World Agroforestry

Guidelines on health management issues of Breeding Seed Orchards established by the Provision of Adequate Tree Seed Portfolio (PATSPO) project in Ethiopia

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Cover photo: *Moringa stenopetala* BSO – 1.5 year old/PATSPO 2021

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We are guided by the broad development challenges pursued by CGIAR, a global research partnership for a food-secure future, which include poverty reduction, increasing food and nutritional security, and improved natural resource systems and environmental services.

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List of abbreviations and acronyms

BSO	Breeding seed orchard
FAO	Food and Agriculture Organization of the United Nations
ICRAF	World Agroforestry
IPM	Integrated pest management
MC	Moisture content
MLD	Mycosphaerella leaf disease
PATSPO	Provision of Adequate Tree Seed Portfolios
RH	Relative humidity

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Last, but definitely not least, I would like to thank the PATSPO field staff for their invaluable support during my visits to the BSO sites in Ethiopia.

Preface

Provision of Adequate Tree Seed Portfolios (PATSPO) is a national tree seed project (2017–2021) financed by the Norwegian Government. This initiative aims to support the Ethiopian Government to make the best possible tree seed available for its ambitious landscape restoration programme which is part of its 'green economy strategy'.

The establishment of new high quality seed sources for priority tree species is one of the priorities of PATSPO. The concept of 'breeding seed orchards' (BSOs) was selected as it combines testing/improvement and seed production at the same time.

In collaboration with its partners, PATSPO has established more than 25 BSOs from 2018 to 2020. The health and vigor of the seed, seedlings and plants established in the field is crucial, as it ensures maximum growth and seed production from the BSOs, which also serve as tree improvement units.

These guidelines introduce health issues and cover: i) principles for forest and plantation forest health management; ii) specific health threats and strategies to observe, monitor and treat them for the various steps in BSO establishment (seed collection, seed storage, nursery operation, field planting and post field planting).

1. Introduction to forest health considerations and management

Globally, forests play an important role in supplying timber, food, fuel, medicine and many other products, as well as hosting vital ecosystems which provide services such as biodiversity, combating desertification, storing carbon and mitigating climate change.

However, there is an enormous range of pests which affect forest health, and monoculture plantation forests in particular. Although the term 'pest' means 'pest insect' to many people, in plant protection this word is used in a broader sense which means all the biotic factors that harm plants including disease-causing microorganisms and weeds, as well as pest insects, mites, birds and mammals. In general, insects include both beneficial and pest insects. In this publication, the term 'insects' refers to pest or damaging insects.

Insects and disease organisms are among the most severe factors damaging trees. They cause substantial economic loss to forests globally every year. The ecological damage to forest ecosystems from use of pesticides to combat insects and diseases are also severe.

In the context of plant health, an insect can be defined as a living organism which damages leaves, stem, root, flowers of the tree and affects its growth and development. Disease is caused by microorganisms that impair the normal functioning of trees. In some cases, the problem of insects and disease overlap. For example, an insect could carry disease-causing organisms (mostly viruses) from infected to uninfected trees, and the damage caused by the disease may be more severe than the damage caused by the insect.

Usually natural forests evolve into a balanced ecosystem. Insects and diseases are a vital part of the ecosystem. For example, the larvae of an insect may eat the leaves of a tree as a pest, while the adults of the same insect could play an important role in spreading pollen, thus allowing the trees to regenerate. Fungi and bacteria can help to break down leaves, litter and root in forests and plantations to recycle the nutrients. If fungi or bacteria cause diseases in trees, it could help to kill some weak trees and keep the more competitive and disease-resistant/tolerant trees. This is the positive natural selection behind adaptive evolution.

Humans interact with forests all over the world every day. Some of the human activities are very harmful to forest ecosystems and have resulted in global warming, deforestation and the breakdown of eco-balances.

One of the greatest threats include insect or disease outbreaks. For example, climate change may favour some insects or diseases, which were previously not considered pests, but could suddenly occur as an epidemic. More frