sometimes even within 24 hours.

The causes of death can be attributed to various factors:

a) Hyphae may force apart muscles.
b) Blood cells may cease circulating due to the increased presence of hyphae.
c) Blockage of the gut by the fungal growth.
d) The toxin produced by the fungus also contributes to the mortality of the host.





Source: Mascarin and Jaronski, 2016 **Source: Sinha *et al.*, 2016**

A. *Beauveria* species: The white muscardine was the first disease in animals caused by a fungus. It has one of the largest host lists among the imperfect fungi and also occurs in soil as a ubiquitous saprophyte. The genus *Beauveria* - 49 species - approximately 22 effective pathogen. Important species of white muscardine disease, *Beauveria bassiana, B. Brongniartii, B. amorpha & B. caledonica*. It produces beauvericin, a cyclic peptide which alters ion permeability of membranes. It is effective against European corn borer, codling moth, cabbage caterpillar, whitefly, mango mealybug, *Spodoptera litura, Holotrichia serrata* etc.

B. *Metarhizium* Species: The green-muscardine fungus, *Metarhizium anisopliae*, is as commonly and as widely distributed with a wide host range. In 1879, Metchnikoff isolated the fungus from the beetle *Anisoplia austriaca* and suggested its use as a microbial agent against insect pests. *Metarhizium anisopliae* has two types :- The short-spored form, *M. Anisopliae var. anisopliae* (conidia 3.5-9.0 µm). The long-spored, *M. Anisopliae var. major* (conidia 9.0-18.0 um).

C. *Verticillium* spp.: It is known as the "white-halo" fungus because of the appearance of the white mycelium around the edges of the infected scale. *Verticillium fusisporum* infects several species of Homoptera but is a less dominant fungus than *V. lecanii* because of its slower rate of sporulation and fewer spores.

D. *Nomuraea* species: - Samson (1974) described the genus *Nomuraea* in detail and retained the species *N. rileyi and N. atypicola.* These fungi form,a dense white mat on insect, turns pale green or purple. *Nomuraea rileyi* is used against green clover worm, cabbage looper, cabbageworm; armyworms, *Heliothis zea, H. virescens and Trichoplusia ni*, *Spodoptera litura*, tobacco budworm etc.

E. *Hirsutella* species*:* The genus *Hirsutella* includes over 30 species that infect nearly all systematic groups of insects and certain mites. In the infection, the amount of mycelium that covers the cadaver is very sparse. Mycar is a commercial formulation containing *Hirsutella thompsani*. *Hirsutella thompsoni* is commercially available as 'Mycar' for the controlof citrus rust mite, coconut mite. Mycohit is a commercial myco acaricidewhich has the *Hirsutella thompsonii* strain MF (Ag)5.

Commercially available fungi-based biopesticides

Fungi	**Host range**	**Products**
Beauveria Bassiana	Effective against a variety of insects such as rickets, white grubs, fire ants, flea beetles, plant bugs, grasshoppers, thrips, mites, mosquito larvae and aphids, fungus gnats, whiteflies and to stored pest	Botani Gard, Mycotrol, Naturalis, Racer BB, Ostrinil, Brocari l, Mycotrol, Mycotrol-0 BotaniGard, Boverin, Naturalis-L, Naturalis- H&G Naturalis-T&O
Metarhizium anisopliae	Effective against a wide range of pests. Black vine weevil, locusts and grasshoppers	Bio-Blast, Bio 1020, Bio-Path, Green Muscle, Met 52 Metaquino Pacer MA Tick- Ex
Trichoderma viride	Effective against Rot disease	EcosomTV, Tricon, Trieco
Trichoderma harzianum	Effective against a variety of soil pathogens	Rootshield, BioTrek, Supresivit
Paecelomyces Fumosoroseus	Effective against whiteflies and thrips	PFRE-97, PreFeral
Verticillum lecanii	Effective against whiteflies and thrips	Vertalec, Mycotal

Usta (2013)

Advantages of fungi-based biopesticides:

a) **Wide host range:** Fungi-based biopesticides have a broad host range, making them effective against various pests, including those in fields, storage, and soil.

b) **Ease of production:** Commercially important fungi like *Beauveria*, *Metarhizium*, *Lecanicillium*, and *Isaria* are relatively easy to mass-produce, requiring minimal substrate resources.

c) **Effectiveness and specificity:** Fungi-based biopesticides are highly effective and specific in targeting pest organisms.

d) **Environmentally friendly**: They are eco-friendly and have minimal impact on the environment.

Disadvantages of fungi-based biopesticides:

a) **Ideal environmental conditions:** Fungi are sensitive to environmental conditions, particularly requiring humidity levels of 80% or higher for spore germination and cuticle penetration in arthropods.

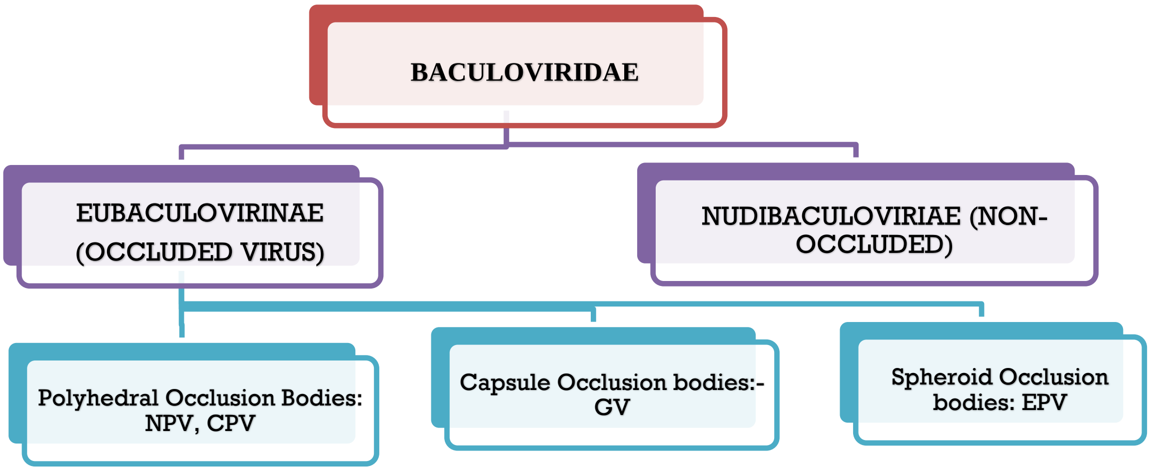
b) **Temperature and UV sensitivity:** Fungi's survival and effectiveness can be affected by temperature fluctuations and exposure to UV radiation.

c) **Challenging conidia production:** The production and stabilization of fragile conidia or durable resting phases in fungi can be challenging.

d) **Higher costs:** Fungi-based biopesticides can be costlier to produce compared to other microbial methods.

3. Entomopathogenic virus: - EPVs are viruses that infect and kill insects. Baculoviruses are the most common and most widely studied group of viruses pathogenic for insects. Baculoviruses are rod-shaped particles which contain circular double stranded DNA genomes.

Classification of entomopathogenic virus



Mode of action of EPV: The mode of action of viruses is similar to that of bacteria, requiring ingestion by insect larvae to initiate infection. Upon ingestion, the virus enters the insect's body through the intestinal epithelium, leading to a systemic infection in the host cells. In the case of NPV, the virus passes through the intestinal epithelium into the hemocoel, fat body, and other tissues, disrupting the integrity of these tissues and ultimately liquefying the cadavers. However, in the case of GV, the infection remains localized within the insect midgut.

The mode of action of EPVs typically involves several stages-

a) Entry through Ingestion: The common mode of entry for insect viruses is through ingestion (per os). Initially, a susceptible insect host feeds on plants contaminated with the occluded form of the virus.

b) **Dissolution in alkaline environment:** Once ingested by the insect, the occlusion bodies (containing the virus) dissolve in the alkaline environment of the host's midgut, typically with a pH of 8.0. This dissolution releases the infective particles, which can be virions or ODV/PDV (occlusion-derived virus/progeny virus), into the midgut.

c) **Peritrophic membrane entry:** The virions (ODV/PDV) enter the peritrophic membrane, either by direct diffusion in association with the microvilli on the brush border of midgut columnar epithelial cells or through adsorptive endocytosis. Their entry may also be receptor-mediated.

d) **Uncoating:** After entering the midgut cells, uncoating of the ODV/PDVs occurs before they pass through nuclear pores.

e) **Nucleus entry:** The uncoated ODV/PDVs travel into the nucleus along with cellular action. Within the nucleus, the DNA of the nucleocapsid is uncoated, and the DNA unwinds due to the phosphorylation of a DNA-binding protein (P6.9). This unwinding enables the expression and replication of viral DNA through the action of viral DNA-polymerase enzymes.

f) **Budding through nucleus:** Newly formed nucleocapsids bud through the nuclear membrane, acquiring an envelope derived from the nuclear membrane itself.

g) **Cytoplasmic membrane envelope:** After shedding into the cytoplasm, the virus acquires another envelope consisting of the cytoplasmic membrane and virus-coded glycoprotein spikes through budding, this time through the midgut's basal membrane.

h) **Budded Viruses (BVs):** At this stage, the virus is referred to as Budded Viruses (BVs). These BVs are released into the insect's hemolymph, where they undergo multiple rounds of multiplication within cells of susceptible tissues.

i) **High replication**: As a result of this process, a single caterpillar that succumbs to virus infection may have over 10^9 occlusion bodies, originating from an initial dose of just 1000.

j) **Spread facilitation:** Infected larvae often exhibit negative geotropism before succumbing to the virus, facilitating widespread dissemination.

k) **Speed of death:** The speed at which the death of the insect host occurs is influenced by environmental conditions. Under optimal conditions, the target pest may be killed in 3-7 days, but when conditions are unfavorable, the death of insects may take 3-4 weeks (Cunningham, 1995; Flexner and Belnavis, 2000).

The main characters and features of important insect viruses are given below:

Nuclear polyhedrosis virus

- ✓ 41% of arthropod viruses develop in host cell nuclei, virions occluded singly/groups in polyhedral inclusion bodies.
- ✓ Rod shaped, double stranded DNA
- ✓ POBs 0.2-15μm in diameter
- ✓ Highly host specific
- ✓ Enters through injection of plant material into insect gut through mouth.

Cytoplasm polyhedrosis virus

- ✓ Develop only in cytoplasm of host midgut epithelial cells
- ✓ Virions occluded singly in polyhedral inclusion bodies, Ds RNA
- ✓ Infection confined to midgut and does not spread to other tissues
- ✓ Infection not always lethal but shows larval growth reduction
- ✓ Continuously shed infective polyhedral in faeces.

Granulosis virus-

- ✓ Develop either in the nucleus/cytoplasm/ tracheal matrix / Fatbodies/epithelial cells of host
- ✓ Virions are occluded singly in small inclusion bodies called capsules.
- ✓ Rod shaped virion, Ds DNA
- ✓ Oval occlusion bodies about 200 x 400nm
- ✓ They enter through ingestion, similar to NPV
- ✓ Fat body is the major organ invaded.
- ✓ Diseased larvae – less active, flaccid, fragile, wilted prone to rupture in later stages,death in 6-20 days.

Symptoms:

Larvae infected with NPV may exhibit initial symptoms such as a whitish and granular appearance or, in some cases, a very dark coloration. Certain larvae may also exhibit unusual behaviors, such as climbing to the top of the plant canopy, ceasing to feed, becoming limp, and hanging from the stems or upper leaves, a condition often referred to as "caterpillar wilt" or "tree top." Meanwhile, Ginfected individuals may become milky white and cease feeding. In both scenarios, the internal contents of the deceased larvae undergo liquefaction, and the cuticle easily ruptures, releasing infectious viral particles. Typically, death resulting from a viral infection occurs within a span of three to eight days.

Commercially available EPVs products

Target Pests	Host	Product available
NPVof *Helicoverpa armigera* (HaNPV)	*Helicoverpa armigera Helicoverpa zea*	Biokill-H, BioVirus-H, Heli-Cide, Heliokill, Helimar-NPV, Helivax, Jas Viro–H, Helicop, Heligard, Somstar-Ha
NPV of *Spodoptera litura (*SlNPV)	*Spodoptera Litura, S. exigua*	BioVirus-S, Jas Viro–S, Spodo-Cide, Spodopterin, Somsta-SL
Nuclear polyhedrosis for Gypsy moth	Gypsy moth caterpillars	Gypchek virus
Tussock moth NPV	Tussock moth caterpillars	TM Biocontrol-1
Pine sawfly NPV	Larvae of pine sawfly	Neochek-S
Granulosis virus for Codling moth (GV)	Codling moth caterpillars	Madex, Carpovirusine, CYD-X
Granulosis virus for Turnip moth (GV)	Turnip moth caterpillars	Agrovir

Usta (2013)

Advantages of viral biopesticides:

a) **Human and environmental safety**: Viral biopesticides are safe for humans and non-target organisms.
b) **Resistance prevention:** Target pests are unlikely to develop resistance against viral biopesticides.
c) **Compatibility:** Viruses can be integrated with other insect control methods, including chemical pesticides.
d) **Self-perpetuating:** Viruses are self-sustaining and help maintain control over pest populations.
e) **Prevention of secondary pest outbreaks:** The use of viral biopesticides does not lead to secondary pest outbreaks.
f) **Residue-free:** They leave no pesticide residues in the environment.
g) **No pre-harvest interval:** There is no need for a waiting period before harvesting crops treated with viral biopesticides.

Disadvantages of viral biopesticides:

a) **Limited pest range:** Viral biopesticides may not be effective against a broad spectrum of pests compared to chemical pesticides.

b) **Extended control period:** Successful pest control with viral biopesticides often requires a longer period of lethal infection.

c) **Environmental sensitivity:** Viruses can be inactivated by environmental factors such as ultraviolet light and extreme temperatures.

4. Entomopathogenic Nematodes (EPN): - Entomopathogenic nematodes are soil-inhabiting parasitic insects, living inside the bodies of their hosts. The most commonly studied genera are those that are useful in the biological control of insect pest, the Steinernematidae and Heterorhabditidae.

Symbiotic bacteria with EPN

- Both *Xenorhabdus* and *Photorhabdus* are with peritrichous flagella.
- It have primary and secondary phases
- Primary phase – optimizes nematode development
- Secondary phase –supplies nutrition and antibiotics to the developing nematodes.
- Nematode protect bacteria in their gut and acts as vector.
- Bacteria convert the insect into suitable food for the nematode's survival, reproduction and produces toxins for killing insect.

Nematode-bacterium complex:

Nematode depends on bacterium for:

- Killing its host
- Creating a suitable environment for nematode development, and prevent secondary infection by microbes.
- Serving as food source
- Breaking down host tissues to serve as nutrient source.

Bacterium depends on nematode for:

- Protection from the external environment
- Penetration into host's haemocoel
- Inhibition of host's antibacterial proteins

Classification of EPNs based on searching behavior

Ambushers

- Have an energy-conserving approach and lie-in-wait to attack mobile insects in the upper soil such as army worm, cutworm, etc. Eg: *Steinernema carpocapsae*

Cruisers

- Highly active and find their host underground. Therefore, they are effective against less mobile pests such as white grubs (Scarab beetles). Eg: *Steinernema glaseri* and *Heterorhabditis bacteriophora*

Mode of action of entomopathogenic nematodes

When infective juveniles of entomopathogenic nematodes are applied to the soil surface in fields or the thatch layer on golf courses, they begin their search for insect hosts. Upon locating an insect larva, the non-feeding infective third-stage juveniles (ranging from 0.4 to 1.5 mm in length) gain entry into the insect through natural openings like the mouth, anus, or breathing holes. Inside the insect's body cavity, the nematodes release their symbiotic bacteria, which are *Xenorhabdus spp*. for Steinernematidae and *Photorhabdus spp*. for Heterorhabditidae, from their gut into the insect's bloodstream. Within the bloodstream, the nematode-bacterium complex multiplies and causes septicemia, typically resulting in the death of the insect host within approximately 48 hours after infection. The nematodes then feed on the cadaver and liquefy their host. Subsequently, nematodes reproduce and give rise to three generations of descendants on the host cadaver.

After completing this cycle, the infective juvenile nematodes exit the deceased insect and search for a new host. Under optimal conditions, nematode-infected pest stages should become apparent 5 to 7 days after their initial application. Insects killed by Steinernematidae typically take on a brown or tan color, while those killed by Heterorhabditidae tend to turn red. However, it's important to note that dead insects are not always visible.

Commercially available EPN based biopesticides

EPNs	Host range	Commercial products
H. bacteriophora	Effective against root weevils, cutworms, fleas, borers and fungal gnats. Effective against black vine weevil populations by 56–100%	BioSafe, Larvanem, Nemaplant, NemaShield-HB, Nematop, Nematech-H NemaTrident-H, NemaTrident-C, Nema-green, Optinem-H
H. indica	*H. armigera*, *Conogethes punctiferalis*, *Athalia proxima*	Soldier, Nema power, GrubTerminator, Grubcure, Calterm, Aarmour
H. downesi	Black vine weevil	NemaTrident-CT
Steinernema feltiae, *S. riobravis*	Effective against black vine weevils, strawberry root weevils, cutworms, cranberry girdler and termites	Biosafe, Ecomask, Hortscan, Guardian, Millenium, Nematac C, NoFlea, Savior WG, Scanmask, Termask, Vector
S. carpocapsae	Borer beetles, caterpillars, crane fly, moth larvae, coconut rhinoceros beetle	Capsanem, Carpocapsae-system, Exhibitline SC, Optinem-C, NemaGard, Nemastar, NemaTrident-T, NemaRed, Nemasys-C, Palma-life

Koul (2011), Gupta *et al*. (2010), Ruiu (2018)

Pathological symptoms

- ✓ Steinernematid nematodes typically induce a creamy or dark brown coloration in infected larvae, whereas Heterorhabditid nematodes tend to cause infected larvae to turn reddish or purplish in hue. An additional distinctive characteristic used for identifying *Heterorhabditis bacteriophora* is the sticky nature of the infected cadavers (Aliyu *et al.*, 2019).
- ✓ Furthermore, a noteworthy feature of the symbiotic bacteria associated with Heterorhabditis spp., Xenorhabditis luminescence, is its ability to fluoresce. This unique trait results in the entire infected insect cadaver emitting a faint glow in the dark, making it easily detectable (Poinar *et al.*, 1980).

Advantages of Entomopathogenic Nematodes (EPN):

a) **Safety:** EPNs are considered safe for humans, plants, animals, and the environment. They do not require personal protective equipment, safety masks, or re-entry intervals after application. Additionally, they leave no residues.

b) **Effective against field pests:** EPNs are effective against a wide range of field pests, including cranberry girdler, root weevil, black vine weevil, webworms, cutworms, armyworms, and wood-borers.

c) **Survival in suitable conditions:** EPNs thrive in soil with moist and humid conditions and are protected from harmful UV light and extreme temperatures, enhancing their survival.

d) **Tolerance to chemicals:** EPNs can withstand short-term exposure (2–24 hours) to many chemical and biological insecticides, fungicides, herbicides, fertilizers, and growth regulators.

Disadvantages of Entomopathogenic Nematodes (EPN):

a) **Environmental sensitivity**: EPNs are sensitive to environmental conditions, particularly UV light and high temperatures, which can be challenging to control.

b) **Cost:** EPNs are generally more expensive compared to traditional chemical insecticides. The balance between insect hosts and nematodes in natural systems can limit their long-term effectiveness. Overloading with nematodes can lead to a decline in their populations until insect populations rebound, necessitating re-application.

c) **Limited habitat:** EPNs can only infect insects that live below the soil, limiting their effectiveness against foliar-inhabiting insects. Nematode formulations also have a short shelf life.

d) **Timing of application:** Application of EPNs is best done early in the morning or evening to protect them from UV radiation.

e) **Soil moisture management:** Pre- and post-irrigation may be necessary to moisten the soil and facilitate the movement of nematodes into the target area.

5. Entomopathogenic protozoan: Entomopathogenic protozoans are an extremely diverse group of organisms comprising thousands of species that attack invertebrates, including insect species, and are commonly referred to as microsporidians. Primary hosts are European corn borer and other caterpillars, locusts, grasshoppers, crickets, forest and tree crop pests, certain crop pests, and mosquito populations (Brooks, 1988). Generally, protozoa are host- specific and slow-acting, producing chronic infections with general debilitation of the host. The infection leads to a reduction in feeding, vigor, fecundity, and longevity of the insect host when microbial control agents are applied inundatively.

Mode of action

- Microsporidia must be eaten to infect an insect.
- The pathogen enters the insect body via the gut wall, spreads to various tissues andorgans.
- These are relatively slow acting organisms, taking days or weeks to debilitate their host.

Different Protozoa used in insect management

S.no.	Protozoa	Against pest
1	*Nosema locustae*	Grasshopper, Locusts
2	*Nosema fumiferarae*	Spruce bud worm
3	*Farinocystis triboli*	*Tribolium casteneum*
4	*Varimorpha necatrix*	Corn earworm, European corn borer
5	*Leptomonas pyrrhocoris*	Bug, Pyrrhocoris apterus
6	*Herpetomonas muscarum*	Diptera
7	*Crithidia fasiculata*	Adult mosquitoes
8	*Adelina triboli*	Stored grain pests

Pathological symptoms

- ❖ Infected insects may be sluggish and smaller than normal.
- ❖ Reduced feeding and reproduction, and difficulty in molting.
- ❖ Death may fallow if the level of infection is high.

Conclusion:

Entomopathogens are invaluable allies in integrated pest management (IPM) strategies, providing effective and environmentally friendly solutions for pest control. These microorganisms, including bacteria, fungi, viruses, nematodes, and protozoa, employ diverse mechanisms of action to infiltrate and infect arthropod pests. Whether entering through the mouth or penetrating the insect's cuticle, these entomopathogens disrupt vital systems within the host, ultimately leading to its demise. *Bacillus thuringiensis* (Bt) bacteria, entomopathogenic fungi like *Beauveria* and *Metarhizium,* baculoviruses, entomopathogenic nematodes (EPN), and protozoa such as microsporidians all play specialized roles in pest management. They exhibit specificity in their targets, making them highly selective in their action while minimizing harm to non-target organisms and the environment. The use of entomopathogens as biopesticides enhances the sustainability of pest control practices in agriculture. Their role in IPM strategies contributes to reduced reliance on chemical insecticides, promotes eco-friendly approaches, and helps maintain a balanced and healthy ecosystem. As we continue to seek innovative and sustainable solutions for pest management, entomopathogens will remain essential components of our toolbox, safeguarding crops and fostering a more resilient agricultural landscape.

References:

1. Aliyu, H.U., Kela, S.L., Agbo, E.B., & Tahir, F. (2019). Isolation and Determination of Morphological Characterization of Heterorhabditid Entomopathogenic Nematodes (EPNs) from Kashere. *Pharmacology and Toxicology, 7(12),* 01-10.
2. Brooks, W. M. (1988). Entomogenous protozoa. In: Handbook of Natural Pesticides, Microbial Insecticides, Part A, Ignoffo, C. M., Mandava, N. B. (Eds.), Entomogenous Protozoa and Fungi. *CRC Press, Baco Raton, FL.,* pp. 1–149.
3. Cunningham, J.C. (1995). Baculoviruses as microbial insecticides. In: Reuveni, R. (Ed.), Novel Approaches to Integrated Pest Management. *CRC Press, Inc., Boca Raton, FL,* pp. 261–292.
4. Dara, S. K. (2017). Entomopathogenic microorganisms: modes of action and role in IPM. *Agriculture and Natural Blogs, University of California,* 7p.
5. Dara, S. K. (2017). Entomopathogenic microorganisms: modes of action and role in IPM. *UCANR eJournal Strawberries and Vegetables, 20 May, 2017.* https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=24119.
6. Deka, B., Baruah, C., & Babu, A. (2021). Entomopathogenic microorganisms: their role in insect pest management. *Egyptian Journal of Biological Pest Control, 31(1),* 1-8.
7. Flexner, J.L. and Belnavis, D.L. (1999). Microbial insecticides. In *Biological and biotechnological control of insect pests (pp. 35-62).* CRC Press.
8. Gupta HCL, Siddiqui AU, Parihar A. (2010). Bio pest management. *Agrotech Pub, Academy.*
9. Jacobsen, B. J. (1997). Role of plant pathology in integrated pest management. *Annual review of phytopathology, 35(1),* 373-391.
10. Koul. O. (2011). Microbial biopesticides: opportunities and challenges. *CAB Rev 6:1–26.*
11. Mascarin, G.M. and Jaronski, S.T. (2016). The production and uses of Beauveria bassiana as a microbial insecticide. *World Journal of Microbiology and Biotechnology, 32,* pp.1-26.
12. Poinar, Jr. G.O. (1975). Entomogenous nematodes, a manual and host list of insect-nematode associations. *Leiden EJ. Brill, 254.*

13. Rajamani, M., Negi, A. (2021). Biopesticides for Pest Management. In: Venkatramanan, V., Shah, S., Prasad, R. (eds) *Sustainable Bioeconomy*. Springer, Singapore. https://doi.org/10.1007/978-981-15-7321-7_11.
14. Ruiu L. (2018). Microbial biopesticides in agroecosystems. *Agronomy 8(11):235.*
15. Singh, B., Sharma, K., Babu, S. R., & Mahla, M. K. (2021). Deployment of Benevolent Alien Genes for Insect Pest Management. *Insect pest management, 24.*
16. Sinha, K.K., Choudhary, A.K. and Kumari, P. (2016). Entomopathogenic fungi. In *Ecofriendly pest management for food security (pp. 475-505).* Academic Press.
17. Skinner, M., Parker, B. L., & Kim, J. S. (2014). Role of entomopathogenic fungi in integrated pest management. *Integrated pest management, 169-191.*
18. Soumia, P. S., Krishna, R., Jaiswal, D. K., Verma, J. P., Yadav, J., & Singh, M. (2021). Entomopathogenic microbes for sustainable crop protection: future perspectives. *Current trends in microbial biotechnology for sustainable agriculture, 469-497.*
19. Usta C. (2013). Microorganisms in biological pest control—a review (bacterial toxin application and effect of environmental factors). *Curr Progress Biol Res:287–317.*
20. Vega, F.E. and Kaya, H.K. (2012). *Insect pathology (Vol. 2).* Academic press.

CLAY MINERALS AND ORGANIC MATTER INTERACTIONS IN RELATION TO SOIL CARBON STABILIZATION

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Abstract:

Understanding the intricate interplay between clay minerals, organic matter, and soil carbon stabilization is crucial for sustainable soil management and combating climate change. This study delves into the complex interactions occurring at the molecular level between clay minerals and organic matter within soil ecosystems. Clay minerals act as catalysts in the formation of stable organo-mineral complexes, significantly enhancing soil carbon sequestration. Various factors, including mineralogy, soil texture, and environmental conditions, influence these interactions. Moreover, the protective role of clay minerals in shielding organic matter from microbial decomposition is explored, shedding light on the mechanisms underlying long-term soil carbon stabilization. The review also investigates the impact of these interactions on soil fertility, nutrient cycling, and overall ecosystem health. Integrating insights from this research into agricultural practices and land management strategies holds the key to maximizing soil carbon storage, mitigating climate change, and ensuring sustainable food production in the face of environmental challenges. In addition to their role in enhancing soil carbon sequestration, these clay mineral-organic matter interactions have broad implications for sustainable agriculture and ecosystem management. Understanding these mechanisms aids in optimizing soil health and fertility, thereby promoting crop productivity. Furthermore, these insights are pivotal for the development of effective carbon sequestration strategies, addressing the pressing issue of rising atmospheric carbon levels and climate change mitigation. By uncovering the intricacies of these interactions and their environmental significance, we pave the way for informed decisions and innovative soil management practices that can simultaneously bolster food security and environmental resilience.

Introduction:

The complex web of interactions between organic matter and clay minerals in soils plays a pivotal role in the dynamic and often fragile balance of carbon storage within terrestrial ecosystems. As the global community grapples with the urgent need to mitigate climate change and enhance soil fertility for sustainable agriculture, understanding these interactions has emerged as a critical research frontier. Soil carbon stabilization is essential not only for long-term carbon sequestration but also for maintaining soil health, nutrient cycling, and ecosystem resilience. This relationship between clay minerals and organic matter offers profound insights into the mechanisms governing carbon sequestration, with significant implications for both climate change mitigation and sustainable food production. The dynamic processes underlying soil carbon stabilization are intimately intertwined with the interactions between organic matter and clay minerals, offering a fascinating and multifaceted realm of study. The intricate dance of carbon within the soil matrix, governed by mineral-organic matter interplay, has garnered increasing attention due to its far-reaching implications for global carbon cycling, climate change mitigation, and sustainable agriculture.

Understanding these interactions is paramount in the quest for effective soil carbon sequestration strategies. The adequacy of soils to retain and stabilize carbon is a linchpin in the global carbon cycle, influencing atmospheric carbon dioxide levels and, consequently, the Earth's climate. As we confront the urgent need to reduce greenhouse gas emissions and adapt to a changing climate, harnessing the potential of soil as a carbon sink becomes an imperative strategy. Clay minerals, ubiquitous constituents of soil, have emerged as key players in this intricate narrative. They act as sorbents, catalysts, and protectors, shaping the fate of organic matter as it interacts with the mineral surfaces. These interactions facilitate the formation of stable organo-mineral complexes, protecting organic carbon from decomposition and thus extending its residence time within the soil. However, the terrain is not without its challenges and complexities. The exact mechanisms and governing factors of these interactions are far from fully elucidated. The mineralogical composition, environmental conditions, and the specific organic matter involved all influence the outcomes of these interactions. Moreover, this dance between clay minerals and organic matter goes beyond carbon sequestration; it impacts soil fertility, nutrient cycling, and the overall health of ecosystems.

Currently, global warming and climate change are the two most debated issues in the world (Lal, 2004). Climate change is primarily caused by anthropogenic activities and natural processes that emit greenhouse gases into our atmosphere (IPCC, 2006). Global temperatures are largely driven by CO_2, one of the most significant greenhouse gases. Decomposition of organic carbon (OC) in the soil, measured by soil respiration, is one of the main sources of CO_2 emissions from agricultural fields (e.g., the practice of residue burning and fossil fuel combustion through farm machinery) (Lal, 2004). Global soils, provided they are properly managed, can act as sinks for CO_2 rather than sources. In order to reduce greenhouse gas emissions from agricultural soils, it is necessary to increase biomass inputs and minimize decomposition of organic matter (OM). The carbon pools in soil can be managed by balancing biomass inputs and losses from decomposition and mineralization (Lal, 2004, 2009). The production of biomass is increased in fertile soils, provided no other factors are limiting. Carbon stabilization is important both in reducing greenhouse gas emissions (CO_2, CH_4) and improving soil fertility, thus contributing to sustainable agriculture.

At the global scale, soil organic C (SOC) is one of the largest pools of carbon (Lützow and Kögel-Knabner, 2009). It is estimated that global soils contain about 2344 Giga ton (Gt) of OC. Organic carbon in the top one meter of soil makes up 1502 Gt of the total terrestrial OC. The total organic carbon in the above two meters of soil is approximately 2157 to 2293 Gt after excluding the carbon present in litter and charcoal (Batjes, 1996). The top 30 cm, 100 cm, and 200 cm of soil had average organic carbon values of 684–724 Gt, 1462–1584 Gt, and 2376–2456 Gt, respectively.

Essentially, the process of carbon sequestration involves the locking of atmospheric CO_2 in permanent pools to prevent it from returning to the atmosphere. Soil properties, such as chemical, physical and biological properties have a significant effect on carbon sequestration (Lamparter *et al.,* 2009). In soils, clay minerals are the most reactive particles, and they are directly or indirectly responsible for both their physical and chemical properties. In addition to the amount of clays, the type of clay also plays a vital role in carbon stabilization. For instance, soils with a high level of smectite clay mineral stabilizes more carbon content than soils with a high level of kaolinite (Hassink, 1997; Wattel-Koekkoek *et al.,* 2001). Clay minerals have greater specific surface areas and are effective for organic carbon stabilization in soils by providing both a variable and permanent surface charge. Based on crystallinity of clays, clay minerals are of different types *viz.,* phyllosilicate minerals (e.g., smectite, kaolinite, illite) and oxide-hydroxides of Fe and Al, which can be either well or poorly crystallized (e.g., allophane) in nature (Churchman and Lowe, 2012). OC remains protected against microbial attack due to its adsorption on clay minerals through various mechanisms (e.g., electrostatic attraction, hydrophobic attraction, ligand exchange, p-bonding) (Baldock and Skjemstad, 2000; Singh *et al.*, 2018).

In this comprehensive exploration, we embark on a journey to unravel the intricate relationships between clay minerals and organic matter in the context of soil carbon stabilization. We delve into the molecular interactions that underpin this phenomenon and navigate the environmental variables that shape its outcomes. As we delve into the depths of this crucial relationship, we aim to shed light on the mechanisms and complexities at play, explore the implications for sustainable agriculture and climate change mitigation, and contemplate the potential for innovative soil management practices that harmonize human needs with the imperatives of a changing planet.

Soil organic matter stabilization

The process of organic matter stabilization in soil is an act that reduces the degradation of SOM by lowering mineralization rate. The SOM stabilization undergoes three mechanisms in soil that are: (i) physical, (ii) chemical, and (iii) biological. The process behind chemically stabilizing soil organic matter (SOM) is believed to stem from the physical or chemical bonding that takes place between the soil minerals and SOM, particularly involving silt and clay particles. In addition to the clay content, clay type (i.e., 2:1 versus 1:1 versus allophanic clay minerals) influences the stabilization of organic C. Physical protection by aggregates is indicated by the positive influence of aggregation on the accumulation of soil organic matter (SOM). Aggregates serve to physically shield SOM by creating barriers between enzymes, microbes, substrates, and regulating the relationships within the food web, thereby influencing microbial turnover. Biochemical stabilization refers to SOM's stabilization due to its inherent chemical composition, comprising recalcitrant compounds (e.g., polyphenols and lignin), and through chemical complexing processes such as condensation reactions occurring within the soil.

1. Physical stabilization

This type of OM stabilization is because of protection from physical obstructions formed in between the zone of degradation of organisms and the SOM. This position of OM and input flows in the various levels of soil are critical in controlling the movement of the organic matter toward microorganisms. The segregation of soil microorganisms and the substrates through micro and macro aggregates is clearly visible by the amount of the microbes being highest in the outside periphery of aggregates. Although considerable amount of SOM is observed at the middle of the aggregates. With cultivation, C is released due to the breakdown of aggregate structures in soil which increases the presence of C degradation. Basically, cultivation causes the conversion in macro aggregates that are C rich into micro aggregates that have lost C and also textural fractions. However, soil organic carbon (SOC) typically remains protected from decomposition when micro aggregates become sealed. These micro aggregates are contained within macro aggregates, which generally exceed 250μm in size.

2. Chemical stabilization

The SOM is stabilized because of the physicochemical or chemical binding to the surfaces of minerals in soil. This type of complexes that are organic-mineral in nature are pivotal to soil C cycle as this tries to stabilize the SOC from the microbial attack. Adsorption of dissolved organic carbon (DOC) in subsoil leads to approximately a 30% reduction in mineralization compared to the mineralization occurring in the soil solution. Soil organic carbon (SOC) stability is significantly influenced by its amorphous nature and the inadequate crystalline structure of mineral components containing higher levels of OH groups or greater chemical capacity. This characteristic facilitates the establishment of a relationship with organic matter in terms of organic carbon (OC), thereby safeguarding minerals in the process. These kinds of organic mineral relationships are due to the greater molecular interactions existing in between OH group of Al and Fe ox hydroxides and also the hydrophobic functional group present in OM. Iron and aluminium oxides, along with clay minerals, perform a crucial function in adsorbing dissolved organic carbon (DOC). Specifically, iron oxides play a significant role in both adsorption and the stabilization of soil organic carbon (SOC). Phyllosilicates also contribute to maintaining dissolved organic carbon. The adsorption of dissolved organic carbon onto the surface of clay minerals relies on their selectivity towards hydrophobic and aromatic compounds. This stabilization of organic carbon in the soil is regulated by the adsorption of dissolved organic carbon onto the silicate mineral layers.

3. Biological stabilization

The intricate chemical makeup of organic matter (OM) is accountable for stabilizing organic carbon (OC) in the soil, primarily through biological protection. This stabilization mechanism arises from their inherent biological resistance to degradation. Additionally, physicochemical interactions involving clay minerals contribute to the stabilization of soil organic carbon (SOC). Polymeric organic molecules containing aromatic rings, such as lignin, and various types of polymethylenic molecules like lipids, wax, and cutin, exhibit high resilience to decomposition. During the initial stages of plant residue decomposition, these constituents are preserved. However, while long-chain lignin compounds stabilize in larger soil fractions, they do not significantly contribute to the refractory components in SOC and undergo conversion more rapidly compared to other SOC constituents like microbial-origin polysaccharides. Lignin, characterized by a complex structure and the presence of non-hydrolyzable bonds, is recognized as recalcitrant. In contrast to proteins and cellulose, this aromatic molecule undergoes slow degradation due to enzymatic action.

Types of clay minerals involved in soil carbon stabilization

The major clay mineral groups found in soil environments include layer and chain silicates, sesquioxides, and other inorganic minerals (Fig. 1). The different types of layer silicates include 2:1, 1:1 and 2:1:1 types and are classified according to the number of building block sheets (alumina octahedral and silica tetrahedral) which are involved in their structures. One tetrahedral sheet of silica and one octahedral sheet of alumina make up the 1:1 type structure (Churchman and Lowe, 2012). In contrast, a 2:1 type consists of two silica tetrahedral sheets sandwiching an alumina octahedral sheet in between them. A 2:1:1 clay mineral contains two silica tetrahedral layers, one alumina octahedral layer, and one magnesium hydroxide (brucite) octahedral layer. The 1:1 type of clay mineral (kaolinite) and 2:1 clay minerals (smectite, illite) are common in all soil types. However, a 2:1:1 clay mineral (e.g., chlorite) is stable in cool, dry climates. In the 2:1 type clay minerals, the smectites and less frequently, the vermiculites, can expand and contract in response to moisture and the presence of certain inorganic and organic chemicals (e.g., exchangeable cations, surfactants, organic molecules). In contrast, illite has no swelling properties.

In a few soils, like palygorskite which are of chain silicates and are non-swelling in nature and contain 2:1 phyllosilicate structures in form of ribbons. All soils with different levels of crystallinity contain sesquioxides, which do not have a lamellar structure. They account for 50% of the total soil mass and are mostly oxides and oxyhydroxides of Fe and Al (Dixon, 1991; Kampf *et al.,* 2012). Ferrihydrite is the most common non crystalline member of the sesquioxides, while goethite, hematite, and magnetite are the key crystalline sesquioxides. Goethite and ferrihydrite can be seen under diverse climatic conditions (Churchman and Lowe, 2012). Special geochemical conditions (for example, volcanic eruptions) can also lead to amorphous or poorly crystalline aluminosilicates. There are two well-known minerals of this subgroup, allophane and imogolite (Calabi-Floody *et al.,* 2011; Wada, 1985). There are also some metal oxides and hydroxides that are found in a poorly crystalline form (e.g., Mn). Some other minerals (e.g., carbonates, sulfates) can also have a direct or indirect effect on soil C dynamics in addition to the previously mentioned layered silicates and sesquioxides. Soils under semiarid or arid conditions may also contain carbonate minerals (calcite, dolomite) which drastically alter the balance between inorganic and organic carbon content in soils (Lal, 2008).

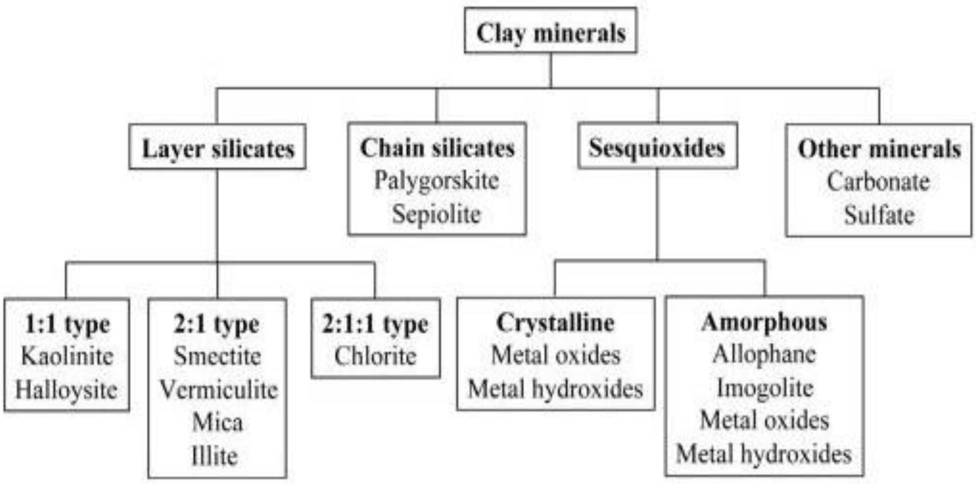

Fig. 1: Different soil clay minerals that participate in soil C protection mechanisms

Capability of different clay minerals in context of c protection

Because of their crystalline structure and physicochemical characteristics, clay minerals are important for stabilizing OC in soils. OC stabilization in soils is directly influenced by the amount and type of clay minerals. It is generally assumed that soils with a high clay content are able to prevent a greater amount of C from being mineralized (i.e., converted to CO_2). The respiration or carbon mineralization rate in soils with 23 times higher clay content was reduced by about 50% (Wang *et al.*, 2003). An increase in clay content in soil by 12 times reduced soil respiration by up to 40% (Franzluebbers, 1999). Clay minerals with a 1:1 composition adsorb fewer dissolved organic carbon molecules (DOCs) in soil than phyllosilicates with a 2:1 composition. These findings have been attributed to the intrinsic properties of some of the mineral prospects according to their physicochemical characteristics (Singh *et al.,* 2017; Stotzky, 1986). Clay minerals of the 2:1 type (e.g., montmorillonite) have a greater specific surface area than clay minerals of the 1:1 type (e.g., kaolinite). Montmorillonite's specific (external) surface area can range from 15 to 160 $m^2\ g^{-1}$, while kaolinite's surface area is between 6 and 40 $m^2\ g^{-1}$. Montmorillonite generally has a smaller average particle size than kaolinite, which gives it a larger surface area per unit mass (Churchman and Lowe, 2012; Saidy *et al.,* 2013; Singh *et al.,* 2016).

Kaolinite has a negligible amount of isomorphous substitution (e.g., replacement of Al^{3+} by cations like $Fe^{2+/3+,}$ Mg^{2+} and/or replacement of Si^{4+} by cations like Al^{3+}, Fe^{3+}). Smectite, however, shows a significant amount of substitution which gives a much larger layer charge than kaolinite and subsequently creates more active sites on the clay mineral's surface of smectite. Clay minerals that contain more active sites have the higher tendency to adsorb soil organic carbon. The cation exchange capacity of kaolinite varies between 0 and 10 cmol $(p^+)\ kg^{-1}$, while the value for smectite can be as high as 160 cmol $(p^+)\ kg^{-1}$. The mica type 2:1 clay minerals, such as illite, have a larger specific surface area (55–195 $m^2\ g^{-1}$) than kaolinite and smectite but a medium range CEC (10-40 cmol $(p^+)\ kg^{-1}$). The nonexpanding illitic clay minerals are crucial for the preservation of organic carbon in soils and are frequently found interstratified with kaolinite or smectite. One of the distinctive physicochemical properties of the allophane materials in the sesquioxide group is their extremely high specific surface area (700–1500 $m^2\ g^{-1}$). The minerals that are hydroxide/oxide also have a large surface area. Therefore, these materials retain notably more organic matter than layered silicate clay minerals (Wiseman and Püttmann, 2006; Alekseeva, 2011; Churchman, 2010; Saidy *et al.,* 2013). Furthermore, these minerals can interact chemically (e.g., ligand exchange) with soil organic matter (SOM) and prevent microbial mineralization (Kleber *et al.,* 2015).

In addition to surface area, surface charge is another important factor influencing the interaction between soil minerals and SOM. It is known that kaolinite clay minerals have a lower layer charge value, but the value may vary depending on the acidity or basicity of the system. There is a predominant permanent negative charge in smectite clay minerals. In contrast, allophane have a highly variable charge depending on pH.

Soil minerals' surface charge can also be affected by organic elements like humic compounds. Furthermore, humic materials can form compounds with minerals found in soil clay that change how those minerals interact with freshly added organic matter. As a result, compared to Ultisol or Alfisol, which contain fewer clay–organic compounds, the interaction and adsorption of externally supplied DOC on a Mollisol might differ significantly. Sesquioxides contribution to the soil's ability to adsorb DOC may be overshadowed by the natural OC concentration of mollisols (Mayes *et al.,* 2012). The removal of native OM from the clay minerals or sesquioxides can significantly increase the surface area of the mineral materials and consequently increase the material's C adsorption/protection capacity. (Kahle *et al.,* 2003; Singh *et al.,* 2016).

Allophanic minerals exhibit distinctive properties that contribute to the enhancement of carbon (C) stabilization within soils. They achieve this by forming stable associations with organic matter through innersphere complexation and employing physical protection mechanisms. Allophane, in particular, plays a pivotal role in extending the mean residence time of various organic carbon materials within soils (Bolan *et al.*, 2012; Dahlgren *et al.*, 2004). Andisols, characterized by their intrinsic high allophane content, contain significantly greater levels of organic matter compared to other soil types, both in terms of equilibrium organic matter content and mean residence time (Broquen *et al.,* 2005; Parfitt, 2009). Allophanic soils also feature free iron (Fe) and aluminium (Al) elements, which can diminish dissolved organic carbon (DOC) availability to microorganisms through the formation of Fe/Al-induced precipitation complexes (Scheel *et al.,* 2008; Schwesig *et al.,* 2003). Consequently, the organic matter content and its preservation in allophanic soils are subject to the influence of multiple processes, including: (1) safeguarding through complexation with Fe, Al, and allophane; (2) reduced bacterial activity attributable to the presence of free Fe and Al; and (3) a low pH environment with limited nutrient availability, especially phosphorus, for soil microorganisms (Bolan *et al.,* 2012; Parfitt, 2009).

Conclusion:

Soil organic carbon (SOC) plays a crucial role in both soil productivity and environmental health. Its diverse functions in food and fiber production are widely acknowledged. Additionally, SOC is gaining increasing recognition for its significant role as a source or sink of greenhouse gases (GHGs) in the atmosphere. The concentrations of GHGs, such as CO_2, in the atmosphere are projected to continue rising and might double or even triple by the end of the century, contributing to further global warming. To address this challenge, it is imperative to implement enhanced carbon sequestration processes. Carbon sequestration and storage in soils offer a valuable means of reducing GHGs in the atmosphere and mitigating the anticipated climate changes.

Recent research has highlighted that on a global scale, most agricultural and degraded soils hold significant potential as sinks for atmospheric CO_2. However, this research has also revealed that not all of the carbon (C) accumulated in the soil is shielded from potential losses. Additionally, it's been observed that the accumulation of soil C does not exhibit continuous growth over time, even with increased C inputs. There exists an upper limit or C saturation point that governs the maximum potential of soil C storage and the rate of C sequestration in mineral soils, irrespective of the C input rate. To effectively manage and enhance soil C sequestration, it is essential to comprehend the mechanisms involved in C stabilization within soils. Several mechanisms and processes have been proposed by different researchers for the stabilization of soil C. While some of these are well-established, others remain in the experimental phase, requiring further data for validation. Furthermore, the relative importance of each proposed mechanism in a given soil and climate context has yet to be systematically compared. Considerable strides have been made in comprehending the physical mechanisms responsible for soil carbon (C) stabilization, particularly those related to soil aggregate formation and the interactions between soil organic matter (SOM) and soil minerals. However, our understanding of the role played by plant roots, soil organisms, both micro and macro, as well as the contributions of black C, inert or recalcitrant C compounds, and refractory C compounds, including hydrophobic components of humic substances (HS), in soil C stabilization remains relatively limited.

Two primary mechanisms have garnered more support than others in this context. Firstly, the generation of inert or black C through natural and human-induced fires, and the production of recalcitrant and refractory C compounds in soils by plants, soil organisms, and microorganisms. Secondly, the encapsulation of soil organic carbon within soil aggregates and the hydrophobic domains of SOM, safeguarding it from the reach of degrading soil microorganisms and their enzymes. These mechanisms and processes are subject to modification based on factors such as soil temperature, moisture content, aeration, and the presence of suitable decomposer organisms. Continued research efforts in these areas are imperative if we are to harness the potential of soil as a sink for atmospheric CO_2, thereby contributing to the mitigation of anticipated climate changes, while also enhancing soil productivity for food and fiber production.

References:

1. Adu, J.K., Oades, J.M. (1978). Physical factors influencing decomposition of organic materials in soil aggregates. Soil Biology and Biochemistry, 10, 109–115.
2. Alekseeva, T.V. (2011). Clay minerals and organo-mineral associates. In: Gliński, J., Horabik, J., Lipiec, J. (Eds.), Encyclopedia of Agrophysics. Springer Netherlands, Dordrecht, pp. 117–122.
3. Baldock, J.A., Skjemstad, J. (2000). Role of the soil matrix and minerals in protecting natural organic materials against biological attack. Organic Geochemistry, 31, 697–710.
4. Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47, 151–163.
5. Bindraban, P.S., Dimkpa, C., Nagarajan, L., Roy, A., Rabbinge, R. (2015). Revisiting fertilisers and fertilisation strategies for improved nutrient uptake by plants. Biology and Fertility of Soils, 51, 897–911.

6. Bolan, N., Kunhikrishnan, A., Choppala, G., Thangarajan, R., Chung, J. (2012). Stabilization of carbon in composts and biochars in relation to carbon sequestration and soil fertility. Science of Total Environment, 424, 264–270.
7. Broquen, P., Lobartini, J.C., Candan, F., Falbo, G. (2005). Allophane, aluminum, and organic matter accumulation across a bioclimatic sequence of volcanic ash soils of Argentina. Geoderma, 129, 167–177.
8. Calabi-Floody, M., Bendall, J.S., Jara, A.A., Welland, M.E., Theng, B.K.G., Rumpel, C., et al. (2011). Nanoclays from an andisol: extraction, properties and carbon stabilization. Geoderma, 161, 159–167.
9. Churchman, G.J. (2010). Is the geological concept of clay minerals appropriate for soil science? A literature-based and philosophical analysis. Physics and Chemistry of Earth, 35, 927–940.
10. Churchman, G.J., Lowe, D.J. (2012). Alteration, formation, and occurrence of minerals in soils. In: Huang, P., Li, Y., Sumner, M.E. (Eds.), Handbook of Soil Sciences: Properties and Processes, second ed. CRC Press, Boca Raton, FL.
11. Conant, R.T., Drijber, R.A., Haddix, M.L., Parton, W.J., Paul, E.A., Plante, A.F., et al. (2008). Sensitivity of organic matter decomposition to warming varies with its quality. Global Change Biology, 14, 868–877.
12. Dahlgren, R., Saigusa, M., Ugolini, F. (2004). The nature, properties and management of volcanic soils. Advances in Agronomy, 82, 113–182.
13. Davidson, E.A., Janssens, I.A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature, 440, 165–173.
14. Dixon, J. (1991). Roles of clays in soils. Applied Clay Science, 5, 489–503.
15. Fang, C., Smith, P., Moncrieff, J.B., Smith, J.U. (2005). Similar response of labile and resistant soil organic matter pools to changes in temperature. Nature, 433, 57–59.
16. Franzluebbers, A.J. (1999). Microbial activity in response to water-filled pore space of variably eroded southern Piedmont soils. Applied Soil Ecology, 11, 91–101.
17. Grace, P.R., Ladd, J.N., Robertson, G.P., Gage, S.H. (2006). SOCRATES—a simple model for predicting long-term changes in soil organic carbon in terrestrial ecosystems. Soil Biology and Biochemistry, 38, 1172–1176.
18. Hassink, J. (1997). The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant and Soil, 191, 77–87.
19. IPCC (2006). IPCC guidelines for national greenhouse gas inventories'. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan.
20. Kahle, M., Kleber, M., Jahn, R. (2003). Retention of dissolved organic matter by illitic soils and clay fractions: influence of mineral phase properties. Journal of Plant Nutrition and Soil Science, 166, 737–741.

21. Kahle, M., Kleber, M., Jahn, R. (2004). Retention of dissolved organic matter by phyllosilicate and soil clay fractions in relation to mineral properties. Organic Geochemistry, 35, 269–276.
22. Kalbitz, K., Solinger, S., Park, J.-H., Michalzik, B., Matzner, E. (2000). Controls on the dynamics of dissolved organic matter in soils: a review. Soil Science, 165, 277–304.
23. Kampf, N., Scheinost, A.C., Schulze, D.G. (2012). Oxide minerals in soils. In: Huang, P.M., Yuncong, L., Summer, M.E. (Eds.), Handbook of Soil Sciences: Properties and Processes. CRC Press, Boca Raton, FL, pp. 2221–2234.
24. Kleber, M., Eusterhues, K., Keiluweit, M., Mikutta, C., Mikutta, R., Nico, P.S. (2015). Mineral–organic associations: formation, properties, and relevance in soil environments. Advances in Agronomy, 130, Academic Press, Cambridge, MA, pp. 1–140.
25. Kong, A.Y., Six, J., Bryant, D.C., Denison, R.F., Van Kessel, C. (2005). The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil Science Society of American Journal, 69, 1078–1085.
26. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623–1627.
27. Lal, R. (2008). Sequestration of atmospheric CO2 in global carbon pools. Energy and Environmental Science, 1, 86–100.
28. Lal, R. (2009). Challenges and opportunities in soil organic matter research. European Journal of Soil Science, 60, 158–169.
29. Lamparter, A., Bachmann, J., Goebel, M.-O., Woche, S. (2009). Carbon mineralization in soil: impact of wetting–drying, aggregation and water repellency. Geoderma, 150, 324–333.
30. Leirós, M.C., Trasar-Cepeda, C., Seoane, S., Gil-Sotres, F. (1999). Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biology and Biochemistry, 31, 327–335.
31. Lützow, M., Kögel-Knabner, I. (2009). Temperature sensitivity of soil organic matter decomposition: what do we know? Biology and Fertility of Soils, 46, 1–15.
32. Lützow, M.V., Kögel-Knabner, I., Ekschmitt, K., Matzner, E., Guggenberger, G., Marschner, B., et al. (2006). Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions: a review. European Journal of Soil Science, 57, 426–445.
33. Marschner, B., Bredow, A. (2002). Temperature effects on release and ecologically relevant properties of dissolved organic carbon in sterilised and biologically active soil samples. Soil Biology and Biochemistry, 34, 459–466.
34. Mayes, M.A., Heal, K.R., Brandt, C.C., Phillips, J.R., Jardine, P.M. (2012). Relation between soil order and sorption of dissolved organic carbon in temperate subsoils. Soil Science Society of American Journal, 76, 1027–1037.

35. McInerney, M., Bolger, T. (2000). Temperature, wetting cycles and soil texture effects on carbon and nitrogen dynamics in stabilized earthworm casts. Soil Biology and Biochemistry, 32, 335–349.
36. Nannipieri, P., Sequi, P., Fusi, P. (1996). Humus and enzyme activity. In: Piccolo, A. (Ed.), Humic Substances in Terrestrial Ecosystems. Elsevier, Amsterdam, The Netherlands, pp. 293–328.
37. Parfitt, R.L. (2009). Allophane and imogolite: role in soil biogeochemical processes. Clay Mineralogy, 44, 135–155.
38. Rasmussen, C., Southard, R.J., Horwath, W.R. (2006). Mineral control of organic carbon mineralization in a range of temperate conifer forest soils. Global Change Biology, 12, 834–847.
39. Rey, A., Petsikos, C., Jarvis, P.G., Grace, J. (2005). Effect of temperature and moisture on rates of carbon mineralization in a Mediterranean oak forest soil under controlled and field conditions. European Journal of Soil Science, 56, 589–599.
40. Saidy, A., Smernik, R., Baldock, J., Kaiser, K., Sanderman, J. (2013). The sorption of organic carbon onto differing clay minerals in the presence and absence of hydrous iron oxide. Geoderma, 209, 15–21.
41. Sarkar, B., Megharaj, M., Shanmuganathan, D., Naidu, R. (2013). Toxicity of organoclays to microbial processes and earthworm survival in soils. Journal of Hazardous Materials, 261, 793–800.
42. Sarkar, B., Megharaj, M., Xi, Y., Krishnamurti, G.S.R., Naidu, R. (2010). Sorption of quaternary ammonium compounds in soils: Implications to the soil microbial activities. Journal of Hazardous Materials, 184, 448–456.
43. Scheel, T., Jansen, B., Van Wijk, A.J., Verstraten, J.M., Kalbitz, K. (2008). Stabilization of dissolved organic matter by aluminium: a toxic effect or stabilization through precipitation? European Journal of Soil Science, 59, 1122–1132.
44. Schwesig, D., Kalbitz, K., Matzner, E. (2003). Effects of aluminium on the mineralization of dissolved organic carbon derived from forest floors. European Journal of Soil Science, 54, 311–322.
45. Setia, R., Rengasamy, P., Marschner, P. (2014). Effect of mono- and divalent cations on sorption of water-extractable organic carbon and microbial activity. Biology and Fertility of Soils, 50, 727–734.
46. Singh, M., Sarkar, B., Biswas, B., Bolan, N.S., Churchman, G.J. (2017). Relationship between soil clay mineralogy and carbon protection capacity as influenced by temperature and moisture. Soil Biology and Biochemistry, 109, 95–106.
47. Singh, M., Sarkar, B., Biswas, B., Churchman, J., Bolan, N.S. (2016). Adsorption-desorption behavior of dissolved organic carbon by soil clay fractions of varying mineralogy. Geoderma, 280, 47–56.

48. Singh, M., Sarkar, B., Sarkar, S., Churchman, J., Bolan, N., Mandal, S., Menon, M., Purakayastha, T.J., Beerling, D.J. (2018). Stabilization of soil organic carbon as influenced by clay mineralogy. Advances in Agronomy. https://doi.org/10.1016/bs.agron.2017.11.001.
49. Sollins, P., Homann, P., Caldwell, B.A. (1996). Stabilization and destabilization of soil organic matter: mechanisms and controls. Geoderma, 74, 65–105.
50. Stotzky, G. (1986). Influence of soil mineral colloids and metabolic processes, growth adhesion, and ecology of microbes and viruses. In: Huang, P.M., Schnitzer, M. (Eds.), Interactions of Soil Minerals with Natural Organics and Microbes, Special Publication 17. Soil Science Society of America, Madison, WI, pp. 305–428.
51. Torn, M.S., Trumbore, S.E., Chadwick, O.A., Vitousek, P.M., Hendricks, D.M. (1997). Mineral control of soil organic carbon storage and turnover. Nature, 389, 170–173.
52. Violante, A., Gianfreda, L. (2000). Role of biomolecules in the formation and reactivity towards nutrients organics of variable charge minerals and organo-mineral complexes in soil environment. In: Bollag, J.-M., Stotzky, G. (Eds.), Soil Biochemistry, 6, Marcel Dekker, New York, NY, pp. 207–270.
53. von Lützow, M., Kögel-Knabner, I. (2009). Temperature sensitivity of soil organic matter decomposition: what do we know? Biology and Fertility of Soils, 46, 1–15.
54. Wada, K. (1985). Distinctive properties of andosols. In B.S. Stewart (Ed.), *Advances in Soil Science* (pp. 173–229). Springer. New York, NY.
55. Wang, W.J., Dalal, R.C., Moody, P.W., & Smith, C.J. (2003). Relationships of soil respiration to microbial biomass, substrate availability and clay content. *Soil Biology and Biochemistry, 35*, 273–284.
56. Wattel-Koekkoek, E.J.W., van Genuchten, P.P.L., Buurman, P., & van Lagen, B. (2001). Amount and composition of clay-associated soil organic matter in a range of kaolinitic and smectitic soils. *Geoderma, 99*, 27–49.
57. Wilson, M.J. (1999). The origin and formation of clay minerals in soils: past, present and future perspectives. *Clay Mineralogy, 34*, 7.
58. Wiseman, C., & Püttmann, W. (2006). Interactions between mineral phases in the preservation of soil organic matter. *Geoderma, 134*, 109–118.

SOYBEAN PESTS AND MANAGEMENT

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Abstract:

Soybean, a vital global crop, faces various pests that can significantly reduce yields. Common soybean pests include aphids, stink bugs, and pod borers. Effective pest management strategies encompass both chemical and non-chemical methods. Integrated Pest Management techniques aim to minimize chemical pesticide use by incorporating practices like crop rotation, resistant cultivars, and beneficial insect release. Regular scouting and monitoring help identify pest outbreaks early, enabling timely interventions. Sustainable pest management not only safeguards soybean yields but also minimizes environmental impacts and supports long-term agricultural sustainability. Incorporating biological control measures, such as releasing natural predators like ladybugs, can enhance pest management. Additionally, promoting practices like maintaining healthy soil and optimizing planting dates can reduce vulnerability to pests. Farmers should stay updated on the latest research and technologies to continually refine their pest management strategies. Balancing pest control with environmental stewardship is crucial for the soybean industry's long-term prosperity.

Keywords: pests, IPM, Soybean, Nature of damage, Symptoms

Introduction:

Soybean (*Glycine max*) also called Soja bean or Soyabean belong to Fabaceae family. It is one of the important oilseed crops in the world and also has tremendous importance as a food legume. It occupies 53% global production share of all oilseed crops. In the world, Brazil occupies first in production (144 million metric tons) and productivity (3564 kg/ha). In India, soybean grown on an area of 114.48 lakh ha with production of 120.38 lakh MT and productivity of 1051kg/ ha. Madhya Pradesh occupies top position in area (50.64 lakh ha) and production (53.24 million metric tons) under soybean cultivation is concern, whereas Gujarat occupies first position in total productivity (1087 kg/ha). Soybean oil production in the world is 385.52 million metric tons. Initially, the soybean was free of diseases and insects in India.

Nevertheless, the ongoing cultivation of soybeans, coupled with an expanding acreage, has resulted in a rise in the incidence of insects, weeds and diseases. The detrimental impact on yield caused by individual insects, weeds or diseases, varies from 20 to 100 percent. However, implementation of an IPM schedule, potentially leading to an additional yield increase of 30-35 percent.

Pests of soybean

1. stem fly:

Scientific name: *Ophiomyia phaseoli / Melanagromyza sojae*

Family: Agromyzidae

Order: Diptera

Marks of identification:

Adult- Shiny bluish- black fly

Larvae (Maggot)- Yellowish

Nature of damage:

Fly deposit eggs in puntures made by fly on young leaves. Maggots bore into nearest vein, traversing the petiole to eventually reach the stem, bore down the stem and feed on cortical layers and may penetrate further, extending into the tap root. Pupation takes place at ground level within the stem. Adult fly exits through a thin semi- transparent window.

Symptoms:

- If the infected stem is opened by splitting, distinct zig zag reddish tunnel can be seen with maggot or pupae inside it.
- Death of plant or branches.

Management:

- Deep summer ploughing.
- Avoid pre monsoon sowing.
- Practice effective crop rotation with diverse crops.
- Adopt an optimal seed rate and adhere to appropriate plant spacing
- Eradicate and dispose of any damaged plant parts.
- Seed treatment with imidacloprid 3g/kg seed gives protection upto 30days.
- Foliar spray with acephate 1.5g/l or Chlorantraniliprole 18.50 % SC dosage per hectare.

2. Leaf eating caterpillar:

S. N: *Spodoptera exigua*

Family: Noctuidae

Order: Lepidoptera

Nature of damage:

The caterpillar causes damage by feeding on leaves. Grown up larvae coils with slightest touch and drops down. The larvae hide during day time in the soil and feed on the foliage at night. Larvae are infected by entomopathogenic fungus, *Nomuraea rileyi* and parasitized by *Bracon* sp.

Symptoms:

- Extensive Defoliation

Management:

- Thiodicarb 1g/l or acephate 1g/l or chloropyriphos 2.5ml/l as foliar spray.

3. Soybean leafminer:

Scientific name: *Aproaerema modicella / Caloptilia soyella*

Family: Gelichidae

Order: Lepidoptera

Marks of identification:

Adult- Brownish grey

Larvae- Green with dark head

Biology:

Moth lays white eggs singly on underside of leaves close to midrib. Young larvae initially mine into leaflets, feed on mesophyll and produces white blotches. Later as it grow web the leaflets together and feed. Pupation takes place within the web.

Symptoms:

- Field looks burnt when viewed from distance.

Management:

- Growing groundnut as trap crop
- Installation of pheromone traps @25/ha
- Acephate 1.5g/l or chloropyriphos 2.5ml/l or quinalphos 2ml/l.

4. Whitefly:

Scientific name: *Bemisia tabaci*

Family: Aleurodidae

Order: Hemiptera

Marks of identification:

Adult- white or greyish wings, yellowish body and red medially constricted eyes.

Nymph- scale like, greenish-yellow color with fringes resembling bristles along the margins, oval-shaped

Biology:

Female lays 70 stalked eggs singly on the undersurface, mostly on the top and middle leaves of the plant. It can often breed parthenogenetically. Egg period ranges from 3-33 days. Nymphs moult thrice. Nymphal period lasts for 9-18days. High temperature and low humidity are reported to be conducive to the multiplication of this pest.

Nature of damage:

Both adults and nymphs suck the sap from undersurface of leaves.

Symptoms:

- Damaged leaves show uniform bronzing.
- Sooty mold development due to honeydew excretion on infested parts. It is a vector of leaf curl virus.

Management:

- Foliar spray with acephate 1.5g/l or triazophos 2ml/l or profenophos 2ml/l.
- Dusting of cow dung ash and spraying of clay suspension as asphyxiants (in small area and low incidence of sucking insects).

5. Girdle beetle:

Scientific name: *Oberea brevis*

Family: Cerambycidae

Order: Coleoptera

Marks of Identification:

Larva- White, soft-bodied worm with a dark head.

Adult- The freshly emerged adult is yellow, red, brown on the head, thorax and bases of elytra.

Nature of damage:

Larvae bores into stem of soybean and tunnel is formed.

Symptoms:

- Dried up appearance of leaves.
- Girdling of stems and petioles.
- Plants cut at about 15-25cms above ground.

Management:

- Deep summer ploughing.
- Destroy crop residues and avoid excess nitrogenous fertilizers.
- Intercropping with maize or sorghum should be avoided.
- Sowing of tolerant varieties like Ahilya-2, Ahilya-3, Gaurav, Indira soy 9 and RAUS 5.
- Spray quinalphos 25 EC @ 2 ml/lit. at the crop age of one month with interval of 15-20 days (1000 l spray/ha).
- Use of optimum seed rate 70-100 kg/ha.
- Regularly remove infested plant parts and bury them in a compost pit to effectively monitor and decrease the populations of girdle beetles.
- Apply carbofuran 3 G @ 30 kg/ha during sowing.

6. Bean aphid:

Scientific name: *Aphis craccivora*

Family: Aphididae

Order: Hemiptera

Nature of damage:

Adults and Nymphs suck the plant sap from the stem, leaves and pods which cause reduction in yield.

Symptoms:

- Excretion of honey dew attracts sooty mould.
- The infested leaves are wilted or curled.
- Plant stunting, reduced pod and seed counts, puckering and yellowing of leaves.

Management:

- Avoid late sowing and excessive use of nitrogen fertilizers.
- Seed treatment with imidachloprid (5g/kg seed).
- Release predator *Coccinella septumpunctata* or *Syrphus* sp or *Chrysoperla carnea*
- Need based spray of dimethoate 30 EC or methyl demeton 25 EC.

7. Jassids:

Scientific name: *Apheliona maculosa*

Family: Cicadellidae

Order: Hemiptera

Symptoms:

- Infested leaves start yellowing from the margins.
- In case of severe attack, all the leaves become yellow and eventually fall off from the plants.

Nature of damage:

Adults and nymph are light green in colour and suck the sap from leaves and stem.

Management

- Install one light trap (200W mercury vapour lamp) per hectare to catch the adults of some nocturnal pests such as jassid.
- Spray 0.05 % oxydemeton methyl 25 EC, quinalphos 25 EC @ 2ml /lit at the crop age of one and half month with interval of 15days if needed.

8. Field bean pod borer:

Scientific name: *Adisura atkinsoni*

Family: Noctuidae

Order: Lepidoptera

Nature of damage:

Larvae feed on the flowers and bore into pods and feed on developing pods.

Management:

- Need based spray of Cypermethrin.

9. Bihar hairy caterpillar:

Scientific name: *Spilosoma obliqua*

Family: Arctidae

Order: Lepidoptera

Nature of damage:

caterpillar feed gregariously on leaves primarily consuming chlorophyll on the underside of the leaves, due to which the leaves look like brownish-yellow in colour.

In later stages, the larvae eat the leaves from the margin.

Symptoms:

- Leaves of the plant give an appearance of net or web.

Marks of Identification:

Larva- Long yellowish to black hairs

Adult- Medium size brown moth with a red abdomen

Management:

- Deep summer ploughing
- Avoid pre-monsoon sowing
- Use optimum seed rate
- Adequate plant spacing should be provided
- Intercropping soybean with either maize, early-maturing pigeon pea varieties, or sorghum in a 4:2 sequence.
- Periodically remove infested plant parts every 10 days, burying them in a compost pit to control and monitor the population.
- Collect and destroy infected egg masses, plant parts and young larvae.
- Dust chloropyriphos 1.5% DP quinalphos 1.5% @ 25 kg/ha when the population is likely to reach 10/m row length (ETL).
- Deploy one light trap (200 W) per hectare to capture nocturnal pests such as hairy caterpillars.

10. GRAM POD BORER:

Scientific name: *Helicoverpa armigera*

Family: Noctuidae

Order: Lepidoptera

Nature of damage:

Caterpillar feed on the chlorophyll of young leaves, which become skeletonized. They exhibit voracious feeding behavior on the foliage during the initial stages, potentially leading to defoliation of the plant. Subsequently, they move to feed on flowers and pods

Identification of the pest:

Eggs: creamish white in colour, round in shape which laid singly

Larva: greenish to brown in colour. It has dark brown grey lines on the body with lateral white lines and also has dark and pale bands.

Pupa: Brown in colour, occurs in soil, leaf, pod and crop debris.

Adult: Light pale brownish yellow stout moth. Forewings are olive green to pale brown with a dark brown circular spot in the centre. Hind wings are pale smoky white with a broad blackish outer margin.

Management:

- Deep summer ploughing
- Install pheromone traps at a distance of 50 m @5 traps/ha for each insect pest.
- Erect bird perches @ 50/ha.
- Clip terminal shoots on 100 days of crop growth.
- Setting of light traps (1 light trap/5 acre) to kill moth population
- Dusting with Chlorpyriphos 1.5 % DP or fenvalerate 0.4% or quinolphos 1.5% @ 25 to 30 kg/ha.
- Spray with Chlorpyriphos 1.5 % DP @1200 ml/ha or quinolphos 25 EC @ 1.0 lit/ha.

11. Tobacco caterpillar:

Scientific name: *Spodoptera litura*

Family: Noctuidae

Order: Lepidoptera

Nature of damage:

Larvae feed on the chlorophyll of the leaves.

Symptom:

- The eaten leaves give the appearance of whitish yellow web.

Identification of the pest

Egg: Egg masses appear golden brown.

Larva: Pale greenish with dark markings. Gregarious in the early stages

Adult: Forewings brown in colour with wavy white marking. Hind wings white in colour with a brown patch along the margin.

Management:

- Deep summer ploughing.
- Avoid pre-monsoon sowing.
- Optimum seed rate (70-100 kg/ha) should be used.
- Collect and destroy infested plant parts, egg masses and larva.
- Install sex pheromone trap @ 10 traps/ha for early deduction of the pest.
- Erection of bird perches @ 10-12/ha.
- Remove the infested plant parts at least once in 10 days and bury them in compost pit to monitor and reduce the populations of tobacco caterpillar. Traps are used for monitoring the pest situation.
- Install one light trap (200W mercury vapour lamp) per hectare to catch the adults of some nocturnal pests such as tobacco caterpillar.
- Install five sex pheromone traps per hectare (change septa after 3 weeks), specific for male adults of tobacco caterpillar (separate pheromone for each).
- Apply Profenophos 50 % EC @ 1000 ml/ha or deltarnethrin 2.8 EC @ 750 ml/ha or quinolphos 25 EC @ 1000ml/ha.
- In case of severe infestation apply polytrin 44% @ 1 lit/ha or profenophos 50 EC 2.00 lit/ha.
- Dust Deltamethrin 2.8% EC or quinalphos 1.5% @ 25kg/ha when their population is likely to reach 10/m row length (ETL). Repeat it as needed.

12. Thrips:

Scientific name: *Thrips tabaci*

Family: Thripidae

Order: Thysanoptera

Symptoms of damage

- The infected leaf turns whitish-brown in colour.
- If the infestation is severe, the leaves undergo desiccation and eventually fall off, resulting in a gradual loss of foliage and plant become leafless.

Management

- Applying cow dung ash through dusting and using a clay suspension for spraying are methods employed as asphyxiants, particularly in limited spaces with a low occurrence of sucking insects
- Spray oxydemeton methyl 25 EC or quinalphos 25 EC @ 2ml /lit at the crop age of one month with interval of 15 days if needed.

IPM:

Cultural practices:

- Cleaning of infected stubbles followed by deep summer ploughing.
- Inter-cropping four rows of soybean with two rows of asafetida (early maturing variety) or maize or sorghum which helps in build-up and conservation of coccinellid beetles, *Chrysoperla* etc.
- Ensure timely sowing when there is adequate soil moisture at a depth of 8-12 cm to promote optimal germination.

Genetic Management:

Insect pest	Resistant/tolerant varieties
Stem fly	JS 335, PK 262, NRC 12, NRC 37, MACS 124 and MAUS 2, MAUS 47
Tobacco caterpillar	JS 81-21, PS 564 and PK 472
Green semilooper	NRC 7, NRC 37, PUSA 16, PUSA 20, PUSA 24, JS 93-05, JS 97-52, MAUS 47 and JS 80-21
Girdle beetle	JS 71-05, NRC 7, JS 97-52, MAUS 32 and Indira Soya 9

Mechanical practices:

- Collection and destruction of girdle beetle infested plant parts, egg masses and gregariously feeding larvae of hairy caterpillar and tobacco caterpillar should be done.
- Installation of pheromone traps for monitoring incidence of *Spodoptera litura* and *Helicoverpa armigera*.
- Using trap crop such as castor to manage tobacco caterpillars and incorporating dhaincha as a strategy to control girdle beetles.

Biological control:

- Conserve praying mantids, spiders, dragon fly, damsel fly, tachinid fly, *Chrysoperla*, meadow grass hoppers and coccinellid beetles thereby use of minimum broad-spectrum pesticides.
- Release *T. remus* @ 50000/ha against *S. litura.*
- Spray SlNPV @ 250 LE/ha
- Applying 5% Neem Seed Kernel Extract spray to control early-stage larvae and sucking pests.
- Use of egg parasitoids such as *Tetrastichus, Trichogramma chilonis and Telenomus* on *Helicoverpa* and *Spodoptera.*
- Use of larval parasitoids such as *Carcelia* spp, *Ichneumon* spp and *Diglyphus isaea* on

Spodoptera and *Helicoverpa.*

- Use of Larva and pupal parasitoid such as *Xanthopimpla flavolineata*
- Pupal parasitoids *Lissopimpla excels* on *Helicoverpa* sp, *Eretmocerus* and *Encarsia formosa* on whitefly.

Chemical control:

Insect	**Insecticides and dose**
Defoliators (*Spodoptera litura)* *(Helicoverpa armigera)*	Chlorantraniliprole 18.5% SC @ 140 ml/ha. *Bacillus thuringiensis* var. *kurstaki*, Strain Z-52, Serotype H-39 @ 0.75- 1.0 Kg/ha Quinalphos 25 EC @ 1000 ml/ha
White fly (*Bemisia tabaci*)	Thiamethoxam 30% FS @ 10 Kg/hg
Stem fly (*Melanogromyza sojae*)	Thiamethoxam 30% FS @ 10 Kg/hg Chlorantraniliprole 18.5% SC @ 140 ml/ha.
Pod borer (*Cydia ptychora and Helicoverpa armigera*)	Indoxacarb 15.8% EC @ 333 ml/ha *Bacillus thuringiensis* var. *kurstaki*, Strain Z-52 @ 0.75- 1.0 Kg/ha
Girdle beetle (*Obereopsis brevis*)	Triazophos 40 EC @ 625 ml/ha Chlorantraniliprole 18.5% SC @ 150 ml/ha.
Blue beetle (*Cneorane* spp.)	Indoxacarb 15.8% EC @ 333 ml/ha

- Using poison bait of 2% zinc phosphide during the green seed stage and podding with a pre-baiting day, or alternatively, applying ready-to-use bromadiolone at 0.005% during the green seed stage to effectively control rodents.

Ecological engineering:

- Rotate cereals with other crops in a manner that disrupts the presence of soil-borne pests, while simultaneously increasing predatory birds and beneficial insects.
- Decrease the intensity of tillage to preserve hibernating natural enemies.
- Grow compatible cash crops such as chrysanthemum, sesame, marigold, radish, sunflower, okra, carrot, coriander, onion, mustard, etc., along the field border. From that arrange taller plants at the borders and shorter plants near the main crop to attract natural enemies and discourage incoming pest populations.

- Apply balanced dose of biofertilizers and nutrients.
- Incorporating organic matter like vermicompost, decomposed crop residue and farmyard manure to enrich the soil with nutrients and below-ground biodiversity.
- Ensure soil coverage throughout the year by cultivating living vegetation and/or retaining crop residue.

Conclusion:

Effective pest management for soybeans requires a multifaceted approach, combining chemical and non-chemical methods, integrated pest management, and sustainable agricultural practices. Adapting to changing pest dynamics and incorporating eco-friendly solutions are essential for safeguarding soybean yields and preserving the environment in the ever-evolving agricultural landscape.

References:

1. Gao, Y., Shi, S., Xu, M., & Cui, J. (2018). Current research on soybean pest management in China. *Oil Crop Science*, *3*(4), 215-227.
2. IPM Package for Soybean- NCIPM.
3. Tnau Agritech Portal Crop protection. (n.d.). Retrieved from https://agritech.tnau.ac.in
4. SOPA. (n.d.). Retrieved from https://www.sopa.org

UNMANNED AERIAL VEHICLES (UAVS): AN INNOVATIVE TECHNOLOGY IN SMART AGRICULTURE

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Abstract:

Drones, hailed as a groundbreaking marvel in science and technology, boast an expansive range of applications. Their versatility finds significance across numerous domains, particularly in agriculture where they revolutionize farm management with unparalleled precision and high-resolution capabilities. These aerial devices swiftly and reliably detect field issues, offering a swift and non-intrusive solution. In contrast to the laborious and time-consuming nature of employing land vehicles in traditional agricultural practices, drones prove vastly more advantageous. Recent surveys underscore the remarkable efficiency of drones, covering 10 to 15 times more ground than conventional methods. Embracing drones in agriculture and its allied sectors paves the way for a new era of intelligent farming. Their widespread integration into agricultural operations promises substantial GDP growth for the country, marking a transformative leap forward.

Introduction:

A drone encompasses any airborne vehicle guided by remote commands or autonomous software. Often termed as unmanned aerial vehicles (UAVs), these machines undertake a spectrum of tasks, spanning from routine to highly perilous endeavors. Within agriculture, the utilization of drones presents distinctive prospects and hurdles. Predominantly, drones serve as remote sensing platforms to evaluate and oversee crops, yet their evolving applications extend to precise dispensing of agricultural substances and biological agents, monitoring livestock health, and conducting remote sampling. Diverse drone designs and sensor varieties are employed, each bearing its own merits and constraints. In agriculture, their primary roles encompass data collection, report generation, physical tasks, animal supervision, crop analysis, and the application of pesticides through spraying, among others (Arbedo, 2019).

The term DRONE originally stood for Dynamic Remotely Operated Navigation Equipment. One of the earliest attempts at a powered unmanned aerial vehicle (UAV) was A. M. Low's "Aerial Target" in 1916. The progression continued post-World War I, notably with the first scaled remotely piloted vehicle (RPV) crafted by Reginald Denny, a film star and model airplane enthusiast, in 1935. The genesis of U.S. UAVs traces back to 1959, prompted by concerns among United States Air Force officers regarding the potential risk of losing pilots in hostile territories. This led to the introduction of highly classified UAVS by the U.S. Navy during the Vietnam War, marking their inaugural combat missions on August 2 and 4, 1964 (Costa *et al.,* 2012).

A myriad of terms and synonyms are linked to remotely piloted aircraft: Unmanned Aerial Vehicle (UAV), Small Unmanned Aerial System (SUAS), Unmanned Aerial System (UAS), Small Unmanned Aerial System (SUAS), Remotely Piloted Aircraft (RPA), Remotely Piloted Vehicle (RPV), Remotely Operated Aircraft (ROA), and Remotely Piloted Aerial Application System (RPAAS). Among these, UAV and UAS stand out as the most prevalent names for this technology. However, within the general public, the term "drone" is the most commonly used descriptor for such systems.

Drones in Indian agriculture

Initially, aerial pesticide spraying relied on helicopters or conventional fixed-wing aircraft piloted by humans. However, a significant shift is occurring. Small remotely piloted aircraft are now increasingly employed for pesticide application worldwide, notably in countries like India. Recent studies project substantial growth in the global agricultural drone market, estimated to surge at a 35.9% Compound Annual Growth Rate (CAGR) and reach $5.7 billion by 2025. For instance, approximately 20.90% of agricultural spraying in India, around 30% in South Korea, and nearly 40% of Japan's rice crop are sprayed using drones. In contrast, drone-based spraying remains in its nascent stages in the United States, yet there's a mounting interest in this technology among pesticide applicators (Dileep *et al.*, 2020).

Spraying via drones isn't a recent innovation. The first instance dates back to 1980 when Unmanned Aerial Systems (UAS) were utilized for crop dusting. Japan, in 1997, introduced the Yamaha RMax drone, resembling a compact helicopter. Featuring a single rotor with a 10-foot diameter, this drone weighs 207 pounds and carries over 4 gallons of spray. With a full tank and a spraying rate of 1 gallon per minute, the tank is depleted in approximately 4 minutes. Powered by gasoline, it runs for an hour before needing refueling and can be retrofitted with three or four nozzles. It received FAA approval for operation in California in 2015. Equipped with a terrain sensor, this aircraft can be manually operated or set on autopilot. The manufacturer doesn't sell the aircraft outright but provides servicing along with a trained team, usually comprising two to three individuals, to operate the aircraft (Puri *et al.,* 2017).

Presently, drone technology is progressively accessible for implementation across diverse agricultural sectors. While still in its early stages in India, numerous companies are striving to make this technology readily accessible to Indian farmers, aiming to enhance efficiency in agricultural output. Initially introduced for non-spraying purposes, drones found their way into agriculture by collecting crop and field-condition data, ultimately enhancing profitability in crop production (Klemas, 2015).

Fig. 1: Yamaha RMax single-rotor drone

Drones capture a number of important data points:

- Identifying various agriculture sites (vegetative areas, water sources, drainage systems, and roads).
- Analysing soil characteristics (type, moisture content, and nutrient composition).
- Assessing crop nutrient stress levels.
- Monitoring crop emergence or stand count.
- Identifying weed species and gauging infestation levels.
- Detecting insects and diseases affecting crops.
- Utilizing drones for aerial photography and videography.
- Search and rescue operations.
- Surveillance activities.
- Traffic monitoring and management.
- Weather monitoring and forecasting.
- Firefighting assistance.
- Personal recreational use.
- Delivery services.

Drones excel in monitoring plant growth by swiftly gathering and transmitting real-time data throughout the entire lifecycle, from plant emergence to harvest. Leveraging advanced GPS or GNSS technology alongside high-resolution cameras, and the flexibility of variable flying speeds and altitudes, these aerial devices offer comprehensive insights into the condition of every minute section of crops and soil (Daponte *et al.*, 2019).

Use of drones for spraying of pesticides is attractive mainly for following reasons (Milics, 2019):

1. Drones excel in spraying small, unevenly shaped fields with enhanced efficiency

2. Challenging topography or soil conditions render traditional ground sprayers or conventional agricultural aircraft impractical.
3. Utilizing airplanes or helicopters becomes either unavailable or too costly.
4. Drones notably minimize the risk of pesticide contamination for applicators, particularly those employing backpack sprayers.

Furthermore, emerging issues like tar spot on corn may elevate the necessity for aerial pesticide application using drones (Mehere *et al.*, 2018).

Fig. 2: Drone with spray nozzle (a) and without spray nozzle (b)

Working principle of drone

Fluid dynamics holds considerable importance in crafting and advancing both aircraft and drones. This field encompasses the fundamental principles governing the aerodynamics crucial to the operation of these aerial machines (Mogili *et al.*, 2018).

Major components of drones

1. Frame:

- It must possess adequate strength to support the momentum of the propeller and bear the added weight of motors and cameras.
- Robust with minimized aerodynamic resistance (Mogili *et al.*, 2018).

2. Propellers:

- The velocity and lifting capacity of a drone are contingent upon its shape, size, and the quantity of propellers it possesses.
- Longer propellers generate substantial thrust, enabling the transportation of heavier payloads at lower speeds (RPM) while being less responsive to speed variations in rotation.
- Shorter propellers handle lighter loads, exhibiting swift changes in rotational speed and necessitating higher speeds to generate more thrust

3. Motor

- Drones can utilize both brushless and brushed motors.
- Brushed motors, being cost-effective, find utility in smaller drones.

- Brushless motors offer higher power and energy efficiency but require an Electronic Speed Controller (ESC) to regulate their speed. They are prevalent in racing, freestyle drones, traffic surveys, and aerial photography applications.

4. ESC (Electronic Speed Controller)

- The ESC serves to link the battery with the electric motor, providing the necessary power.
- It translates the signal received from the flight controller into the motor's revolutions per minute (RPM).
- Each motor of the drone is equipped with its dedicated ESC.

5. Flight Controller (FC)

- This computer processor oversees and regulates balance and communication controls through various transmitters.
- This unit contains sensors for the accelerometer, barometer, magnetometer, gyrometer, and GPS.
- Distance measurement can be facilitated by an ultrasound sensor.

6. Radio transmitter sends the radio signal to ESC to pilot to control motor speed.

7. Radio receiver: Received the signal from the pilot. This device is attached to the quadcopter

8. Battery: High-power capacity, Lithium Polymer (LiPo) is used for most drones. The battery can have 3S (3 cells) or 4S (4 cells).

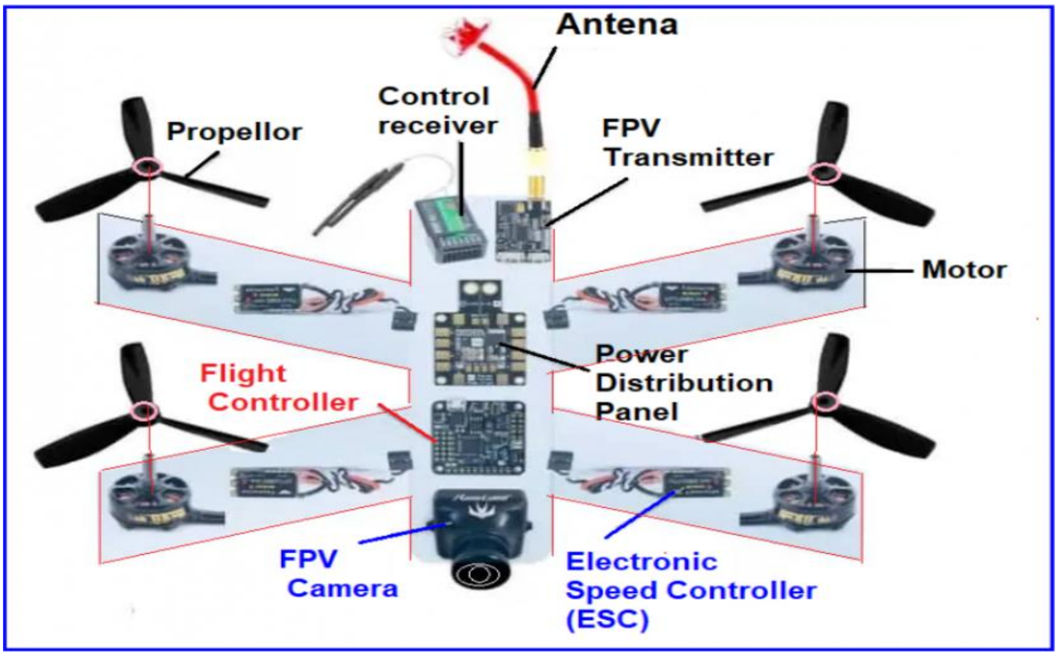

Fig. 3: Different component of Drone

Despite their small size, drone sprayers encompass nearly all the components found in larger ground or conventional aerial sprayers: tanks, pumps, hoses, filters, nozzles, and flow meters (Mogili *et al.*, 2018).

- Upon receiving commands from either the pilot or autonomous system, the flight controller transmits signals to the motors, prompting the propellers to rotate.
- To attain the intended motion, the motors and propellers' speed and direction are modified. Sensors gather data that aids the flight controller in stabilizing the drone mid-air and modifying its trajectory.
- Drones can either be manually operated via a remote controller or programmed for autonomous flight. Autonomous drones utilize sensors and pre-set instructions to navigate to designated locations, execute tasks such as capturing photos or delivering packages, and then return to their initial point of departure

Types of drones: Features and differences

Drones encompass diverse types, designed to meet specific needs across various industries. For instance, individuals may seek lightweight drones equipped with cameras for photography purposes, while others might require sturdy drones capable of transporting bulky medical supplies. Consequently, companies manufacture drones categorized into four primary types: single-rotor helicopters, multi-rotors, fixed-wings, and fixed-wing hybrid VTOL models.

Common types of drones

1. Single-Rotor Helicopter Drones
2. Multi-Rotor Drones
3. Fixed-Wing Drones
4. Fixed-Wing Hybrid VTOL Drones (Aasen *et al.*, 2012)

Single-rotor helicopter drones

Single-rotor helicopters resemble miniature versions of traditional helicopters and can be powered by either gas or electricity. Their single blade and gas propulsion contribute to enhanced stability and longer flight capabilities. These UAVs are commonly employed for transporting heavier cargo, such as LiDAR systems, utilized for land surveying, storm research, and mapping erosion caused by climate change.

Advantages: The endurance of single-rotor drones, particularly those fuelled by gas engines, elevates their popularity. Their single, larger blade enhances flight efficiency, surpassing the performance of multi-rotor counterparts. Consequently, many pilots favour single-rotor helicopter drones for heavier payload transportation.

Disadvantages: Operating single-rotor helicopter drones demands extensive training due to the risks associated with their larger blades, capable of causing serious injury. Moreover, these drones tend to be pricier in the market owing to the expertise required for their operation.

1. Multi-rotor drones

Multi-rotor drones typically represent some of the smallest and lightest options available in the drone market. While they offer limited range in distance, speed, and altitude, they serve as an excellent choice for enthusiasts and aerial photographers. These drones can typically sustain flight for 20-30 minutes while carrying a lightweight payload, like a camera.

Advantages: Multi-rotor drones stand out as among the most user-friendly drones accessible to the public due to their ease of control and manoeuvrability in flight. Certain models cater to beginner pilots, contributing to their affordability in the drone market.

Disadvantages: Despite their ease of use, multi-rotor drones lack the endurance and payload capacity compared to single-rotor helicopter drones. Sustaining flight for over 30 minutes with a multi-rotor drone is a challenge, and they tend to become unstable in windy conditions, limited in range from their controller.

2. Fixed-wing drones

Fixed-wing drones look like normal airplanes, where the wings provide the lift instead of rotors- making them very efficient. These drones usually use fuel instead of electricity, allowing them to glide in the air for more than 16 hours. Since these drones are usually much larger, and because of their design, they need to take off and land on runways just as airplanes do. Fixed-wing UAVs are used by the military to carry out strikes, by scientists to carry large amounts of equipment and even by nonprofits to deliver food and other goods to areas that are hard to reach.

Advantages: Fixed-wing drones are durable and can cover longer distances and carry heavier objects than other drones. Their sturdy frame also enables them to withstand windier conditions, remaining steady while maintaining a swift travel speed.

Disadvantages: Because fixed-wing drones cannot hover and must be moving forward at all times, they are much more difficult to land than other drones. They need plenty of space to take off and touch down, just like regular airplanes. As a result, fixed-wing drones require extensive training and reside on the higher end of the price spectrum.

Fixed-wing hybrid VTOL drones

Fixed-wing hybrid VTOL drones combine aspects of both fixed-wing and rotor-based drones, featuring wings equipped with attached rotors. This hybrid technology blends the endurance inherent in fixed-wing designs with the vertical flight capabilities typical of rotor-based designs. Companies leverage this fusion, employing fixed-wing hybrid VTOL drones to streamline delivery times while offering a versatile flight experience.

Advantages: These drones exhibit the endurance necessary for extended travel distances, even when carrying heavier payloads. Their ability to hover and fly vertically enhances their versatility compared to fixed-wing drones.

Disadvantages: Fixed-wing hybrid VTOL drones serve as versatile generalists, excelling in various tasks without specializing in any specific area. They can fly forward and hover but might not excel at either. Pilots require training to operate these drones and should expect a higher price tag. As a relatively new technology, ongoing development might reveal additional shortcomings as the industry continues to refine fixed-wing hybrid VTOL drones (Hoffmann et al., 2017).

Types of drones based on the number of propellors

Drones are equipped with varying numbers of propellers. Increasing the number of propellers enhances drone stability and its ability to carry heavier loads. However, such drones require additional battery power to drive more motors, enabling higher power output. Among drones, the quadcopter stands out as a particularly popular choice (Rasmussen et al., 2013)

- Bicopter (2 propellers)
- Triplecopter (3 propellors)
- Quadcopter (4 propellers)
- Hexacopter (6 propellers)
- Octacopter (8 propellers)

How to operate a drone: Flying a drone can offer an enjoyable and fulfilling experience, yet it's crucial to ensure safe and lawful operations. Here are some general guidelines for operating a drone (Rasmussen et al., 2013):

- Read the manual
- Register your drone
- Charge your drone battery
- Find a suitable location
- Check the weather
- Turn on the drone
- Calibrate the drone
- Take off
- Fly the drone
- Land the drone
- Turn off the drone

Operating characteristics of multi-rotor spray drones

The application rate for spray drones in row crops typically ranges from 1.5 to 2 gallons per acre, contingent on various factors. Primarily, this rate relies on the spray tank capacity, flying speed, spray swath width, number of nozzles or rotary atomizers on the drone, and the flow rate (volume sprayed per minute). For instance, a 5-gallon tank might require 2–3 minutes to empty, with some drones equipped with tank sensors indicating liquid levels. These sensors can pause spraying and guide the drone back to its base for a refill. After replenishment, the drone resumes spraying from where it left off.

The maximum flying speed of multi-rotor drones typically spans 10–30 miles per hour, flown approximately 7–12 feet above the ground or crop canopy. Forestry applications may demand flying heights exceeding 30 feet above the ground to circumvent obstacles. All current drone models incorporate terrain sensors, maintaining optimal flight height to spray uneven and hilly terrain, autonomously navigating hills and slopes. Spray drone prices fluctuate between $20,000 and $40,000, contingent on size, spraying capacity, manufacturer, and additional features. Most models support Real-Time Kinematics (RTK), ensuring centimetre-level location precision during flight (Berner et al., 2017).

Precautions during the drone use

Using a drone can offer both enjoyment and utility, but improper use can pose risks. Here are precautions to consider when operating a drone:

- Familiarize yourself with relevant laws and regulations.
- Maintain visual contact with your drone at all times.
- Opt for open spaces for flying.
- Respect others' privacy when flying your drone.
- Steer clear of flying in adverse weather conditions.
- Ensure your drone is well-maintained.
- Safely manage and handle drone batteries.
- Be ready to handle emergencies during flight.

Advantages of drones

- Drones facilitate deliveries efficiently.
- They aid in executing hazardous tasks safely.
- Enabling exploration of remote areas without physical presence.
- Offering solutions for conflict resolution.
- Versatile use in agriculture.
- Potential assistance in cloud seeding efforts.
- Crafting detailed 3-D maps with drone technology.
- Navigation facilitated via GPS for drones.
- Capturing stunning imagery using drones.
- Serving as an entertaining gadget for many.
- Often exempt from requiring a driver's license in several countries.
- Playing a vital role in food delivery post natural disasters.
- Utilizing drones selectively for various purposes.

Advantages of drones over traditional methods

Compare Item	**UAV drone** crop sprayer	**Traditional spraying way**		
		Knapsack sprayer	**Tractor sprayer**	**Elevated spraying vehicle**
Efficiency	40-53 ha/day	0.8-1.3 ha/day	6.7-20 ha/day	66.7-80 ha/day
Safety	Away from field during spraying to avoid the pesticide poisoning	Pesticides enter human body by mouth, respiratory passage or skin contact, easily lead to pesticide poisoning.	Applying pesticide from close range, easily lead to pesticide poisoning.	Applying pesticide from close range, easily lead to pesticide poisoning.
Water consumption per hectare	The water can be saved up to 90% compared with the traditional plant protection working mode. Spraying uniformly with low dilution rate and high concentrated liquid pesticide.	Traditional immersion jet spraying, resulting in waste of water, and most of the pesticides lost into the soil along with water.	Traditional immersion jet spraying, resulting in waste of water, and most of the pesticides lost into the soil along with water.	Traditional immersion jet spraying, resulting in waste of water, and most of the pesticides lost into the soil along with water.
Adaptability (terrain, crop growth stage, etc)	Strong adaptability. Not effected by mountain, hilly terrain and paddy field. Not be influenced by crop growth stage, can solve the problem of ground machinery is hard to enter inside to work, during the middle and later stage of the crop growth.	Crop, flower and fruit are easily damaged, trampled or dropped by human. Some high stem crops are difficult in spraying.	Challenges arise in hilly terrains where working with tractors can damage crops and reduce production. During later stages of crop growth when foliage covers the ground entirely, spraying becomes challenging for tall-stemmed crops.	Can't work in mountain or hilly terrain. The crop are easily damaged by elevated spraying vehicle and the crop are also rolled by the elevated spraying vehicle when turn around, to cause low production. In the middle and later stage of crop growth, when crops' foliages cover the ground completely, it is difficult in spraying.

Pesticide utilization efficiency	15% - 35% pest control efficiency more than traditional plant conservation ways, effective utilization of pesticides up to more than 85%.	Applying large amount of pesticide liquid, but with bad atomization performance, the pesticide utilization efficiency is very low. Only about 30% of pesticides are used effectively, the other 70% of pesticides do not play a role in pest control, but cause serious pollution on the ecological environment	Applying large amount of pesticide liquid, but with bad atomization performance, the pesticide utilization efficiency is very low. Only about 30% of pesticides are used effectively, the other 70% of pesticides do not play a role in pest control, but cause serious pollution on the ecological environment	Applying large amount of pesticide liquid, but with bad atomization performance, the pesticide utilization efficiency is very low. Only about 30% of pesticides are used effectively, the other 70% of pesticides do not play a role in pest control, but cause serious pollution on the ecological environment

Drone use advantages in agriculture

- Check Crop Health
- Avoid Chemical Overuse
- Prepare for weather glitches
- Crop Spraying
- Geo Fencing
- Livestock Management
- Soil and field analysis
- Crop Monitoring
- Plantation
- Monitor Growth

Disadvantages of drones

- Drones present a potential threat to aircraft.
- They pose a risk to public safety.
- As a relatively new technology, drones are not yet fully mature.
- Insufficient regulation concerning drones can lead to issues.
- Flying drones requires practice and skill.
- Potential insurance complications associated with drones.
- Restrictions may prohibit drone use in specific areas.
- People might overestimate their proficiency in flying drones.
- Privacy concerns related to drones are widespread.
- Critics argue that drones are not entirely safe.
- Acquiring drones for personal use can be expensive.
- Drones can be hazardous if mishandled.
- Managing drone use on an international scale is challenging.

Regulations related to using drones to spray pesticides in india

A. **Drone related** (Cracknell, 2017)

1. Only drones certified or approved by the Director General of Civil Aviation (DGCA) are authorized to conduct agricultural spraying. DGCA certification ensures the reliability of the drone.
2. The drone should possess the capability to manage varying payloads, such as a depleting tank. The nozzle system must be configured to ensure a continuous spray swath when operating at the minimum permitted height above uniformly distributed crops like paddy or sugarcane.
3. Equipped with precise altitude sensors, the drone must consistently maintain the desired height above the crops during the entire spraying operation.
4. To establish safety parameters, the drone's GPS accuracy and map precision are assessed, determining the safety margins for geo-fencing around the field or any obstacles.
5. The drone's spray system should offer variable flow control, ensuring consistent and uniform dispersal of the payload.
6. Essential fail-safes, including Return to Home (RTH) when the tank is empty, and an automated mission restart from the point where RTH was activated, are required features.
7. The drone's spray system must be leak-proof, preventing any dripping of pesticides or insecticides during application. Pre-flight checks are essential to ensure this.

B. Pesticides/Insecticides related (Cracknell, 2017)

1. Only pesticides or insecticides approved by the Central Insecticides Board and Registration Committee (CIB&RC) are permitted for use
2. The dosage applied must fall within the range approved by the CIB&RC.
3. Prior to the mission, compatibility tests between the pesticides or insecticides (liquid/solid) and the drone spray system are essential. This ensures solubility, formulation stability, and compatibility with the type of nozzles installed in the drone. If mixing multiple pesticides or insecticides, adherence to CIB&RC guidelines is mandatory
4. Determination of the minimum dilution is based on meeting the aforementioned requirements and ensuring effective coverage both horizontally and vertically
5. Pesticides or insecticides should only be diluted with clean water where applicable or with other approved ingredients as specified by the CIB&RC.

C. Environment limitations (Cracknell, 2017)

Drone-based spraying may be authorized under favorable weather conditions to optimize outcomes concerning ideal wind speed, temperature, relative humidity, and similar factors.

D. Pilot training (Cracknell, 2017)

1. Only pilots certified by the DGCA will be authorized to operate agricultural drones.
2. Mandatory training, as developed by NIPHM, Hyderabad, covering pesticide and insecticide handling, mission-specific operational protocols for agriculture, and pertinent crop protection guidelines, will be required for pilots operating pesticide or insecticide spray drones.

The use of agri-drones is on the rise

Numerous drone-based agricultural initiatives are underway in India, exemplified by real-life instances (Costa *et al.*, 2012):

- January 26, 2022: The Indian Government introduced a certification scheme for agricultural drones, permitting drones to carry payloads excluding chemicals or liquids used in spraying. These substances can be applied following relevant rules and regulations.
- January 23, 2022: The Indian government offered a 100% subsidy or a maximum of 10 lakhs, until March 2023, to institutions such as Farm Machinery Training and Testing Institutes, ICAR Institutes, Krishi Vigyan Kendras, and State Agriculture Universities. This initiative aims to promote drone usage in agriculture, easing the labour burden on farmers.
- Additionally, a contingency fund of Rs. 6000/hectare was established to facilitate the hiring of drones from Custom Hiring Centres (CHC). These subsidies and contingency funds aim to make this advanced technology accessible and affordable for farmers.
- November 16, 2020: The Indian government granted permission to the International Crops Research Institute (ICRISAT) for the use of drones in agricultural research activities. This

initiative aims to inspire researchers and entrepreneurs to explore cost-effective drone solutions beneficial for over 6.6 lakh Indian villages.

Until 2023, in India, spray drones have primarily been employed for applying insecticides and fungicides across various field crops and certain vegetables on expansive acres. Presently, the exploration of spot spraying herbicides on weeds using drones is underway. Drones are being considered to target sections of fields inaccessible to large, heavy ground sprayers due to excessively wet soil conditions, a common occurrence in certain areas. This approach allows for effective spraying where traditional equipment faces limitations due to soil moisture.

Conclusion:

Currently, there is tremendous interest in using drones to spray crop-protection products. Drones are now a viable option when choosing equipment to spray pesticides and the number of companies offering drone spraying services is rapidly increasing in Karnataka and other places in the India. The adoption of modern technologies in agriculture has great potential to revolutionize the Indian agriculture and ensure country's food security. The farmers face many problems like unavailability or high cost of labour, health problems by coming in contact with chemicals (fertilizers, pesticides, etc.) while applying them in the field, bite by insects or animals, etc. In this context, drones can help farmers in avoiding these troubles in conjunction with the benefits of being a green technology and also its emerging as a component of precision agriculture along with contributing to sustainable development of agriculture. Use of drones in agriculture also have ample opportunities to provide employment to people in rural areas.

References:

1. Aasen, H., & Bolten, H. (2018). Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers-From theory to application. *Remote Sensors in Environment, 205*(374–389).
2. Arbedo, J. G. A. (2019). A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. *Drones, 3*(40).
3. Berner, B., & Chojnacki, J. (2017). Influence of the air stream produced by the drone on the sedimentation of the sprayed liquid that contains entomopathogenic nematodes. *Journal of Research and Applied Agricultural Engineering, 62*(26-29).
4. Costa, R. T., Ueyama, F. J., Osorio, F., Vargas, P., & Pessin, G. (2012). The use of unmanned aerial vehicles and wireless sensor network in agricultural applications. In *IEEE conference on Geoscience and Remote Sensing Symposium (IGARSS-2012), 5045-5048*.
5. Costa, F. G., Ueyama, J. T., Braun, G., Pessin, F. S., Osório, S., & Vargas, P. A. (2012). The use of unmanned aerial vehicles and wireless sensor network in agricultural applications (pp. 5045–5048). In *IEEE International Geoscience and Remote Sensing Symposium, 22–27 July 2012, Munich, Germany*.

6. Cracknell, A. P. (2017). UAVs: Regulations and law enforcement. *International Journal of Remote Sensors, 38*(3054-3067).
7. Daponte, P., De Vito, L., Glielmo, L., Annelli, L., Liuzza, D., Picariello, F., & Silano, G. (2019). A review on the use of drones for precision agriculture. In *IOP Conference on Earth Environmental Sciences, 275-277*.
8. Dileep, M. R., Navaneeth, A. V., Ullagaddi, S., & Ajit Danti, A. (2020). Study and analysis on various types of agricultural drones and its applications. In *5th International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), 181-185*.
9. Hoffmann, W. C., Lan, Y., Huang, Y., Wu, W., & Fritz, B. K. (2017). Development of a spray system for an unmanned aerial vehicle platform. *Applied Engineering in Agriculture, 25*(6), 803-809.
10. Klemas, V. V. (2015). Coastal and environmental remote sensing from unmanned aerial vehicles: An overview. *Journal of Coastal Research, 5*(1260-1267).
11. Mehere, P. N., & Morey, N. S. K. (2018). Agriculture drone for fertilizers and pesticides spraying. *International Journal for Engineering Applications and Technology, 5*(3), 2321-8134.
12. Milics, G. (2019). Application of UAVs in precision agriculture. *International Climate Protection, 3*(258-260). Springer International Publishing.
13. Mogili, U. M. R., & Deepak, B. B. V. L. (2018). Review on the application of drone systems in precision agriculture. *Procedia Computer Sciences, 133*(502-509).
14. Puri, V., Nayyar, A., & Raja, L. (2017). Agriculture drones: a modern breakthrough in precision agriculture. *Journal of Statastical Management System, 20*(507-518).
15. Rasmussen, J., Nielsen, J., Garcia-Ruiz, F., Christensen, S., & Streibig, J. C. (2013). Potential uses of small unmanned aircraft systems (UAS) in weed research. *Weed Research, 53*(242-248).
16. Yang, S., Yang, X., & Mo, J. (2018). The application of unmanned aircraft systems to plant protection in China. *Precision Agriculture, 19*(278-292).

NEW METHODS OF SEED EXTRACTION, STORAGE, TEMPERATURE CONDITIONS AND PACKAGING VEGETABLE SEED

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Introduction:

India, a vast country with diverse soils and varied agro-climatic zones, facilitates year-round crop cultivation. While most seed crops thrive in the Kharif season, Rabi season sees the majority of vegetable crop production, known for yielding higher quality seeds. Indian farmers have the flexibility to practice multiple cropping systems, cultivating cereals, pulses, oilseeds, vegetables, fiber crops, etc., in Kharif, Rabi, and summer. Seeds play a pivotal role in agricultural production, influencing the effectiveness of other inputs. The National Seeds Policy of 2002 underscores the need for continuous development of new crop varieties and an efficient seed production and supply system to enhance productivity. The policy emphasizes the importance of increasing seed replacement rates for various crops to meet future food production targets. Over the past three decades, progress has been significant, with the green revolution being essentially a seed revolution. The production of high-quality seeds, characterized by high generation, vigor, physical purity, and health, was crucial for the success of the green revolution. Quality seeds are fundamental for a positive response to fertilizers and other inputs; otherwise, the seed of hope may lead to frustration. Seed, being a relatively inexpensive input, forms a small part of the total cultivation cost. Good seeds not only enhance crop production efficiency but also respond favorably to fertilizers. Vegetable seeds, prone to impurities, undergo various processes for separation, including:

1. Separation based on weight (or specific gravity): Cleaning seeds by exploiting differences in specific gravity is an age-old technique. This includes winnowing, where seeds and materials are dropped before a wind source, allowing heavier materials to fall closer to the wind source, while lighter materials are carried further away. Gravity tables, widely used machines, separate seeds based on weight by blowing air through a fine-screened, tilted deck. The lighter material 'floats' down the deck, while the heavier material remains in contact due to the screening material's nap, moving up the deck.

2. Cleaning wet-seeded crops: Wet seeds from fruits like tomatoes, cucumbers, and squash are processed by hand crushing or using a wet seed extractor. Some benefit from a fermentation process post-extraction, while others can be washed thoroughly and dried.

Wet seed processing:

1. **Extraction:** To harvest seeds from fleshy fruits like squash, cucumbers, and tomatoes, allow full ripening on the plant. Harvest the fruit at a more mature stage than for consumption, wash, break it open, and extract seeds. Clean pulp residue through washing or fermentation.
2. **Drying:** Spread seeds on a tray in a warm, dry place, ensuring temperatures stay below 95°F.
3. **Fermentation:** Seeds of crops like tomatoes, peppers, cucumbers, and squash are often processed through fermentation to ease pulp removal and combat certain bacterial seed-borne pathogens.

Fermentation process (Nine steps):

- Rinse dirt and debris from the fruit.
- Mash the fruit and transfer the seed, pulp, and juice mixture to a large container (garbage cans are suitable).
- Place the container in a 75-80°F (24-27°C) location, fermenting tomatoes for up to three days and squash for up to two days, adjusting based on ambient temperature (42 to 72 hours at 75-80°F).
- Stir the fermenting mixture two or three times daily for even fermentation.
- After 2-3 days, a white scum may appear, indicating successful fermentation. Once this occurs, the seed is ready for rinsing.
- Pour off the top layer of scum and pulp, doubling the volume with water.
- Stir, let the mix settle, and pour off the top layer of pulp and debris. Some lighter, less viable seed may be removed with this layer.
- Repeat washing 3-6 times until the water is fairly clear.
- Pass the remaining seed through a large strainer, retaining the seed and draining off excess water. Spread the drained seed on a fine screen for drying. Use fine mesh window screening for most seeds, ensuring a thin layer (less than 1/4 inch). Avoid paper, as drying seed may stick to it. Stir the seed frequently for even drying. If possible, place the seed in front of a fan or gentle breeze to expedite drying.

Vegetable seed storage: Methods, temperature conditions, and packaging:

Storage Methods:

1. **Ordinary seed stores:** Common in hilly regions, especially in snow-bound, arid, and dry temperature areas. These stores, located near houses, are simple, cost-effective, easily constructed by local masons, and efficient for storing vegetable seeds.
2. **Temporary shelters:** Intended for peak harvesting seasons, these shelters store graded or ungraded seed produce after proper drying. They are used in vegetable seed production areas and removed after use, protecting seed produce from direct sun, rain, and other weather variations.
3. **Air cooled storage:** Insulated structures above and partly underground, cooled by circulating colder air. Air-cooled stores are cheap, easy to install and operate, and widely used for storing most vegetable seeds.
4. **Insulated seed storage:** Featuring insulated walls, floor, and ceiling, maintaining the desired temperature and humidity for specific vegetable seeds. The inside temperature and humidity remain constant throughout the year, but the initial cost may be high.
5. **Refrigerated storage:** Primarily for long-term storage of high-value seed material, such as germplasm collections and breeder stocks. Refrigeration is also useful in sub-tropical areas for various categories of vegetable seed stocks. Special attention is needed for thermal insulation and store structure when incorporating refrigeration into control systems.
6. **Dehumidification:** An alternative system to refrigeration, using chemical desiccants like silica gel to control humidity. Silica gel, capable of absorbing up to 40% of its dry weight in water, is commonly used. The operation of alternating beds is usually controlled by a time clock.
7. **Storage in vapour proof containers:** Recent developments have led to storing small lots (e.g., 1, 2, 5, 10 kg) of vegetable seeds in sealed, moisture-proof containers. Seed lots are dried slightly below normal open storage moisture levels, then sealed in metal cans, packets, or other suitable moisture-proof containers. This packaging allows each seed lot to be stored at ambient temperature and humidity for 1-2 years or longer, with minimal impact on germination.

Temperature conditions in seed storage:

The potential viability and longevity of vegetable seeds in storage are influenced by the interplay of temperature and relative humidity. In numerous regions, fluctuating temperatures paired with periods of high relative humidity hasten seed deterioration during uncontrolled storage.

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Table 1: Recommended storage conditions and approximate length of seed storage

Vegetable	Safe seed moisture level for storage at ambient temperatures				Approximate length of storage (year)
	Ordinary	Vapour proof	Temperature ^{0}C	Relative humidity (%)	
Asparagus	8	7	20-30	40-60	2-3
Brinjal	8	6	25-30	40-60	2-3
Broccoli	7	5	15-20	35-55	2-3
Brussels sprouts	7	5	15-20	35-55	2-3
Cabbage	7	5	15-20	40-60	2-3
Capsicum	8	6	20-30	45-65	1-2
Carrot	8	7	15-20	40-55	1-2
Cauliflower	7	5	15-20	35-55	2-3
Chillies	8	6	25-30	45-60	2
Celery	8	7	15-20	40-50	2-3
Cucumber	8	6	25-30	45-65	3-4
Garden beet	9	7.5	15-25	40-60	2-3
Garden pea	9	7	15-25	40-60	2-3
Knolkhol	7	5	15-20	40-55	2-3
Lettuce	7	5.5	15-20	40-55	2-3
Lima bean	8	7	25-30	45-65	1-2
Muskmelon	8	6	25-30	45-65	3-4
Onion	7	6	15-20	40-55	1-2
Okra	8-10	8	25-30	40-65	2
Pumpkin	8	6	25-30	45-65	3-4
Radish	8	5.5	20-24	40-60	2-3
Snapbean	8	7	25-30	45-60	1-2
Spinach	9	8	20-25	40-60	3-4
Squash	8	6	25-30	45-65	2-3
Tomato	8	6	25-30	40-65	3-4
Turnip	8	6	15-20	40-60	3-4
Watermelon	8	6.5	25-30	45-65	3-4
Parsnip	8	6	15-20	40-60	1-2
Parsley	8	6.5	15-20	40-60	1-2

In certain temperate (arid) zones within hilly regions, the potential germination of seeds isn't significantly reduced during brief episodes of unregulated storage. This is attributed to satisfactory natural drying of seeds post-maturity in the field and low relative humidity during subsequent storage. Even relatively short-lived seeds, such as those of onions, can be stored with minimal reduction in germination capacity between seasons in many arid areas.

Temperature and seed moisture content are pivotal factors influencing seed longevity. Generally, as temperature decreases, the longevity of "orthodox" seeds—those adhering to general guidelines for storage—increases. For every 5.6°C decrease in temperature within the range of 32°F (0°C) to 122°F (50°C), longevity doubles, assuming constant moisture content. This guideline is a broad overview; some vegetable species experience faster declines in longevity than suggested, while others exhibit slower declines in relation to storage temperature. Subfreezing temperatures generally do not impact seed longevity provided the moisture content remains below 14% (preventing the formation of ice crystals). Numerous reports on the storage and germination testing of vegetable, flower, and herb seeds at 20°F (-7°C) and below have confirmed excellent germination. Seeds dried to approximately five percent moisture content and stored for twenty years have shown robust germination. This method, especially suitable for small seeds requiring minimal freezer space, is optimal for preserving seed quality. However, a cautionary note is warranted—frequent cycling of seeds in and out of the freezer without proper redrying may lead to degradation of germination. A study involving vegetable species seeds stored in containers with calcium chloride at various temperatures revealed a decrease in germination as temperature increased, even in a dry atmosphere. This underscores the importance of temperature control, even in low humidity conditions, for maintaining seed viability during storage.

Seed moisture and humidity:

The moisture content of seeds in equilibrium with specific relative humidity varies among crop species. Relative humidity denotes the moisture present in the air as a percentage of the maximum moisture it can hold at the same temperature. Warmer air can hold more water than cooler air. Hence, a constant water amount with increased temperature results in decreased relative humidity and vice versa. Seed moisture significantly influences longevity, surpassing the impact of temperature. Most seeds adhere to general guidelines linking moisture and longevity. Typically, for each one percent rise in seed moisture within the 5 to 13% range, longevity decreases by half. Beyond 13% moisture, seed storage fungi and heightened respiration induce a much faster decline in longevity. At 18 to 20% moisture, increased respiration and microbial activity lead to rapid seed deterioration. Most non-dormant seeds germinate at 30% moisture. Seeds stored at 4 to 5% moisture are resistant to seed storage fungi but have a slightly shorter longevity than those stored at a marginally higher moisture content.

Relationship between relative humidity and seed moisture content:

In commercial seed storage, using desiccants to dry seeds for storage is often impractical and costly unless the seeds are small and expensive. Commercial seeds are typically packaged for short or long-term storage under ambient humidity conditions. Understanding the relationship between humidity and seed moisture is crucial, as the moisture content eventually reaches equilibrium with the surrounding air. Regardless of storage conditions, the moisture content of seeds aligns with the moisture in the air. For instance, grains with high carbohydrate content reach 13 to 15% moisture at 75% relative humidity, while oil-rich seeds like peanuts can maintain 9 to 11% moisture at the same humidity. Once relative humidity surpasses 70%, seed moisture content rises significantly, reaching approximately 13%, where increased respiration and seed storage fungi become problematic. Above 70% relative humidity, the moisture content increases dramatically.

Effect of temperature and moisture on seed storage life:

Temperature, moisture, and relative humidity collectively influence seed longevity. The combined effects of relative humidity and temperature on seed longevity can be calculated, ensuring the sum of storage temperature (in degrees F) and relative humidity (in percent) does not exceed 100. Given the paramount importance of seed moisture, the rule specifies that not more than half the sum should be contributed by temperature. Most crop seeds experience a rapid loss of viability when humidity approaches 80% at temperatures ranging from 77°F (25°C) to 86°F (30°C). Seeds stored at a relative humidity of 50% or less and a temperature below 41°F (5°C) can remain viable for at least ten years. When transferring seeds from cold or frozen storage to room temperature, precautions must be taken to prevent condensation on the seeds. Seeds in sealed containers should reach room temperature before opening, while those stored in paper should be placed in a plastic bag, excess air removed, sealed, and left to stabilize at room temperature before opening.

Disease and insect management in seed storage:

While testing for seed-borne diseases and insect infestations is a routine part of seed quality inspection globally, it has been historically less emphasized in South Asia compared to purity and germination testing. Nevertheless, such testing is crucial because seeds can harbor various pathogens and insects, some of which may not be immediately visible. Their impact may become evident under favorable environmental conditions. Managing pests during the appropriate stage of vegetable seed crop development is critical. This can be achieved through safe chemical use, sanitation, growing resistant varieties, safe storage practices, and proper drying to meet the International Seed Testing Association's moisture limit. Insect pests can be controlled by maintaining good storage facilities and employing insecticides, fungicides, and fumigants effectively. The destruction of seeds by fungi or insects can be mitigated through chemical treatments. Phyto-sanitary certificates are often required for imported seeds to prevent the introduction of seed-borne pathogens from one country to another. Seed health testing is gaining recognition globally due to both domestic and international factors. This testing, encompassing pathological and entomological aspects, is increasingly seen as an integral part of the seed testing process.

Seed-borne diseases of important vegetable crops:

Table 2: Seed borne diseases of some important vegetables crop

Crop	Disease	Symptoms
Tomato	Fusarium wilt	Lower leaves become yellow, wilt and die
	Bacterial canker	Lower leaves wilt, brown streaks and canker develop on stem
	Bacterial wilt	Plant wilt at any stage without yellowing
Chillies & Bell pepper	Anthracnose	Branches show die back symptoms, fruits have dark sunken spots alongwith pink areas
	Leaf blight	Water soaked bleached spots appear on leaves resulting in blightening
	Fruit rot	Small water soaked spots appear on fruits
Garden pea	Ascochyta blight	Plant wilt, root turn brown, brown spot appear on foliage and stem
	Bacterial blight	Brown water soaked spot appear on leaf margins, nodel points and pods. Early infection result in complete wilting.
Potato	Late blight	Purplish black on leaves. The disease spreads to haulms and then to tubers.
Cruciferous	Alternaria leaf spot	Spots pale brown, papery often coalesce cause distortion and withering of leaves.
	Black rot	Leaf tissue turn yellow and chlorosis progress towards centre forming 'V' shaped lesions.
Ginger	Rhizome rot	Rhizome become soft, pulpy and on pressing easily collapse.

Fungi, causing the majority of plant diseases, are more prevalent in or on seeds than bacteria or viruses. Over 8000 fungal species are identified as plant pathogens. Seeds can host both saprophytic and pathogenic fungi, with the latter posing a more significant threat to crop productivity. Saprophytic fungi are not host-specific, while pathogenic fungi usually have a limited host range. Both types can exist on the seed surface, in cracks, or inside the seed coat.

Pathogenic fungi may also occur within the seed itself. While saprophytic fungi can contaminate germination media, pathogenic fungi pose a more serious risk to crops. Saprophytic fungi spores are numerous in storage environments exceeding 75% relative humidity and 15°C temperature. Approximately 200 plant viruses cause plant diseases, with about 80 considered seed-transmitted. Some viruses, like Tobacco Mosaic Virus (TMV), are carried on or inside the seed but outside the embryo, while others, like Bean Common Mosaic Virus (BCMV), are carried inside the embryo. Phyto-sanitary measures are crucial for imported seeds to prevent the introduction of seed-borne pathogens. Seed health testing is increasingly recognized as an essential part of the seed testing process globally.

Management of seed-borne diseases:

Pre-harvest control:

Pre-harvest control of seed-borne diseases can be achieved through three primary methods:

1. **Selection of disease-free seed production area:** Producing seed under environmental conditions that limit disease occurrence is crucial. For instance, seeds cultivated in dry, irrigated areas are more likely to be free of bacterial blight than those in humid regions.
2. **Cultural practices:** Cultural practices play a pivotal role in preventing and controlling seed-borne diseases. Key practices include:
    - Planting disease-free seeds.
    - Treating seeds with fungicides and antibiotics.
    - Applying fungicides, bactericides, and antibiotics to seed fields to prevent disease buildup.
    - Hand-roguing of diseased plants.
    - Avoiding overhead irrigation to prevent conditions conducive to disease buildup.
    - Using resistant cultivars.
    - Practicing crop rotation.
    - Isolating seed fields from potential sources of infection.
    - Implementing chemical and biological control of insect vectors.
3. **Point of origin of infection:** This method involves inspecting seed fields before harvest to detect and eliminate potential issues. Diseased areas may be destroyed or diverted from seed use, reducing the likelihood of seed infection, although it may not completely prevent contamination by surface-borne dust.

Post-harvest control:

Postharvest control of seed-borne diseases should be considered as a last resort, with prevention being the preferred approach. However, several methods can enhance the phytosanitary quality of seeds after harvest:

1. **Surface disinfection by chemical seed treatment:** Treating seeds with chemical disinfectants is effective, particularly against surface-borne pathogens.
2. **Separation of diseased seed and foreign materials:** Implementing measures to separate diseased seeds and foreign materials from a seed lot can help eliminate disease-infested components.
3. **Hot water treatment:** This method involves subjecting seeds to hot water to reduce pathogen presence.
4. **Organic solvent infusion of antibiotics:** Treating seeds with antibiotics, especially against surface-borne pathogens, can be effective. In some cases, organic solvent infusion improves antibiotic penetration, addressing internal infections.

Table 3: Chemical seed treatment schedules for vegetable seeds

Vegetable	Chemical recommended	Dose per kg seed		Method of treatment
		Chemical (g)	Water (l)	
Bean	Captain 75 WDP	1	0.050	Slurry treatment
	Thiram 75 dust	2.5	-	Dry dressing
Okra	Thiram 75 WDP	1	0.050	Slurry treatment
Brinjal	Thiram 75 dust	2.5	-	Dry dressing
	Captain 75 dust	2.5	-	Dry dressing
Carrot	Thiram 75 dust	2.5	-	Dry dressing
Chilli	Thiram 75 dust	2.5	-	Dry dressing
Cole crops	Thiram 75 dust	2.5	-	Dry dressing
Cucurbits	Thiram 75 dust	2.5	-	Dry dressing
	Captan 75 WDP	2.5	-	Dry dressing
Onion	Thiram 75 dust	2.5	-	Dry dressing
Tomato	Thiram 75 dust	2.5	-	Dry dressing

Insect management during seed storage:

Damage to vegetable seeds primarily occurs during storage and transit if not managed effectively. However, field damage is also possible, with no apparent seed injury visible until closer inspection, especially in crops nearing maturity, such as cucurbits and garden peas. This concealed infestation poses challenges in separating infested seeds from healthy ones during the seed cleaning process. Implementing proper storage facilities, along with the correct use of insecticides and fumigants, is crucial for insect control. The following preventive measures are recommended:

1. **Pre-arrival cleaning and disinfection:**
   - Thoroughly clean, white-wash, and disinfect all processing and storage structures before the arrival of new produce.

- Apply insecticides, such as malathion 50 EC (1 in 100 parts of water), for disinfection.
- Treat seed containers to prevent infestation.

2. **Seed preparation:**
   - Clean seeds, reducing their moisture content to below 9%.
   - Treat processed seeds with malathion 5% dust at a rate of 0.5g/kg of seed.
3. **Reusable bag treatment:**
   - Thoroughly clean and treat previously used bags with malathion sprays or fumigants like aluminum phosphide for 5 to 7 days in an airtight space.
   - Ensure proper cleaning and treatment for reuse.
4. **Proper storage practices:**
   - Store processed seeds separately from unprocessed or carry-over seeds.
   - Store different types of seeds separately to manage insect pests more effectively.
   - Regularly inspect seeds fortnightly.
   - If any living insect or infestation is detected, fumigate seeds under airtight conditions with aluminum phosphide (2-3 tablets of 3g each/ton of seed).
5. **Post-fumigation measures:**
   - After fumigation, aerate seed godowns and clean thoroughly to remove all dead insects.
   - Apply surface treatment with malathion 50 EC or fenitrothion 50 EC (1 part in 100 parts of water) or malathion dust 5% to prevent reinfestation.
   - Conduct surface treatment at 2 to 4 weeks' intervals, alternating between malathion and fenitrothion to prevent insect resistance.
6. **Safety measures:**
   - Exercise caution in using insecticides due to their high toxicity to humans.

Packaging and labeling of vegetable seeds:

Seed packaging is a critical final operation in the vegetable seed industry, impacting storage, transit, and distribution. Various materials and container types are employed for packaging, depending on factors such as seed type, storage duration, environmental conditions, moisture content, cost, and geographical location. The main objectives of packaging include facilitating handling, maintaining seed viability, providing identification, and protecting seeds from pathogens, insects, rodents, and mechanical injury.

Packaging materials and containers:

1. Materials for short-term storage:

- Cotton, paper, and composite materials like multi-wall paper and plastic film are used for short-term storage.

- These materials are generally porous, providing protection against mixing but offering limited defense against moisture or seed viability loss.

2. Materials for long-term storage:

- Metal and glass containers, properly sealed to prevent moisture and gas exchange, are ideal for long-term storage.
- Plastic is not recommended for long-term storage due to its unreliability in maintaining seed quality.

Commonly used packaging materials:

- **Conventional packaging:** Jute bags, cloth bags, paper bags, multi-paper bags, etc.
- **Moisture-resistant packaging:** Polythene bags with less than 700 gauge thickness, jute bags laminated with thin polythene film.
- **Moisture-proof containers:** Sealed steel bins, aluminum foil pouches, sealed polythene bags with more than 700 gauge thickness, tin cans, etc.

Table 4: Initial safe seed moisture level to vegetable seeds under ordinary and vapour proof containers for storage at ambient temperatures

Vegetable	Moisture %	
	Ordinary packaging	Vapour proof packaging
Cole crops	7	5
Tomato	10	8
Brinjal	8	6
Pepper	8	6
Pumpkin	7	6
Lettuce	8	6
Spinach	9	8
Turnip	6	5
Muskmelon	7	6
Water Melon	7	6
Radish	6	5
Garden beet	9	8
Sugar beet	9	8
Cucurbits	7	6
Gardenpea	9	8
Beans	9	7
Carrot	8	7
Onion	8	5
Okra	8	6
Chinese cabbage	7	5

Considerations for packaging:

- Packaging materials should not only be cost-effective but also capable of controlling seed moisture.
- Selection depends on temperature, humidity during storage, storage duration, and seed industry development.

Seed moisture content and storage:

Take, for example, cole crop seeds containing 7-8% moisture. When sealed in a moisture-proof container, the enclosed atmosphere will stabilize at a relative humidity of approximately 55%. Unfortunately, this level is too high for safe storage, activating storage pathogens and elevating seed respiration rates. Most vegetable species have seeds with a safe moisture content for sealed storage between 8 and 9%, while some species require even lower levels, dipping below 8%.

Labeling:

Throughout the growing season, from planting to harvest and processing, meticulous labeling of all crops is indispensable. This becomes especially critical post-harvest when numerous seeds may bear a visual resemblance. Each container should bear a label, persisting through every processing and cleaning stage. Despite its apparent simplicity, remembering the contents of a specific container can be challenging.

Record keeping:

Comprehensive records, spanning planting times and locations for each variety, lot numbers, seed sources, germination percentages, or notes on germination and vigor, are vital. Additional details such as the number of transplanted plants (useful for future seed yield calculations), maturity data, yield information, insect challenges, details of organic fertilizers and amendments, and any other pertinent data should be documented. Maintaining a well-organized file or computer database is crucial for variety characteristics and performance tracking. These detailed records serve as a valuable resource for future reference and decision-making.

Conclusion:

In summary, the effective processing and storage of vegetable seeds involve meticulous steps such as wet processing, temperature control, and disease management. Practices like pre-harvest controls and post-harvest measures are essential, along with careful insect management during storage. Packaging and labeling play vital roles in preserving seed quality, with choices influenced by storage duration and environmental conditions. Thorough record-keeping is crucial for tracking the entire seed journey. Overall, attention to detail at each stage ensures the long-term viability and quality of vegetable seeds, contributing to sustainable agricultural practices.

References:

1. https://www.agricultureinindia.net/seed/storage/vegetable-seeds-storage-methods-temperature-conditions-and-packaging/19756
2. http://eagri.org/eagri50/GPBR112/lec30.html
3. https://link.springer.com/chapter/10.1007/978-981-19-5888-5_7
4. https://www.mdpi.com/2227-9717/8/2/209
5. http://www.celkau.in/Agrienterprises/enerprise/21.%20Seed%20and%20Seedling/5.%20Seed%20extraction%20methods%20in%20vegetable%20crops.pdf
6. https://www.ciks.org/downloads/seeds/3.%20Seed%20Storage%20Techniques%20-%20A%20Primer.pdf
7. https://annamalaiuniversity.ac.in/studport/download/agri/gen/resources/SST%20623%20SEED%20PROCESSING%20AND%20STORAGE.pdf

INDIA’S G20 MEETING AND INDIA’S STAND ON CLIMATE CHANGE ADAPTATION

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Abstract:

India's stance on climate change adaptation within the G20 framework reflects its commitment to addressing the profound challenges posed by global warming limit of temperature below 2.0℃, while ensuring sustainable development. India acknowledges the urgency of climate change adaptation, particularly given its vulnerability to extreme weather events, changing precipitation patterns, and rising sea levels. G20 countries, which are collectively responsible for some 80 percent of global greenhouse gas emissions. India's position on climate change adaptation within the G20 reflects its commitment to a sustainable and resilient future. It advocates for collective action, equity, and inclusivity in addressing the impacts of climate change while ensuring that developmental goals are not compromised. India's stance contributes to the broader G20 efforts to advance global climate resilience and sustainable development.

Introduction:

The G20 summit held in Delhi on September 9 and 10 in New Delhi under the theme ‘**Vasudhaiva Kutumbakam’** under India’s Presidency was significant for the global fight against climate change as we have one earth, one family, and one future**.** where the decisions make now will determine the future of people and planet. It is with the philosophy of living in harmony with our surrounding ecosystem that commit to concrete actions to address global challenges. G20 cooperation is essential in determining the course the world takes. The meet addressed a key issue related to climate mitigation goals, namely climate finance (Buraman, 2023). In fact, the declaration at the end of the summit underlined the need to make funds available for developing nations struggling to balance their developmental goals and climate challenges. The global leaders also adopted a ‘green development pact’ to speed up measures to tackle the challenges of environment and climate change.

Proposals made by India’s G20 as a part of climate adaptation agenda:

The G20 recognized climate change, energy transition, and food and nutrition security as some of the key points of discussion under its preamble, *For the Planet, People, Peace and Prosperity*, indicating its perspectives and priorities.

- The G20 nations, responsible for 80% of global emissions, agreed to triple the global renewable energy capacity by 2030. They also reached an agreement on India's proposal for a Voluntary Action Plan on Doubling the Rate of Energy Efficiency.
- The decision to reform the processes of Multilateral Development Banks (MDBs) to mobilize climate finance for developing countries at G20, a forum of economic importance, shows great promise.
- The G20 Declaration has reaffirmed the climate finance commitments of developed countries. Further, it suggests a revision of the finance requirement from USD 4 trillion to USD 5.8 - 5.9 trillion (Aditi Singh, 2023).
- The G20 Declaration included the launch of the Resource Efficiency and Circular Economy Industry Coalition (RECEIC) which seeks to promote resource efficiency and circular economy practices within industries across the world. This followed the global reception of India's initiative Lifestyle for Environment Mission (Mission LiFE) that the member states aimed to mainstream under the Green Development Pact.
- India also launched the Global Biofuel Alliance to expedite the global uptake of biofuels with the declaration recognizing the importance of sustainable biofuels in zero and low-emission development strategies.
- The G20 leadership summit saw the establishment of the Green Hydrogen Innovation Centre for "promoting the adoption and advancement of green hydrogen as a key driver in the transition to a low-carbon, renewable energy economy"; steered by the International Solar Alliance (ISA), launched by India and France in 2015.

1. Action plan on doubling the rate of energy efficiency:

In an era characterized by growing energy demands, climate change concerns, and resource scarcity, doubling the rate of energy efficiency is a critical imperative. Doubling the rate of energy efficiency is a monumental task that requires collective action. This voluntary action plan serves as a blueprint for individuals, organizations, and communities to contribute to this vital cause. By raising awareness, conducting energy audits, promoting energy-efficient technologies, fostering innovation, and setting clear targets, collectively work towards a sustainable and energy-efficient future, mitigating the impacts of climate change while ensuring a more secure and prosperous country for generations to come.

2. Multilateral Development Banks (MDBS) to mobilize climate finance:

Multilateral development banks are essential players in the global effort to combat climate change. Their roles encompass mobilizing finance, reducing risks, providing technical assistance, and promoting policies and projects that contribute to both climate mitigation and adaptation while fostering sustainable development in developing countries. Their expertise and financial resources make them central actors in the global climate finance landscape.

3. **Resource Efficiency and Circular Economy Industry Coalition (RECEIC):**

Resource efficiency and circular economy initiatives have gained significant importance in recent years as a means to promote sustainability, reduce waste, and minimize the environmental impact of industrial processes. Several organizations and coalitions worldwide are actively working in this space.

4. **The five pillars of Green Development Pact:**

The pact was signed by keeping in mind the objective of the United Nations Framework Convention on Climate Change, which is to tackle climate change by strengthening the effective implementation of the Paris Agreement and its goal to limit temperature increase to well below two degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees Celsius (Burman, 2023). These can be fulfilled by implementing the five pillars of the Green Development Pact, under India's G20 Presidency, are envisaged to include:

I. Lifestyle of Environment (LiFE),

The G20, consisting of major economies, plays a critical role in addressing climate change due to its significant carbon footprint. LiFE, in this context, focuses on encouraging individuals and communities within G20 member countries to adopt environmentally conscious lifestyles that can collectively contribute to mitigating climate change by reducing the greenhouse gas emissions. Greenhouse gas emissions for 2022 the estimate at 58 giga tonnes (GT). To keep to the targeted limit of a 1.5℃ temperature rise, the world needs to cut down annual emissions by 3GT per year for the next three decades (D'souza and Sarkar, 2023).

II. Circular Economy

A Circular Economy is an economic system designed to minimize waste, promote sustainability, and maximize the use of resources. In the G20, the adoption of a Circular Economy approach is seen as crucial for addressing environmental challenges, reducing greenhouse gas emissions, and achieving long-term economic prosperity. The following components as to be fulfill for the effective circular economy.

A. **Waste reduction and recycling**: G20 countries are focusing on waste reduction and promoting recycling as a means to keep materials and products in use for as long as possible. In India only 30% of plastic waste as recycled of total amount of 7.3 MT (MoEFCC, 2023). They implement policies and infrastructure to enhance recycling rates and reduce landfill waste.
B. **Extended Producer Responsibility (EPR)**: The G20 recognizes the importance of EPR programs, which hold manufacturers responsible for the entire lifecycle of their products. This encourages companies to design products with recycling and sustainability in mind.

C. **Product life extension**: Initiatives within the G20 aim to extend the lifespan of products by encouraging repairs and refurbishment. This reduces the need for new manufacturing and conserves resources.

D. **International cooperation**: Recognizing that the challenges posed by the linear economy are global, G20 nations are working together to promote circularity on an international scale.

E. **Monitoring and reporting**: G20 countries are developing metrics and reporting mechanisms to track progress in transitioning to a Circular Economy. This helps ensure transparency and accountability.

III. Climate finance

India is the third largest military spender after the United States and China, with the expenditure going up by 0.9 per cent from 2020 to $76.6 billion (Tadas, 2023), Stockholm International Peace Research Institute (SIPRI). The budget allocation for the Ministry of Environment, Forest and Climate Change increased from a revised estimate of Rs 2,478 crore in the last budget to Rs 3,079.4 crore this year. A separate budget has been allocated for the National Mission on Natural Farming, at Rs 459 crore (Burman *et al*. 2023).

IV. Accelerating progress on SDGs

G20 Summit serves as a platform for major economies to demonstrate leadership in advancing the SDGs (food security, gender equality, quality education, health & well-being, global partnership). By aligning their policies, financial commitments, and actions with the 2030 Agenda (McBride *et al*, 2019), G20 nations can accelerate progress towards a more equitable, sustainable, and resilient future for people and the planet.

V. Energy transitions & energy security

As the world grapples with the twin challenges of climate change and energy security, the role of sustainable biofuels in the global energy landscape has gained significant importance. Biofuels offer a viable solution to reduce greenhouse gas emissions, promote energy independence, and foster rural development.

5. The International Solar Alliance (ISA):

A multinational alliance of solar-rich countries that aims to promote solar energy deployment and reduce the cost of solar power globally. It was launched at the 2015 United Nations Climate Change Conference (COP21) in Paris and has garnered significant attention and support. By integrating the International Solar Alliance into the G20 has provided a significant boost to global solar energy efforts, contributing to climate goals, economic development, and sustainable energy access. However, it would require careful coordination, resource allocation, and diplomatic efforts to ensure its success.

6. Green hydrogen innovation center:

Within the framework of the G20 served as a hub for advancing green hydrogen technologies and promoting international cooperation in this critical area. Green hydrogen, produced using renewable energy sources, has gained attention as a versatile and sustainable energy carrier that can contribute to various sectors, including transportation, industry, and energy storage. G20 could accelerate the development and adoption of green hydrogen technologies, contributing to global decarbonization efforts, economic growth, and energy security.

7. Strategies for food and nutritional security

Climate change poses a significant threat to food and nutritional security worldwide. As temperatures rise and weather patterns become more unpredictable, it is imperative that we take proactive measures to adapt and mitigate these impacts. By promoting climate-resilient agriculture, diversifying crops, improving infrastructure, and implementing supportive policies, can work toward a future where food and nutritional security are safeguarded, even in the face of a changing climate, With green revolution effect India now in the position of self-sufficient in food security with total food grain production of 330.5 MT (Indiastats, 2022), but global hunger index India stood 107 position out of 121 countries (Directorate of Economics and statistics, 2022). To meet the food security collective action, innovation, and global cooperation are key to ensuring that everyone has access to safe, nutritious, and sustainable food in the coming years following measures were proposed in the eve of G20 summit, 2022 on name of climate resilient agriculture.

A. **Crop diversification:** Encourage farmers to diversify their crops and cultivate resilient, climate-adapted varieties. This can help mitigate the risks associated with climate-induced crop failures.
B. **Improved infrastructure:** Invest in resilient infrastructure, such as irrigation systems, storage facilities, and transportation networks, to reduce post-harvest losses and ensure food reaches consumers efficiently.
C. **Climate information and early warning systems:** Enhance climate information services to provide farmers with accurate weather forecasts and early warnings of extreme events, enabling them to make informed decisions.
D. **Education and awareness:** Raise awareness about the link between climate change and food security, educating consumers about the importance of sustainable food choices.

8. Reducing disaster risk and building resilient infrastructure

Disaster risk encompasses a wide range of hazards, from earthquakes and floods to pandemics and cyberattacks (Vaidya *et al.*, 2019). The G20 nations must recognize that these risks are interconnected, and a holistic approach is essential. Reducing disaster risk and building resilient infrastructure is not only a moral imperative but also a strategic necessity for the G20 nations.

Conclusion:

In the face of an increasingly urgent climate crisis, India's host and participation in the G20 meeting serves as a reminder of the importance of collective action and shared responsibility in tackling climate change adaptation. It underscores the significance of finding common ground among nations with diverse needs and aspirations to work together toward a more resilient and sustainable world. India's stand within the G20 reaffirms its commitment to protecting the planet and improving the well-being of its people while contributing to the global effort to address the challenges of climate change adaptation.

References:

1. Burman, A., Sharma, S., Joseph, A.K., Priyadarshini, D., & Rai, S. (2023). *The Road to the G20 New Delhi Leaders' Declaration*, 1-29.
2. D'souza, R., & Sarkar, D. (2023). *Climate Performance Index: A Study of the Performance of G20 Countries in Mitigation*.
3. Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India. (2022). https://eands.dacnet.nic.in/.
4. Indiastat. (2022). *Focused on Facts*. https://www.indiastat.com.
5. McBride, B., Hawkes, S., & Buse, K. (2019). Soft power and global health: the sustainable development goals (SDGs) era health agendas of the G7, G20 and BRICS. *BMC Public Health*, *19*(1), 1-14.
6. Ministry of Environment, Forest and Climate Change (MoEFCC). (2023). *Third Biennial Update Report to the United Nations Framework Convention on Climate Change*. Ministry of Environment, Forest and Climate Change, Government of India.
7. Singh, A. (2023, February 3). India's EV Economy: The Future of Automotive Transportation. *Invest India*. https://www.investindia.gov.in/team-india-blogs/indias-ev-economy-future-automotive-transportation.
8. Tadas, G.A. (2023, August). *G20 initiatives in infrastructure investment & finance: Progress & shortfalls*. RIS Discussion Paper Series. New Delhi: India. Research and Information System for Developing Countries. Retrieved from https://ris.org.in/sites/default/files/Publication/DP-276-Dr-GA-Tadas.pdf.
9. Vaidya, R.A., Shrestha, M.S., Nasab, N., Gurung, D.R., Kozo, N., Pradhan, N.S., & Wasson, R.J. (2019). Disaster risk reduction and building resilience in the Hindu Kush Himalaya. In *The Hindu Kush Himalaya assessment: Mountains, climate change, sustainability and people*, 389-419.

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MODERN METHODS OF PACKAGING - PACKAGING MATERIALS AND TRANSPORTATION

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Introduction:

Packaging fresh fruits and vegetables is one of the more important steps in the long and complicated journey from grower to consumer. Bags, crates, hampers, baskets, cartons, bulk bins, and palletized containers are convenient containers for handling, transporting, and marketing fresh produce. More than 1,500 different types of packages are used for produce in the U.S. and the number continues to increase as the industry introduces new packaging materials and concepts. Although the industry generally agrees that container standardization is one way to reduce cost, the trend in recent years has moved toward a wider range of package sizes to accommodate the diverse needs of wholesalers, consumers, food service buyers, and processing operations.

The cost of packaging and packaging supplies is a substantial expense for the produce sector, so it's critical that packers, shippers, buyers, and consumers are aware of the many packaging options available. The various types of packaging are discussed in this information sheet along with its uses, restrictions, and purposes. There is also a list of the typical produce containers used by the industry, organised by commodity.

Benefits of packaging

1. Packaging serves as an efficient handling unit
2. It serves as a convenient storage unit
3. Packaging protects quality and reduces waste
    - ❖ Protects from mechanical damages
    - ❖ Protects against moisture loss

- ❖ may provide beneficial modified atmosphere
- ❖ provides clean produce
- ❖ may prevent pilferage

4. Provides service and sales motivation
5. Reduces cost of transport and marketing
6. Facilitates use of new modes of transportation

Function of the packaging are

1. To assemble the produce into convenient units for handling(called unitisation)
2. To protect the produce during distribution, storage and marketing.
3. Presentation
4. Preservation
5. Containment – package contains the product with in it and prevents leakage etc.

Requirement for an ideal package

1. Package should have sufficient mechanical strength to protect the content during handling, transportation and stacking.
2. It should be unaffected by moisture content, when wet and high RH for its strength.
3. Stabilise and secure product against movement within the package while handling.
4. Free from chemicals that could transfer to the produce and taint it or be toxic to the produce or to humans.
5. Meet handling & marketing requirement in terms of weight(light), size and shape (rectangle) .
6. Allow rapid cooling of the contents, and/or offer degree of insulation from the external heat/cold.
7. Utilises the gas barrier (eg. plastic films) with sufficient permeability to respiratory gases as to avoid any risk of anaerobiosis (ventillation) and any bad odour.
8. It must be easy to assemble, fill and close either by hand or by use of a simple machine.
9. Offer the security for the contents, and /or ease of opening and closing in some marketing situation (eg. promotional activity).
10. Facilitate easy disposal, reuse or recycling.
11. It should be easily transported when empty and occupy less space than when full.

Eg. Plastic boxes which nest in each other when empty

Collapsible plastic crates, cardboard boxes, fibre or paper or plastic sacks and.

12. Package must be readily available.

Factors affecting packaging

Along with the functions mentioned above, there are some other factors which also affect the packaging such as:

1. Purpose of packaging

2. Nature of product
3. Distance
4. Material handling system
5. Product sensitivity

1. Purpose of packaging

Type of packaging will depend on the purpose of packaging. Packaging for logistical purpose will be different from packaging for marketing (i.e. consumer) purpose.

2. Nature of Product

Distinct products will have different packaging. Which style of packaging would be more suitable will depend on the physical form of the product (such as solid, liquid, or gas). It is possible to find different types of packaging, such as cans, bottles, tetra packs, etc., even for products with the same physical form, such as liquid.

3. Distance

Packaging may also depend upon transportation distance. Longer distance would require tougher as well as more protective packaging.

4. Material Handling System

When choosing packaging, it's important to consider the kind of material handling system that will be employed. Larger packages can be handled by automated and mechanical devices, whilst smaller packages must be used for physical material handling.

5. Product Sensitivity

The product's sensitivity to the physical environment and external elements should also be taken into account. Certain products are more susceptible to factors like heat, cold, humidity, dust, chemicals, etc.

Packaging points

Recyclability/Biodegradability: A growing number of U.S. markets and many export markets have waste disposal restrictions for packaging materials. In the near future, almost all produce packaging will be recyclable or biodegradable, or both. Many of the largest buyers of fresh produce are also those most concerned about environmental issues.

Variety: The trend is toward greater use of bulk packages for processors and wholesale buyers and smaller packages for consumers. There are now more than 1,500 different sizes and styles of produce packages.

Shelf life: Modern produce packaging can be custom engineered for each commodity to extend shelf life and reduce waste.

Sales appeal: High quality graphics are increasingly being used to boost sales appeal. Multi-color printing, distinctive lettering, and logos are now common.

Containment

The produce must be contained in the container in manageable portions for handling and distribution. With little empty space, the vegetables should fit snugly inside the container. Potatoes, onions, and apples are examples of small agricultural items that can be packaged effectively using a range of different container forms and sizes. But many produce items, like asparagus, berries, or soft fruit, could need containers that are specifically made for them. Produce packages that are frequently handled by hand are typically restricted to 50 pounds. Forklifts can transport bulky packages that weigh up to 1,200 pounds.

Protection

The fruit must be shielded from mechanical harm and unfavourable climatic circumstances while being handled and distributed by the package. Buyers of produce sometimes assume that damaged produce packages, such as those that are torn, dented, or collapsed, have been handled carelessly. Containers for produce must be strong enough to withstand damage during storage, packaging, and delivery to the market. Since nearly all produce packaging are palletized, produce containers must have enough stacking strength to withstand crushing in low-temperature, high-humidity conditions. Although the price of packaging supplies has skyrocketed recently, buyers and packers no longer accept low-quality, light-weight containers that are quickly destroyed by moisture or handling. Containers must be extremely strong for produce going to foreign markets.

Air-freighted produce may require special packing, package sizes, and insulation. Marketers who export fresh produce should consult with freight companies about any special packaging requirements. Additionally, the USDA and various state export agencies may be able to provide specific packaging information.

One of the main reasons for rejected produce and low buyer and consumer satisfaction is damage brought on by inadequate environmental management during handling and shipping. There are specific criteria for temperature, humidity, and ambient gas composition for each fresh fruit and vegetable commodity. Produce-friendly packaging will help to maintain the best conditions for the longest shelf life. These materials could be specialised plastic liners that maintain a favourable ratio of oxygen and carbon dioxide, specific materials to delay the loss of water from the product, insulation materials to block the heat, or both.

Identification

The package must identify and provide useful information about the produce. It is customary (and may be required in some cases) to provide information such as the produce name, brand, size, grade, variety, net weight, count, grower, shipper, and country of origin. It is also becoming more common to find included on the package, nutritional information, recipes, and other useful information directed specifically at the consumer. In consumer marketing, package appearance has also become an important part of point of sale displays.

Types of packaging materials

Wood pallets

Wood Most fresh produce is transported to consumers on pallets, which serve as the actual platform. The first time pallets were utilised was to move products effectively during World War II. Of the 700 million pallets made in the U.S. each year, the produce business uses about 190 of them. Single-use pallets make up about 40% of these. The pallets are made as cheaply as possible and thrown away after usage because many are non-standard sizes. Even while standardisation efforts have been ongoing for a while, they have recently been sped up by environmental pressure, the expense of pallets, and landfill tipping costs, in addition to environmental groups' lobbying.

In the early 1950s, an alternative to the pallet was introduced. It is a pallet-size sheet (slipsheet) of corrugated fiber board or plastic (or a combination of these materials) with a narrow lip along one or more sides. Packages of produce are stacked directly on this sheet as if it were a pallet. Once the packages are in place, they are moved by a specially equipped fork lift equipped with a thin metal sheet instead of forks.

Produce packaging is frequently secured using plastic stretch film. Stretching, maintaining flexibility, and adhering to the packages are all necessary qualities of a good film. Plastic film can easily conform to loads of different sizes. It helps prevent the parcels from losing moisture, strengthens the pallet against theft, and can be applied partially automatically. But ventilation is greatly hampered by plastic film. Plastic netting is a popular substitute for stretch film and is significantly superior at stabilising some pallet loads, like those that need forced-air cooling. Stretch film and plastic netting that has been used may be challenging to handle and recycle appropriately.

Pallet bins

To transport produce from the field or orchard to the packaging facility, large wooden pallet bins made of milled lumber or plywood are typically employed. The capacity can range from 12 to more than 50 bushels, depending on the purpose. The length and width are typically the same as a normal pallet, though the height may vary (48 inches by 40 inches). In some produce companies, double-wide pallet bins that are 48 inches by 80 inches and more efficient are becoming increasingly popular.

Since the majority of pallet bins are built locally, it is crucial that they maintain consistency in terms of their structure, materials, and most importantly, size, from lot to lot. For instance, minor variations in the overall size When several hundred pallet bins are piled together for cooling, ventilation, or storage, the difficulties might become severe. Additionally, it's critical to effectively reinforce stress spots. An outdoor-stored hardwood pallet bin has an average lifespan of five years. Pallet bins may be functional for 10 years or more if they are adequately weatherproofed.

Wooden crates and lugs

The once-common usage of wooden crates for apples, stone fruit, and potatoes has almost entirely been supplanted by other forms of containers. They are now only used for a select few specialist commodities, including pricey tropical fruit, due to the relative cost of the container, increased attention to tare weight, and technological advancements in material handling. It is becoming more common to employ less expensive alternatives in favour of the 15-, 20-, and 25-pound wooden lugs that are still used to bunch grapes and some speciality crops.

Wooden baskets and hampers

For a range of commodities, including strawberries and sweet potatoes, wire-reinforced wood veneer baskets and hampers in various sizes were historically utilised. They can be nested when empty for more effective transport, and they are sturdy. Their use is now primarily restricted to regional grower markets where they can be reused numerous times due to cost, disposal issues, and difficulty in efficient palletization.

Corrugated fiber board

Corrugated fiberboard, often known as cardboard or pasteboard, is produced in a variety of designs and weights. It currently serves as the primary material for produce containers and is likely to do so for some time to come because to its affordability and adaptability. Corrugated fiberboard has recently made strides in terms of its durability and strength.

The majority of corrugated fiberboard is formed from paperboard that has been kraft-processed into three or more layers. The paper must be thicker than 0.008 inches to qualify as paperboard. The weight (in pounds per 1,000 square feet) and thickness of the different classes of paperboard are used to identify them. Unbleached pulp is used to provide the strong, recognisable brown hue of unbleached kraft paper. A fraction of synthetic fibres, sizing (starch), and other elements may be added to Kraft paper in addition to virgin wood fibres to increase strength and improve printability. Recycled fibres are present in most fiberboards. Laws may set minimum recycling requirements, and the proportion is anticipated to rise in the future. Tests have shown that cartons of fully recycled pulp have about 75 percent of the stacking strength of virgin fiber containers. The use of recycled fibers will inevitably lead to the use of thicker walled containers.

Double-faced corrugated fiberboard is the predominant form used for produce containers. It is produced by sandwiching a layer of corrugated paperboard between an inner and outer liner (facing) of paper-board. The inner and outer liner may be identical, or the outer layer may be preprinted or coated to better accept printing. The inner layer may be given a special coating to resist moisture.

Fiberboard containers lose strength in both cold temperatures and high humidity levels. If the container is not specifically treated, moisture absorbed from the environment and the contents may cause a reduction in the container's strength of up to 75%. There are now new anti-moisture coatings (both wax and plastic) that can significantly lessen the impacts of moisture. The stacking strength of the container is often only a small factor in corrugated fiberboard container applications. For instance, when piled, canned foods mostly support their own weight. Typically, fresh produce can only support a little amount of vertical load without suffering damage. To prevent the produce from being crushed, stacking strength is one of the most sought properties of corrugated fiberboard containers. Because of their geometry, most of the stacking strength of corrugated containers is carried by the corners. For this reason, hand holes and ventilation slots should never be positioned near the corners of produce containers and be limited to no more than 5 to 7 percent of the side area.

For many years, labels were printed on heavy paper and glued or stapled to the produce package. The high cost of materials and labor has all but eliminated this practice. The ability to print the brand, size, and grade information directly on the container is one of the greatest benefits of corrugated fiberboard containers. There are basically two methods used to print corrugated fiberboard containers:

Pulp containers

The majority of tiny consumer packets of fresh produce are packaged in containers made from recycled paper pulp and a starch binder. In conventional sizes, pulp containers come in a wide range of forms and sizes and are reasonably priced. Small fruit and berries that are readily affected by water benefit from the ability of pulp containers to absorb surface moisture from the product. Additionally recyclable, constructed from recycled materials, and biodegradable are the containers for pulp.

Paper and mesh bags

The only produce items currently packaged in paper bags are consumer packs of potatoes and onions. Wider applications exist for the stronger mesh bag. In mesh bags are also packaged cabbage, turnips, oranges, other speciality goods, and potatoes and onions. Some markets may still sell sweet corn in mesh bags. Mesh has the benefit of unimpeded air flow in addition to being reasonably priced. Onions especially benefit from good airflow. Small mesh bags provide beautiful displays that encourage purchases, which is why produce managers at supermarkets enjoy them.

However, bags of all kinds have a number of significant drawbacks. Small bags do not effectively fill the space within corrugated fiberboard containers, while large bags do not palletize well. Bags do not provide defence against hard handling. Mesh bags don't offer much defence against pollutants or light. Additionally, consumers accurately believe that produce packaged in bags is of a lower quality than other produce. Few consumers are willing to pay more for product that is bagged.

Plastic Bags

Fruit and vegetable consumer packaging is predominantly made of plastic bags (polyethylene film). In addition to the extremely low material costs, automated bagging equipment lowers packing costs even more. Film bags are transparent, making it simple to see the contents, and they easily accommodate high-quality designs. Plastic films can be manufactured to manage the ambient gases inside the bag and come in a variety of thicknesses and grades. In order to maintain the ideal balance of oxygen, carbon dioxide, and water vapour inside the bag, the film material "breathes" at a rate that is essential. Since each producing item has a different need for environmental gases, packaging material for modified atmospheres needs to be uniquely designed for each product. Research has shown that the shelf life of fresh produce is extended considerably by this packaging. The explosive growth of precut produce is due in part to the availability of modified atmosphere packaging. In addition to engineered plastic films, various patches and valves have been developed that affix to low-cost ordinary plastic film bags. These devices respond to temperature and control the mix of environmental gases.


Shrink wrap

The shrink-wrapping of individual produce pieces is one of the newest packaging techniques for produce. Potatoes, sweet potatoes, apples, onions, sweet corn, cucumbers, and a range of tropical fruits have all been packaged effectively using shrink wrapping. With the use of designed plastic wrap, product can be shrunk wrapped in a way that minimises mechanical damage, reduces shrinkage, and offers a nice surface for stick-on labelling.

Rigid plastic packages

Clamshells are plastic containers having a heat-formed top and bottom made of one or more pieces of plastic. Clamshells are becoming more and more popular as a result of their low cost, adaptability, superior produce protection, and attractive consumer packaging. Clamshells are most frequently used with consumer packs of high-value product items, such as little fruit, berries, mushrooms, etc., or goods that are readily damaged by crushing. Clamshells are frequently served with precut fruit and salads that have already been made. It has been tested to replace waxed corrugated fiberboard with moulded polystyrene and corrugated polystyrene containers. Since they are now not generally cost-competitive, they might become more prevalent as environmental demands increase. Heavy-molded polystyrene pallet bins have been adopted by a number of growers as a substitute for wooden pallet bins. Although at present their cost is over double that of wooden bins, they have a longer service life, are easier to clean, are recyclable, do not decay when wet, do not harbour disease, and may be nested and made collapsible.

The disposal and recycleability of packaging material of all types will become a very serious issue as environmental pressures continue to increase. In a landfill, ordinary polyethylene may take 200 to 400 years to decompose. The period will be shortened to 20 years or fewer with the addition of 6% starch. Companies that produce packaging materials are working to create starch-based polyethylene alternatives that will decompose in landfills just as quickly as regular paper.

Standardization of packaging

Various groups have different perspectives on the standardisation of produce packaging. Market demand from numerous different produce sector groups led to the large range of packaging sizes and material combinations that are currently available. For instance, folks who purchase fresh vegetables in great quantities are frequently ones who are most concerned about the environment. They desire more recyclable and biodegradable materials and less packing, but they also want a variety of package sizes for convenience. The trend toward preprinted, customised containers was started by packers, who desire to reduce the variety of packages they need to have in store. Standardizing package sizes will enable easier handling and palletizing for shippers and haulage companies. Produce buyers are not a homogeneous group. Buyers for grocery chains have different needs than buyers for food service. For grocery items normally sold in bulk, processors want largest size packages that they can handle efficiently - to minimize unpacking time and reduce the cost of handling or disposing of the used containers. Produce managers, on the other hand, want individualized, high quality graphics to entice retail buyers with in-store displays.

Packaging materials in use

The packaging of perishable goods uses a wide range of materials. They consist of corrugated fibre board, wood, bamboo, stiff and foam plastic, and solid cardboard. The type of material or structure used depends on the perforation technique, the travel time to the final destination, the cost of the product, and the market's demands.

1. CFB boxes

Corrugated fibreboard is the most widely used material for fruit & vegetable packages because of the following characteristics:

i. Light in weight
ii. Reasonably strong
iii. Flexibility of shape and size
iv. Easy to store and use
v. Good pointing capability
vi. Economical

2. Wooden boxes

Materials used for manufacture of wooden boxes include natural wood and industrially manufactured wood based sheet materials.

3. Sacks

Traditionally, jute fibre or other comparable natural materials were used to make sacks. A plain weave is offered on the majority of jute bags. Materials weighing no more than 250 grammes per square metre are used for a tonne of vegetable transportation. Due to concerns about cost, aesthetics, mechanical qualities, and the risk of insect infestation and spread, synthetic and paper-based sacks have frequently replaced natural fibre sacks. For root crops, polypropylene sacks of the plain weave kind are frequently utilised. 70–80 grammes per square metre is the most typical fabric weight.

Palletisation

In all industrialised nations, pallets are frequently utilised to transport fruit and vegetable bundles. Handling packages on pallets has the following benefits:

1. Handling labour costs are significantly decreased.
2. Transport expenses might be decreased.
3. Goods are safeguarded and damage is minimised.
4. Mechanized handling is frequently quite quick.
5. Storage space can be utilised more effectively by high stacking.
6. Pallets support the adoption of uniform packaging dimensions.

The handling of export packages on pallets for shipping or for transport and storage inside the importing country is a crucial consideration in the design process. Pallet dimensions are typically 1200 mm x 1100 mm.

Ventilation of packages

One of the main criteria for limited permeability packaging materials is the reduction of moisture loss from the product. With the creation and widespread use of semi-permeable plastic sheets, moisture loss issues from produce were addressed. To prevent the buildup of heat from the commodity's respiration, airflow through the ventilation holes helps heated fruit or vegetables to slowly cool. With forced air cooling, holes are especially crucial for cooling the fruit when the packages are placed in a cold storage. Ventilation holes aid in the distribution of generated ethylene.

Cushioning materials

When there is a vibration or impact, the purpose of the cushioning materials is to stabilise the goods inside the packages and stop them from moving about in respect to one another and the box itself. Certain cushioning materials can also provide packages more stacking power. Wrapping paper, fibreboard (single or double wall), moulded paper pulp trays, moulded foam polystyrene trays, moulded plastic trays, foam plastic sheet, plastic bubble pads, finely shredded wood, and plastic film liners or bags are some examples of the cushioning materials used, depending on the commodity.

Controlled and Modified Atmospheric Packaging (CAP and MAP)

Normal air is made up of 78% nitrogen, 21% oxygen, 0.03% carbon dioxide, and several noble gases. Perishable and semi-perishable food goods can have their shelf lives extended using a technique called modified environment packaging that modifies the relative quantities of the atmospheric gases surrounding the produce. Although the phrases modified atmosphere (MA) and controlled atmosphere (CA) are frequently used interchangeably, there is a clear distinction between the two.

Controlled atmosphere (CA)

This describes an atmosphere for storing perishable goods that is distinct from the usual atmosphere in terms of its composition and is maintained during storage and distribution. The component gases are precisely adjusted to certain concentrations. In order to maintain a controlled atmosphere, the storage atmosphere's composition must be continuously monitored, and when necessary, the proper gases or gas mixes must be injected into the atmosphere. As a result, the system can only be used for refrigerated bulk storage or the shipment of goods in huge containers because it needs sophisticated devices to monitor the gas levels.

Potential advantage could become a real catastrophe if the atmosphere in the CA system is not carefully regulated or if the storage atmosphere is unintentionally changed. Between cultivars, growing regions for the same cultivars and years for a given location, as well as between cultivars themselves, there are differences in the degree of injury susceptibility and the specific symptoms. Even after removing the tomato fruit to the air, excessively low O2 or high CO2 levels inhibit optimal ripening, and CA increases the risk of chilling injury.

Modified Atmospheric Packaging (MAP)

In contrast to CAPs, once a package has been hermetically sealed, there is no way to precisely control the atmospheric components at a given concentration in MAP. Inside the packages, altered atmospheric conditions are produced by the commodity itself and/or via active manipulation. Commodity respiration results in the evolution of commodity-generated or passive MA. In order to swiftly build the desired EMA composed to a passively generated EMA, active modification entails establishing a slight vacuum inside the package and replacing it with a desired combination of gases.

Utilizing carbon dioxide or ethyl absorbers (scavengers) inside the container to stop the buildup of the specific gas inside the package is another active modification strategy. This process is known as active packing. Iron powder is also known to absorb carbon dioxide, as are substances like hydrated lime, activated charcoal, and magnesium oxide. To absorb ethylene inside the packages, you can use phenyl methyl silicone, squakna, and potassium permanganate. These scavengers may be contained in tiny sachets inside of the packages, impregnated into the wrappers, or incorporated into porous materials like vermiculite. When it comes to produce that breathes actively, such as fruits and vegetables, the packaging atmosphere should have the right amounts of oxygen and carbon dioxide. In general, MA containing between 2-5% Oxygen and 3.8% carbon dioxide have been shown to extend the shelf life of a wide variety of fruits and vegetables.

Vacuum packaging

In-depth protection from corrosion, oxidation, moisture, drying out, dirt, dust attraction by electric charge, ultra violet radiation and mechanical damages, fungus growth or perishability, etc. is provided by vacuum packaging. For tropical nations with significant levels of atmospheric humidity, this technique is admirably relevant. The product is placed in a vacuum bag (made of special, hermetic filling), which is then evacuated in a vacuum chamber and then hermetically sealed to create a complete barrier against air and moisture. If there is a vacuum inside the package and some of the product cannot withstand atmospheric pressure, the packages are flushed with inert gases like nitrogen and carbon dioxide following evacuation.

Edible packaging

A thin continuous layer of edible material created on, deposited on, or sandwiched between the foods or food components is simply referred to as an edible film or coating. The package is a crucial component of the food and can be consumed along with the entire food item. Based on its ability to operate as a barrier to moisture and gases, mechanical strength, physical characteristics, and resistance to microbial development, a material is chosen for use in edible packaging. Lipids, proteins, and polysaccharides, or a combination of any two or all of these, are the common ingredients used in edible packaging. Many lipid compounds, such as animal and vegetable fats, acetoglycerides have been used in the formulation of edible packaging for fresh produces because of their excellent moisture barrier properties. Lipid coatings on fresh fruits and vegetables reduce weight losses due to dehydration during storage by 40-70 per cent. Research and development effort is required to develop edible films and coatings that have good packaging performance besides being economical.

Conclusion:

As global trade grows, improved packaging will be more crucial in India. Transactions between sellers and purchasers might benefit substantially from standardised packaging of sized and graded produce that will maintain the quality during marketing. Improved packaging ought to have an immediate impact on waste reduction. It takes a lot of background study to package perishable goods and flowers in a way that mimics the real handling conditions that are anticipated during marketing.

References:

1. Robertson, G. L. (2003). *Food Packaging Principles and Practices.* Marcel and Deckker, Inc., New York.
2. NIIR Board. (2000). *Handbook on Modern Packaging Industries.* Asia Pacific Press Inc., Delhi, India.
3. Mahadevah, M., & Gowramma, R. V. (1996). *Food Packaging Materials.* Tata-McGraw-Hill Pub. Company, Limited, New Delhi.

4. Crosby, N. T. (1981). *Food Packaging Materials.* Applied Science Publishers Ltd., New York.
5. Heiss, R. (1970). *Principles of Food Packaging: An International Guide.* P. Keppler Verlag KG, Heusenstamn, Germany.
6. Paine, & Paine. (1983). *Handbook of Food Packaging.* Blackie and Son Ltd., London.
7. Anderson, W. A. C., & Castle, L. (2003). Benzophenone in cartonboard packaging materials and the factors that influence its migration into food. *Food Addit Contam, 20*(6), 607–618.
8. Barran, L. M., & McCormick, D. E. (2018). Patent application no. 29/575,248. U.S. Patent and Trademark Office, Washington.
9. Begley, T., Castle, L., Feigenbaum, A., Franz, R., Hinrichs, K., Lickly, T., & Rijk, R. (2005). Evaluation of migration models that might be used in support of regulations for food-contact plastics. *Food Addit Contam, 22*(1), 73–90.
10. Elfithri, R., Ghee, T. K., Basri, N. E. A., & Zain, S. M. (2012). Integrated paper recycling management system in UKM campus. *Procedia Soc Behav Sci, 60*, 556–561.
11. Fadiji, T., Coetzee, C., Pathare, P., & Opara, U. L. (2016). Susceptibility to impact damage of apples inside ventilated corrugated paperboard packages: effects of package design. *Postharvest Biol Technol, 111*, 286–296.
12. FSSR. (2011). *Food Safety and Standards Act, Rules and Regulations.* New Delhi: Akalnak Publications.
13. Hartman, R. R., Berger, B. D., & DeHaan, K. J. (1991). Patent No. 4,982,064. Patent and Trademark Office, Washington.
14. Hauptmann, M., & Majschak, J. P. (2011). New quality level of packaging components from paperboard through technology improvement in 3D forming. *Packag Technol Sci, 24*, 419–432.
15. IS:SP-7 NBC. (2016). *National Building Code of India.* New Delhi: Bureau of Indian Standards.
16. Jones, P., & Comfort, D. (2017). The forest, paper and packaging industry and sustainability. *Int J Sales Retail Mark, 6*(1), 3–21.
17. Khwaldia, K., Arab-Tehrany, E., & Desobry, S. (2010). Biopolymer coatings on paper packaging materials. *Compr Rev Food Sci Food Saf, 9*(1), 82–91.
18. Kirwan, M. J. (2005). *Paper and Paperboard Packaging Technology.* Oxford: Blackwell Publishing.
19. Romaine, C. (2005). Composite cans. In *Paper and Paperboard Packaging Technology*, (pp. 175–196). Oxford: Blackwell Publishing.

20. Smook, G. A. (2002). *Handbook for Pulp and Paper Technologists.* Vancouver: Angus Wilde Publications.
21. Tetra Pak. (n.d.). *Facts and Figures.* https://www.tetrapak.com/. Accessed Dec 2018.
22. Trier, X., Granby, K., & Christensen, J. H. (2011). Polyfluorinated surfactants (PFS) in paper and board coatings for food packaging. *Environ Sci Pollut Res, 18*(7), 1108–1120.
23. Villanueva, A., & Wenzel, H. (2007). Paper waste–recycling, incineration or landfilling? A review of existing life cycle assessments. *Waste Manag, 27*(8), S29–S46.
24. Wang, L., Sharifzadeh, M., Templer, R., & Murphy, R. J. (2013). Bioethanol production from various waste papers: economic feasibility and sensitivity analysis. *Appl Energy, 111*, 1172–1182.
25. Zhu, H., Fang, Z., Preston, C., Li, Y., & Hu, L. (2014). Transparent paper: fabrications, properties, and device applications. *Energy Environ Sci, 7*(1), 269–287.

FROM FARM TO TABLE: MODERN APPROACHES TO POST HARVEST PRESERVATION

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Abstract:

This book chapter offers a comprehensive examination of contemporary strategies and technologies revolutionizing the journey of agricultural produce from farm harvests to consumer tables. The chapter begins by addressing the critical issue of post-harvest losses, emphasizing the pivotal role of advanced preservation methods in ensuring food security and sustainability. It navigates through cutting-edge innovations, such as controlled atmosphere storage and modified atmosphere packaging, shedding light on how these technologies are reshaping traditional storage and transportation practices to extend the shelf life of perishable goods. A significant focus is placed on the integration of smart technologies and the Internet of Things (IoT) in cold chain management, showcasing their role in real-time monitoring and control of environmental conditions during storage and transportation. The chapter explores the potential of sustainable approaches like solar drying and dehydration techniques to mitigate losses and enhance the longevity of fruits, vegetables, and herbs. Success stories and case studies illustrate the tangible impact of these modern preservation methods on reducing post-harvest losses and increasing farmers' income. This book chapter serves as a valuable resource for researchers, practitioners, and policymakers engaged in the fields of agriculture and food technology, providing insights into the transformative potential of modern approaches to post-harvest preservation in meeting the evolving demands of a globalized food supply chain.

Keywords: Harvest; Agriculture; Preservation; Supply; Technology.

Introduction:

Post-harvest preservation plays a pivotal role in ensuring food security by minimizing losses and maintaining the quality of agricultural produce throughout the supply chain. According to the Food and Agriculture Organization (FAO), approximately one-third of the world's food produced for human consumption is lost or wasted annually, with a significant portion occurring during post-harvest handling and storage. Efficient preservation methods help mitigate this loss, contributing to increased food availability and accessibility. Furthermore, post-harvest preservation is essential for extending the shelf life of perishable goods, reducing reliance on seasonal availability, and ensuring a more consistent and diverse food supply, especially in regions where climatic conditions or transportation infrastructure pose challenges to year-round fresh produce availability (FAO, 2019) [1].

Post-harvest losses, characterized by spoilage and waste, present formidable challenges with wide-reaching implications for food security, economic sustainability, and environmental conservation. A comprehensive analysis published in the "Annual Review of Environment and Resources" underscores the magnitude of this issue, revealing that globally, around one-third of the food produced for human consumption is lost or wasted annually. The factors contributing to post-harvest losses are multifaceted, encompassing inadequate infrastructure for storage and transportation, suboptimal handling practices, and inefficient supply chain management. Spoilage during storage is a prominent concern, leading to nutrient degradation and diminishing the overall quality of the harvested produce. The consequences of post-harvest losses extend beyond mere quantitative reductions in food availability. A study in the journal "Global Food Security" highlights the economic ramifications, emphasizing that these losses undermine the income of farmers and exacerbate poverty within agricultural communities [2]. Additionally, inefficient post-harvest practices intensify the environmental impact of food production, as resources invested in cultivating lost or wasted crops, such as water, energy, and land, are essentially squandered. Addressing these challenges requires a holistic approach that integrates advanced storage technologies, improved transportation infrastructure, and enhanced supply chain management practices to minimize post-harvest losses and promote sustainable food systems (Gustavsson *et al.*, 2011; Lipinski *et al.*, 2013).

Emerging trends in post harvest technologies:

Recent advancements in post-harvest preservation have witnessed the integration of cutting-edge technologies aimed at mitigating losses and ensuring the quality of agricultural produce. Controlled atmosphere storage (CAS) stands out as a notable innovation, as discussed in the "Postharvest Biology and Technology" journal. CAS involves regulating the levels of oxygen, carbon dioxide, and humidity within storage facilities to create an environment tailored to specific crops, slowing down the ripening and decay processes. This technology is particularly beneficial for fruits and vegetables, extending their shelf life and preserving their nutritional content [3]. Another breakthrough, highlighted in the "International Journal of Food Science & Technology," is Modified Atmosphere Packaging (MAP). This technique involves modifying the composition of gases surrounding the produce within packaging, thereby slowing down respiration and microbial activity. MAP has proven effective in maintaining the freshness and quality of a variety of perishable items during transportation and storage, offering a promising solution to post-harvest losses.

In tandem with controlled atmosphere storage and modified atmosphere packaging, advanced refrigeration methods have emerged as pivotal tools in the arsenal against post-harvest losses. A study in the "Journal of Food Engineering" delves into the application of advanced refrigeration, including vacuum cooling and hydrocooling, to rapidly reduce the temperature of freshly harvested produce. This swift cooling process helps in preserving the quality and extending the shelf life of fruits and vegetables by minimizing physiological changes and inhibiting the growth of spoilage microorganisms. The synergy of these technologies showcases a transformative approach to post-harvest preservation, demonstrating the potential to revolutionize the landscape of global food supply chains (Dehghannya *et al.*, 2015; Mir *et al.*, 2018).

Innovative packaging solutions:

Modern packaging techniques play a pivotal role in extending the shelf life of perishable goods, addressing challenges associated with post-harvest losses and ensuring the delivery of fresh, high-quality produce to consumers. One noteworthy innovation is Modified Atmosphere Packaging (MAP), as discussed in the "Journal of Food Science and Technology." MAP involves adjusting the composition of gases within the packaging to create an optimal atmosphere for specific products, effectively slowing down the respiration rate and microbial growth. By reducing the levels of oxygen and increasing the concentration of carbon dioxide, MAP inhibits the decay of fruits, vegetables, and other perishable items, thereby extending their shelf life and preserving their nutritional quality. This technology is particularly advantageous in the storage and transportation of fresh produce, offering a controlled environment that minimizes deterioration [4].

Active packaging is another modern approach designed to enhance the shelf life of perishable goods. This technique involves incorporating active substances, such as antimicrobial agents or oxygen scavengers, into the packaging material. The antimicrobial agents help inhibit the growth of spoilage microorganisms, while oxygen scavengers reduce the exposure of the product to oxygen, minimizing oxidative reactions that contribute to deterioration. A study published in the "Journal of Food Engineering" highlights the efficacy of active packaging in maintaining the freshness of meat products during storage. By leveraging these modern packaging techniques, producers and distributors can significantly reduce post-harvest losses, ensuring that consumers have access to a longer-lasting and higher-quality selection of perishable goods (Goyanes *et al.*, 2012; Limbo *et al.*, 2016).

Biodegradable polymers:

- Derived from renewable resources like cornstarch, sugarcane, or potato starch.
- Naturally breaks down over time, reducing long-term environmental impact.
- Represents a more sustainable alternative to traditional non-biodegradable plastics.

Compostable packaging:

- Designed to decompose in industrial composting facilities

- Results in nutrient-rich compost without generating harmful byproducts
- Offers a closed-loop system that aligns with circular economy principle

Recyclable materials:

- Includes commonly recycled materials like paper, cardboard, and specific plastics.
- Contributes to a circular economy by reducing the need for virgin resources.
- Promotes resource conservation and waste reduction.

Mycelium packaging:

- Derived from fungi mycelium, the root structure of mushrooms.
- Biodegradable and environmentally friendly.
- Provides a sustainable alternative to traditional packaging materials.

Minimalist design and lightweight materials:

- Focuses on reducing packaging waste through streamlined design.
- Utilizes lightweight materials to decrease transportation-related carbon emissions.
- Encourages efficient use of resources and minimizes environmental impact.

Recycled content:

- Incorporates post-consumer recycled materials into packaging.
- Reduces the demand for virgin materials and minimizes environmental footprint.
- Encourages the recycling loop and supports a more sustainable supply chain.

Reusable packaging:

- Emphasizes durability and reusability of packaging materials.
- Encourages consumers to reuse packaging for various purposes.
- Reduces overall waste generation and promotes a culture of sustainability.

Water-based inks and adhesives:

- Substitutes traditional inks and adhesives with environmentally friendly water-based alternatives.
- Reduces the environmental impact of printing and labeling processes.
- Aligns with sustainable practices in the packaging industry.

Life Cycle Assessment (LCA):

- Considers the environmental impact of packaging throughout its life cycle.
- Evaluates factors such as raw material extraction, manufacturing, transportation, use, and disposal.
- Guides the selection of materials and design choices to minimize overall environmental impact.

Consumer education and engagement:

- Raises awareness among consumers about the importance of eco-friendly packaging.

- Encourages responsible disposal practices and recycling habits.
- Fosters a collective commitment to sustainability across the supply chain and consumer base.

Cold chain management: ensuring freshness:

The cold chain, a temperature-controlled supply chain, plays a crucial role in preserving the quality and nutritional value of agricultural produce from the farm to the consumer. It involves maintaining a consistently low temperature throughout the entire journey of perishable goods, from harvest to retail. This controlled environment helps slow down the metabolic and enzymatic processes in fruits, vegetables, and other perishables, minimizing the degradation of essential nutrients and preserving their freshness [5]. By preventing the growth of spoilage microorganisms and controlling the ripening process, the cold chain ensures that consumers receive produce with optimal taste, texture, and nutritional content. The integrity of the cold chain is essential in mitigating post-harvest losses, extending the shelf life of products, and delivering a healthier and safer food supply to consumers.

The nutritional benefits of the cold chain are particularly significant as it helps retain essential vitamins, minerals, and antioxidants in fruits and vegetables. Studies have shown that maintaining low temperatures during storage and transportation helps to slow down the loss of certain nutrients, ensuring that consumers receive produce with higher nutritional value. Moreover, the cold chain reduces the risk of foodborne illnesses by inhibiting the growth of pathogenic bacteria. Overall, the cold chain not only safeguards the economic interests of farmers by minimizing losses but also contributes to public health by delivering fresh, nutritious, and safe agricultural produce to consumers worldwide.

Solar drying and dehydration techniques:

Sustainable approaches to post-harvest preservation, such as solar drying and dehydration, have gained prominence for their effectiveness in extending the shelf life of fruits, vegetables, and herbs while minimizing energy consumption and environmental impact.

1. Solar drying:

- Principle: Solar drying harnesses the energy from sunlight to remove moisture from produce, inhibiting the growth of microorganisms and preventing spoilage.
- Process: Fruits, vegetables, or herbs are arranged on trays or racks in an open-air structure, exposed to direct sunlight. The natural heat causes water evaporation, effectively dehydrating the produce.
- Benefits: Solar drying is an energy-efficient method, utilizing renewable solar energy. It reduces the reliance on electricity or fuel-powered dehydrators, making it a sustainable and cost-effective option for small-scale farmers and communities.

2. Dehydration:

- Principle: Dehydration involves the removal of water content from produce to inhibit microbial activity and enzymatic reactions, thereby extending shelf life.
- Process: Various dehydration techniques, including air drying, freeze-drying, and osmotic dehydration, are employed. Air drying, for example, involves circulating dry air around the produce to gradually reduce moisture levels.
- Benefits: Dehydration is energy-efficient when compared to other preservation methods. It results in lightweight, compact products that require less storage space and transportation, contributing to reduced carbon emissions and environmental impact.

Smart storage solutions:

The incorporation of smart technologies, sensors, and Internet of Things (IoT) devices in storage facilities has emerged as a transformative strategy in minimizing post-harvest losses. Smart sensors deployed throughout storage spaces continuously gather real-time data on crucial environmental factors such as temperature, humidity, and gas concentrations. This data is then seamlessly transmitted through interconnected IoT networks, providing storage managers with instantaneous insights into the conditions within the facility [6]. Automated systems, guided by this data, can make precise adjustments to environmental parameters, ensuring that they remain within optimal ranges for the stored produce. For example, if the temperature rises above a predetermined threshold, the system can trigger cooling mechanisms to prevent accelerated spoilage. This real-time monitoring and control significantly enhance the ability to create and maintain conditions that extend the shelf life of agricultural produce, reducing the risk of deterioration and subsequent losses.

These advanced technologies contribute to a proactive approach in post-harvest preservation. Alerts and notifications are generated in response to deviations from optimal conditions, enabling storage managers to take immediate corrective actions. Moreover, predictive analytics, an integral part of smart storage solutions, can anticipate potential issues, allowing for preemptive interventions to sustain ideal storage conditions. By optimizing resource usage and energy efficiency, smart technologies not only enhance the quality and longevity of stored produce but also align with sustainable practices. The integration of data-driven decision-making ensures that storage facilities operate at peak efficiency, minimizing waste and ultimately playing a pivotal role in creating a more resilient and environmentally conscious post-harvest process [7].

Post-harvest preservation in developing countries:

Implementing modern post-harvest technologies in developing nations is fraught with challenges that span economic, infrastructural, and educational domains. One significant hurdle is the limited financial resources available for investing in advanced technologies and infrastructure. The initial costs associated with acquiring state-of-the-art storage facilities, refrigeration systems, and sensor networks can be prohibitively high for many developing countries. This financial constraint extends to ongoing operational expenses, including maintenance and energy costs, which can strain already tight budgets. The disparity in financial capabilities poses a considerable barrier to the widespread adoption of modern post-harvest technologies, especially for smallholder farmers and local cooperatives.

Infrastructure limitations present another formidable challenge. Inadequate storage facilities and unreliable transportation networks are common issues in developing nations. The lack of proper cold storage and controlled atmosphere facilities can result in rapid deterioration of perishable produce, leading to substantial post-harvest losses. Additionally, inefficient transportation systems can further exacerbate the problem, causing delays and mishandling of goods during transit. Addressing these infrastructure challenges requires not only significant investments but also coordinated efforts to build a robust supply chain that ensures the efficient movement of produce from farms to markets.

Moreover, the diverse agricultural landscape in many developing nations introduces complexities in the implementation of modern post-harvest technologies. Different crops have distinct storage and preservation requirements, necessitating tailored solutions for each. The prevalence of smallholder farmers, who may lack the scale to justify large-scale technological investments, adds another layer of complexity. To overcome these challenges, there is a critical need for customized, scalable solutions that accommodate the diversity of crops and the realities of small-scale agricultural practices. Additionally, comprehensive training programs are essential to empower farmers with the knowledge and skills to effectively utilize modern technologies and optimize their post-harvest processes [8]. Addressing these multifaceted challenges requires a holistic approach that considers the unique circumstances and needs of each developing nation, involving collaborations between governments, international organizations, and local communities.

Future prospects and research directions:

Ongoing research in post-harvest preservation is marked by a quest for innovative solutions to enhance the longevity and quality of agricultural produce. One area of notable interest is the development of advanced packaging materials with inherent antimicrobial properties. Researchers are exploring the integration of natural antimicrobial agents, such as essential oils and plant extracts, into packaging materials to create a protective barrier against microbial growth. This approach not only minimizes the need for chemical preservatives but also extends the shelf life of fruits, vegetables, and herbs. Additionally, breakthroughs in nanotechnology are showing promise in post-harvest preservation. Nanomaterials, such as nanoparticles and nanocomposites, are being investigated for their ability to inhibit microbial growth, control moisture levels, and provide enhanced barrier properties in packaging, thus contributing to the preservation of freshness and nutritional quality [9].

Another area of significant research involves the application of smart technologies and data analytics to optimize post-harvest processes. IoT-enabled sensors are being developed to provide real-time monitoring of storage conditions, enabling swift responses to deviations from optimal parameters. Advanced data analytics and machine learning algorithms are being employed to analyze vast datasets generated by these sensors, offering insights into patterns, predicting potential issues, and optimizing storage conditions. This data-driven approach aims to create intelligent post-harvest systems that adapt dynamically to environmental changes, contributing to reduced losses and improved overall efficiency in the preservation of agricultural produce. The integration of these cutting-edge technologies holds the potential to revolutionize post-harvest preservation, making strides towards a more sustainable and resilient global food supply chain [10].

Conclusion:

In conclusion, the book chapter on "From Farm to Table: Modern Approaches to Post Harvest Preservation" delves into the transformative landscape of post-harvest preservation, exploring a myriad of modern approaches that bridge the gap between agriculture and consumers. The chapter highlights the significance of adopting sustainable and innovative technologies, such as solar drying, dehydration, smart sensors, and IoT devices, in preserving the quality, nutritional value, and market readiness of agricultural produce. By addressing challenges faced by diverse agricultural landscapes, the chapter emphasizes the need for scalable and cost-effective solutions, showcasing the potential of solar technologies, community-based storage, low-cost sensors, and educational programs in empowering smallholder farmers and enhancing post-harvest practices.

Moreover, the research breakthroughs discussed in the chapter underscore the dynamic nature of the field, with ongoing studies focusing on advanced packaging materials with natural antimicrobial properties and the integration of nanotechnology. The chapter concludes by highlighting the promising trajectory of post-harvest preservation, steering toward a future where intelligent, data-driven systems optimize storage conditions and contribute to the reduction of post-harvest losses. As we navigate the complexities of global food supply chains, this comprehensive exploration serves as a guide for researchers, policymakers, and practitioners, fostering a deeper understanding of the evolving landscape and inspiring further advancements in ensuring the seamless journey of produce "From Farm to Table”.

References:

1. Fatchurrahman, D., Amodio, M. L., & Colelli, G. (2022). Quality of Goji Berry Fruit (*Lycium barbarum* L.) Stored at Different Temperatures. *Foods, 11,* 3700. doi: 10.3390/foods11223700.

2. Ma, Y., Wang, C., Liu, C., Tan, J., Ma, H., & Wang, J. (2021). Physiochemical Responses of the Kernel Quality, Total Phenols and Antioxidant Enzymes of Walnut in Different Forms to the Low-Temperature Storage. *Foods, 10,* 2027. doi: 10.3390/foods10092027.
3. Mu, B., Xue, J., Zhang, S., & Li, Z. (2022). Effects of the Use of Different Temperature and Calcium Chloride Treatments during Storage on the Quality of Fresh-Cut "Xuebai" Cauliflowers. *Foods, 11,* 442. doi: 10.3390/foods11030442.
4. Njie, A., Zhang, W., Dong, X., Lu, C., Pan, X., & Liu, Q. (2022). Effect of Melatonin on Fruit Quality via Decay Inhibition and Enhancement of Antioxidative Enzyme Activities and Genes Expression of Two Mango Cultivars during Cold Storage. *Foods, 11,* 3209. doi: 10.3390/foods11203209.
5. Medina-Santamarina, J., Serrano, M., Ruiz-Aracil, M. C., Ilea, M. I. M., Martínez-Romero, D., & Guillén, F. (2022). A Synergistic Effect Based on the Combination of Melatonin with 1-Methylcyclopropene as a New Strategy to Increase Chilling Tolerance and General Quality in Zucchini Fruit. *Foods, 11,* 2784. doi: 10.3390/foods11182784.
6. Wu, X., Yuan, J., Wang, X., Yu, M., Ma, R., & Yu, Z. (2021). Synergy of Nitric Oxide and 1-Methylcyclopropene Treatment in Prolonging Ripening and Senescence of Peach Fruit. *Foods, 10,* 2956. doi: 10.3390/foods10122956.
7. Mudalal, S., Kanan, D., Anabtawi, O., Irshaid, A., Sabbah, M., Shtaya, M., Shraim, F., & Mauriello, G. (2022). Application of the Hurdle Technology Concept to the Fresh Za'atar (*Origanum syriacum*) Preservation. *Foods, 11,* 3002. doi: 10.3390/foods11193002.
8. Vieira, T. M., Alves, V. D., & Moldão Martins, M. (2022). Application of an Eco-Friendly Antifungal Active Package to Extend the Shelf Life of Fresh Red Raspberry (*Rubus idaeus* L. cv. 'Kweli'). *Foods, 11,* 1805. doi: 10.3390/foods11121805.
9. Ghafoor, K., Al-Juhaimi, F. Y., Babiker, E. E., Mohamed Ahmed, I. A., Shahzad, S. A., & Alsawmahi, O. N. (2022). Quality Attributes of Refrigerated Barhi Dates Coated with Edible Chitosan Containing Natural Functional Ingredients. *Foods, 11,* 1584. doi: 10.3390/foods11111584.
10. Imeneo, V., Piscopo, A., Martín-Belloso, O., & Soliva-Fortuny, R. (2022). Efficacy of Pectin-Based Coating Added with a Lemon Byproduct Extract on Quality Preservation of Fresh-Cut Carrots. *Foods, 11,* 1314. doi: 10.3390/foods11091314.

MICROBIAL BIOTECHNOLOGY FOR SUSTAINABLE AGRICULTURE – A REVIEW

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Abstract:

The concept of sustainable agriculture, which involves crop cultivation and livestock rearing on a specific land without causing harm to the environment, has become increasingly important in contemporary times. This field of study has delved into various aspects that contribute to the sustainable growth of agriculture, including the crucial role played by microbial entities. The research has shed light on the significance of microbial contributions in sustainable agriculture, such as the positive impact of rhizobacteria, mycorrhizae, and azotobacter. Additionally, biofertilizers have emerged as an essential component in promoting sustainable agriculture by enhancing soil fertility and reducing the need for chemical fertilizers. Furthermore, the integration of nanotechnology has paved the way for novel and innovative methods to enhance agricultural sustainability by enabling efficient resource utilization and minimizing waste.

Keywords: Sustainable, Biofertilizers, Microbial Biotechnology, Soil Fertility

Introduction:

The FAO defines sustainable agriculture development as the conservation of natural resources and technology to meet present and future needs. Sustainability has long been defined as enhancing environmental quality, providing basic human needs, and improving farmers' quality of life. The Triple Bottom Line (TBL) evaluates sustainability based on social, environmental, and economic factors. However, factors such as participation, cooperation, and knowledge level may affect sustainable agricultural objectives in developing countries [1].

A holistic and structured approach is necessary for achieving sustainable agriculture, involving various sub-systems ranging from molecules to social entities. These sub-systems are interconnected, with ecological systems being influenced by factors such as climate and soil, and human systems being comprised of population, technology, social structure, and ideology, all of which impact each other [2].

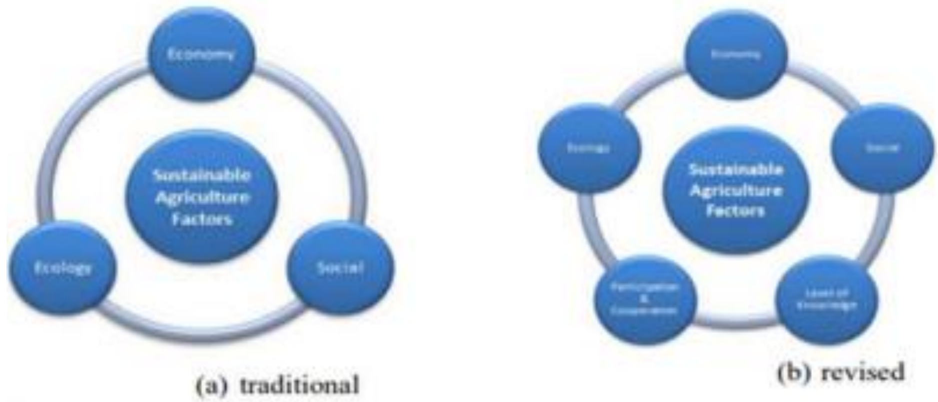

Figure 1: Factors of Sustainable Agriculture

Image source -DOI: 10.24326/fmpmsa.2017.7[1]

As India's economy grows, addressing the harmful effects of technology-based farming on soil degradation and productivity becomes crucial. Sustainable agriculture practices offer a solution to secure farm incomes, nutrition security, and natural capital in a changing climate. To promote their adoption, public support structures must be reassessed, evidence built, and farmer capacity increased, with policy incentives to support their expansion [3].

Microbes play a pivotal role in the development of sustainable agriculture. The health and fertility of soil are maintained by these tiny organisms, which are essential for promoting plant growth, development, and yield [4,13]. Recent research on plant microbiomes has shown that microbes interact with plant hosts in both direct and indirect ways. The direct impact of the plant microbiome includes nitrogen fixation, hormonal regulation, and the production of enzymes. Microbes use a range of methods to reduce host damage caused by infection, including the production of antibiotics, volatile compounds, competitive exclusion, predation, and microbe mediated immunity [5,6].

The key to sustainable agriculture lies in exploring the world of microbes, particularly PGPB (plant growth promoting bacteria) and fungi [7,14]. These microorganisms form beneficial relationships with plant roots, increasing absorption of water and nutrients. Nitrogen-fixing organisms and phosphate-solubilizing fungi can also boost plant growth and yield [8,12]. The utilization of omic approaches has led to the discovery of various microbes with potential application in biotic and abiotic stress management, including bioremediation, toxic material breakdown, improved growth, and biocontrols [10,11].

Biofertilizer can be used in sustainable agriculture to avoid negative effects of excess chemicals on plants and agroecosystems. Nanotechnology has the potential to enhance food quality and safety, reduce agricultural inputs, and enrich nutrient absorption from soil. Specific applications of nanotechnology in agriculture includes nanofertilizers and nanopesticides to increase productivity without soil contamination, and as sensors to monitor soil quality and maintain plant health [9].

"Microbial contributions: Pioneering sustainable agriculture for a better future"

Rhizobacteria

Rhizobacteria play a crucial role in making agriculture sustainable through various mechanisms that enhance plant growth, improve nutrient availability, and protect crops against pests and diseases. Here's a detailed breakdown of their contributions:

- **Nitrogen fixation**: Some rhizobacteria, known as nitrogen-fixing bacteria, convert atmospheric nitrogen (N2) into ammonia (NH3) through a process called nitrogen fixation. This ammonia can be directly used by plants as a nitrogen source, reducing the need for synthetic fertilizers that contribute to environmental pollution [15].
- **Nutrient solubilization**: Rhizobacteria possess the ability to solubilize minerals, making essential nutrients like phosphorus, iron, and zinc more accessible to plants. It helps to enhance nutrient uptake and promote plant growth.
- **Phytohormone production**: Rhizobacteria can produce plant growth-promoting hormones such as auxins, cytokinins, and gibberellins. These hormones stimulate root development, enhance flowering, and increase overall plant vigor.
- **Biocontrol**: Certain rhizobacteria have antagonistic interactions with pathogenic microorganisms in the soil. They produce antibiotics and other secondary metabolites that help suppress the growth of plant pathogens, reducing the need for chemical pesticides [15, 18].
- **Induced Systemic Resistance (ISR):** Rhizobacteria can trigger the plant's defense mechanisms, leading to induced systemic resistance. This means that the plant becomes more resistant to a wide range of pathogens, even those not directly targeted by the rhizobacteria. This natural defense mechanism decreases reliance on chemical fungicides.
- **Disease suppression**: Rhizobacteria can outcompete pathogenic microorganisms for resources and space around the plant's root zone. By establishing a protective barrier, they prevent harmful pathogens from infecting the plant [15].
- **Improved soil structure**: Some rhizobacteria produce exopolysaccharides that improve soil aggregation and structure. This enhances water retention, aeration, and nutrient movement in the soil, ultimately benefiting plant growth [19].
- **Reduced environmental impact**: The use of rhizobacteria reduces the need for chemical fertilizers, pesticides, and other synthetic inputs, which can have harmful effects on soil, water, and ecosystems. This leads to a more sustainable agricultural system with lower environmental impact [18].
- **Enhanced crop yield and quality:** Collectively, the positive effects of rhizobacteria on

nutrient uptake, disease suppression, stress tolerance, and growth promotion contribute to increased crop yield and improved crop quality [15].

Incorporating rhizobacteria into agricultural practices can lead to more efficient resource utilization, reduced chemical dependency, and enhanced ecological balance. However, successful implementation requires careful consideration of factors such as bacterial strains, crop compatibility, soil conditions, and proper management practices to harness the full potential of rhizobacteria for sustainable agriculture [16].

Mycorrhizae

Mycorrhizae play a crucial role in promoting sustainable agriculture by fostering healthier plant growth, improving nutrient uptake, enhancing soil structure, and increasing overall ecosystem resilience. Here's a detailed explanation of how mycorrhizae contribute to agricultural sustainability:

- **Enhanced nutrient uptake**: Mycorrhizal fungi establish a symbiotic connection with plant roots. They extend their thread-like structures called hyphae into the soil, significantly increasing the root's surface area for nutrient absorption. This allows plants to access nutrients, such as phosphorus, nitrogen, and micronutrients, that might otherwise be immobile or inaccessible to the plant alone.
- **Reduced fertilizer use**: By facilitating efficient nutrient uptake, mycorrhizae reduce the need for excessive fertilizer application. This not only saves costs for farmers but also helps prevent nutrient runoff that can lead to water pollution and other environmental issues.
- **Pest and disease resistance**: Mycorrhizae can induce systemic resistance in plants against various pathogens. This is achieved through the activation of the plant's defense mechanisms, making it less susceptible to diseases and pests. This natural protection reduces the need for chemical pesticides and promotes safer, environmentally friendly farming practices.
- **Carbon sequestration**: The mycorrhizal network contributes to carbon sequestration in the soil. As fungi decompose organic matter, they convert it into stable forms of carbon that remain in the soil for extended periods. This process aids in addressing climate change by capturing and sequestering carbon dioxide from the atmosphere.
- **Crop yield and quality improvement:** The synergistic relationship between mycorrhizae and plants results in healthier and more vigorous crops. Improved nutrient availability, water uptake, and disease resistance translate to higher yields and better quality produce.
- **Reduced environmental impact**: Mycorrhizal associations reduce the need for chemical inputs like fertilizers and pesticides. This reduces the environmental footprint of agriculture, minimizing soil and water contamination and safeguarding ecosystem health.

In summary, mycorrhizae are an essential component of sustainable agriculture due to their multifaceted benefits. By enhancing nutrient efficiency, improving water uptake, fostering soil health, and bolstering plant defenses, these beneficial fungi contribute to more resilient, productive, and environmentally friendly farming systems.[20]

Azotobacter

Azotobacter is a genus of bacteria that plays a crucial role in making agriculture sustainable through its ability to fix atmospheric nitrogen and enhance soil fertility. Here's how Azotobacter contributes to sustainable agriculture:

- **Nitrogen fixation**: Azotobacter is known for its ability to fix atmospheric nitrogen into a usable form for plants. Nitrogen is an essential nutrient required for plant growth, and conventional agriculture relies heavily on synthetic nitrogen fertilizers. By utilizing Azotobacter, farmers can reduce their dependence on chemical fertilizers, thereby minimizing their negative environmental impacts like groundwater contamination and greenhouse gas emissions.
- **Nutrient cycling**: Azotobacter not only fixes nitrogen but also helps in cycling other essential nutrients in the soil. These bacteria break down organic matter, releasing nutrients like phosphorus and micronutrients. This enhances nutrient availability to plants and reduces the need for external inputs, contributing to sustainable soil fertility management.
- **Reduces environmental impact**: The excessive use of synthetic fertilizers can lead to nutrient runoff, water pollution, and soil degradation. Azotobacter-based farming practices can reduce the need for these chemical inputs, which, in turn, minimizes the negative impact on water bodies, ecosystems, and overall environmental health.
- **Promotes plant growth**: Azotobacter produces growth-promoting substances like auxins, gibberellins, and cytokinins. These compounds stimulate root development, enhance nutrient uptake, and improve overall plant growth. As a result, crops tend to be more vigorous and productive.
- **Biofertilizer application**: Azotobacter is commonly used as a component of biofertilizers. These biofertilizers contain live microbial populations that, when applied to soil, contribute to its biological activity. Azotobacter-containing biofertilizers not only supply nitrogen but also improve soil health and promote sustainable agricultural practices.
- **Reduces greenhouse gas emissions**: Synthetic nitrogen fertilizers are a significant source of nitrous oxide (N_2O), a potent greenhouse gas. Azotobacter-based nitrogen fixation can potentially reduce the need for synthetic nitrogen fertilizers, thus lowering the emission of N_2O and contributing to climate change mitigation.

Incorporating Azotobacter into agricultural practices is just one aspect of achieving sustainability. Integrated approaches that combine various eco-friendly methods, such as crop rotation, cover cropping, and reduced tillage, alongside the use of beneficial microorganisms like Azotobacter, can contribute to the long-term viability of agriculture while minimizing environmental impacts [22].

Biofertilizer significant role in advancing sustainable agriculture

Biofertilizer can be use in the sustainable agriculture, because excess amount of chemicals biofertilizer can affect the plants as well as agroecosystem [23].

- **enhanced nutrient availability**: Biofertilizer contain microorganisms that can solubilize phosphorus and atmospheric nitrogen, making these essential nutrients available to the plants. This reduces the on chemical fertilizers, which can lead water pollution, soil erosion and soil degradation [26, 29].
- **Improved soil structure**: The microorganisms in biofertilizers that help the aggregates in the soil, improving soil structure and water holding capacity. This also help in enhance the root penetration and soil health ,leading to better crop growth.
- **Disease suppression**: Biofertilizers contain beneficial microorganisms that can suppress plant pathogens or diseases. The "biocontrol agents" can also help in reducing the need for chemical pesticides and promoting the environmentally friendly pest management.
- **Increased nutreint uptake**: Mycorrhizal fungi, a type of biofertilizer form of symbiotic relationships with the plant roots. They expand the root surface area , allowing the plants to access nutrients from a large soil volume. This leads to more efficient nutrient uptake and reduced fertilizers requirements. Sustainable agriculture encourages diverse ecosystems. By maintaining soil health and reducing chemicals inputs [25, 27].
- **Reduced environmental impact**: Biofertilizers minimize the release of greenhouse gas associated with production. They contain living microorganisms that enhance nutrient availability to plants and improve soil health. By promoting sustainable agriculture practices, biofertilizers can help minimize soil degradation, water pollution.
- **Water conservation:** Improved soil structure and nutrient availability from biofertilizers lead to reduced water runoff and better water retention in the soil. This helps conserve resources, especially in regions prone to drought. Biofertilizers also supports the growth of plant species, promoting biodiversity in agricultural diversity.
- **Long term sustainability-** Use of biofertilizer contributes to the long term sustainable agriculture practices. They help maintain soil fertility, reduce the risk of soil degradation and soil erosion.

Biofertilizers are essential for enhancing the sustainability of agriculture. They consist of beneficial microorganisms that fix atmospheric nitrogen, solubilizes phosphates and promotes nutrient availability in soil. Reducing the need for chemical fertilizers, biofertilizers helps to maintain soil health, and minimize environment population [24, 30].

Nanotechnology offers several ways to enhance agricultural sustainability

- **Precision farming:** Nanosensors can monitor soil conditions, nutrient levels, and moisture content at a very localized level, allowing for precise application of fertilizers and irrigation, minimizing waste.
- **Improved nutrient delivery:** Nano-sized nutrient particles can be engineered to release nutrients gradually, improving nutrient uptake by plants and reducing environmental contamination.
- **Pest and disease management:** Nano-formulated pesticides and herbicides can be targeted to specific pests, reducing the need for large-scale chemical application and minimizing harm to beneficial organisms.
- **Enhanced crop resilience:** Nanoparticles can be used to enhance plant resistance to stresses like drought, pathogens, and extreme temperatures, leading to increased crop yields and reduced losses.
- **Water management:** Nanomaterials can improve water filtration and purification, making it easier to recycle and reuse water for irrigation while removing pollutants and contaminants.
- **Smart delivery of growth factors:** Nanoparticles can encapsulate growth-promoting compounds, ensuring controlled and sustained release for better crop growth and yield.
- **Soil improvement:** Nanoparticles can modify soil structure and increase its water-holding capacity, aiding in water retention and reducing soil erosion.
- **Biodegradable packaging:** Nanotechnology can help develop biodegradable and edible coatings for fruits and vegetables, extending their shelf life and reducing packaging waste.
- **Nano-enabled fertilizers:**Nano-fertilizers can improve nutrient availability and uptake by plants, reducing the amount of fertilizer needed and minimizing nutrient runoff.
- **Energy-efficient greenhouses:** Nanomaterials can enhance the insulation properties of greenhouse structures, reducing energy consumption for temperature control.
- **Monitoring and data collection:** Nanosensors can monitor plant health and environmental conditions in real-time, providing valuable data for decision-making and early detection of issues.
- **Bioremediation:** Nanoparticles can aid in the removal of pollutants and heavy metals from soil, contributing to land restoration and food safety.

It's important to note that while nanotechnology holds great promise for sustainable agriculture, potential risks related to the safety of nanoparticles, their environmental impact, and regulatory considerations should also be carefully evaluated and addressed [28].

Conclusion:

Sustainable development involves conserving natural resources and utilizing technology for current and future needs. Rhizobacteria aid in sustainable agriculture by improving plant growth, nutrient availability, and crop protection. Incorporating rhizobacteria can lead to efficient resource use, reduced chemical dependency, and ecological balance, but requires careful consideration of factors such as bacterial strains and soil conditions. Mycorrhizae are also essential in sustainable agriculture due to their benefits in enhancing nutrient efficiency, water uptake, soil health, and plant defenses. Integrated approaches with eco-friendly methods and beneficial microorganisms, like Azotobacter, can contribute to long-term agricultural viability and minimize environmental impacts.

Biofertilizers can be utilized in sustainable agriculture to avoid excessive chemical use that could harm both plants and agroecosystems. These fertilizers contain microorganisms that fix nitrogen from the atmosphere, solubilize phosphates, and promote nutrient availability in soil. By reducing the need for chemical fertilizers, biofertilizers help maintain soil health and minimize environmental pollution.

Nanotechnology for enhancing agriculture sustainability ways is precision framing, improved nutrient delivery, pest and disease management, enhanced crop resilience, water management, smart delivery of growth factors, soil improvement biodegradable packaging, nanoenbaled fertilizers, energy –efficient greenhouses, monitoring and data collection with help of Nano sensors, bioremediation with help of nanoparticles.

References:

1. 9th International Scientific Symposium. (2017). Farm Machinery and Processes Management in Sustainable Agriculture. DOI: 10.24326/fmpmsa.2017.70
2. Naresuan University Journal: Science and Technology 2015; 23(1) 63. The Viewpoints of Sustainable Agriculture Within the System Approach in Agriculture., 2015.
3. Do We Know Enough to Scale Up Sustainable Agriculture in India?. (2022). Chem. Proc.. https://doi.org/10.3390/IOCAG2022-12220
4. The Microbial Connection to Sustainable Agriculture. (2023).Plants. https://doi.org/10.3390/plants12122307
5. Egamberdieva, D.; Wirth, S.J.; Alqarawi, A.A.; Abd_Allah, E.F.; Hashem, A. (2017). Phytohormones and Beneficial Microbes: Essential Components for Plants to Balance Stress and Fitness. Front. Microbiol. 8, 2104.
6. Vannier, N.; Agler, M.; Hacquard, S. (2019). Microbiota-mediated disease resistance in plants. PLoS Pathog.15, e1007740.

7. Gopalakrishnan, S.; Sathya, A.; Vijayabharathi, R.; Varshney, R.K.; Gowda, C.L.; Krishnamurthy, L. (2015). Plant growth promoting rhizobia: Challenges and opportunities. 3 Biotech, 5, 355.
8. Tariq, M.R.; Shaheen, F.; Mustafa, S.; Ali, S.; Fatima, A.; Shafiq, M.; Safdar, W.; Sheas, M.N.; Hameed, A.; Nasir, M.A. (2022). Phosphate solubilizing microorganisms isolated from medicinal plants improve growth of mint. PeerJ, 10, e13782.
9. Nanotechnology in Sustainable Agriculture: Recent Developments, Challenges, and Perspectives. (2017). Frontiers in Microbiology
10. Nadarajah, K. (2021). Metagenomics for Improving Soil Fertility. In Soil Nitrogen Ecology. Soil Biology; Springer: Cham, Switzerland, Volume 62, pp. 267–282.
11. Singh, J.; Saini, D.K.; Kashyap, R.; Kumar, S.; Chopra, Y.; Sandhu, K.S.; Goraya, M.; Aggarwal, R. (2022). Omics technologies for agricultural microbiology research. In Trends of Applied Microbiology for Sustainable Economy; Elsevier: Amsterdam, The Netherlands, pp. 343–394.
12. Shah, A.; Nazari, M.; Antar, M.; Msimbira, L.A.; Naamala, J.; Lyu, D.; Rabileh, M.; Zajonc, J.; Smith, D.L. (2021). PGPR in Agriculture: A Sustainable Approach to Increasing Climate Change Resilience. Front. Sustain. Food Syst., 5, 667546.
13. Bala, S.; Garg, D.; Thirumalesh, B.V.; Sharma, M.; Sridhar, K.; Inbaraj, B.S.; Tripathi, M. (2022). Recent Strategies for Bioremediation of Emerging Pollutants: A Review for a Green and Sustainable Environment. Toxics, 10, 484.
14. Hamid, N.W.A.; Nadarajah, K. (2022). Microbe Related Chemical Signalling and Its Application in Agriculture. Int. J. Mol. Sci., 23, 8998.
15. Penrose, D. M., & Glick, B. R. (2003). Methods for isolating and characterizing ACC deaminase-containing plant growth-promoting rhizobacteria. Physiologia plantarum, 118(1), 10–15. https://doi.org/10.1034/j.1399-3054.2003.00086.x.
16. Narwal, E., Kannepalli, A., Choudhary, J., Singh, Y. V., & Shah, M. P. (2022). Bioprospecting plant growth-promoting rhizobacteria from rice genotypes and their influence on growth under aerobic conditions. Journal of basic microbiology, 62(2), 135–149. https://doi.org/10.1002/jobm.202100463.
17. Lyu, D., Backer, R., Berrué, F., Martinez-Farina, C., Hui, J. P. M., & Smith, D. L. (2023). Plant Growth-Promoting Rhizobacteria (PGPR) with Microbial Growth Broth Improve Biomass and Secondary Metabolite Accumulation of Cannabis sativa L. Journal of agricultural and food chemistry, 71(19), 7268–7277. https://doi.org/10.1021/acs.jafc.2c06961.
18. Beneduzi, A., Ambrosini, A., & Passaglia, L. M. (2012). Plant growth-promoting rhizobacteria (PGPR): Their potential as antagonists and biocontrol agents. Genetics and

molecular biology, 35(4 (suppl)), 1044–1051. https://doi.org/10.1590/s1415-47572012000600020.

19. Li, Z., Zhao, M., Li, L., Yuan, Y. Y., Chen, F. J., Parajulee, M. N., & Ge, F. (2023). Azotobacter inoculation can enhance the resistance of Bt cotton to cotton bollworm, Helicoverpa armigera. Insect science, 10.1111/1744-7917.13190. Advance online publication. https://doi.org/10.1111/1744-7917.13190.
20. Beneficial Microbiomes for Sustainable Agriculture: An Ecofriendly Approach. (2021). DOI:10.1007/978-981-15-6949-4_10
21. Biotechnology: Role Of Microbes In Sustainable Agriculture And Environmental Health (2012). Internet Journal of Microbiology. DOI: 10.5580/2b91
22. Biofertilizer for crop production and soil fertility (2018). DOI:10.15413/ajar.2018.0130
23. Microbial Biotechnology: Role of Microbes in Sustainable Agriculture. https://www.researchgate.net/publication/341609431
24. Agricultural Sustainability: Microbial Biofertilizers in Rhizosphere Management. Agriculture https://doi.org/10.3390/agriculture11020163
25. Arora, S., Murmu, G., Mukherjee, K., Saha, S., & Maity, D. (2022). A comprehensive overview of nanotechnology in sustainable agriculture. Journal of biotechnology, 355, 21–41. https://doi.org/10.1016/j.jbiotec.2022.06.007
26. Basu, S.; Rabara, R.C.; Negi, S. (2018). AMF: The future prospect for sustainable agriculture. Physiol. Mol. Plant Pathol., 102, 36–45.
27. Parihar, M.; Chitara, M.; Khati, P.; Kumari, A.; Mishra, P.K.; Rakshit, A.; Rana, K.; Meena, V.S.; Singh, A.K.; Choudhary, M. (2020). Arbuscular mycorrhizal fungi: Abundance, interaction with plants and potential biological applications. In Advances in Plant Microbiome and Sustainable Agriculture; Springer: Berlin/Heidelberg, Germany, pp. 105–143.

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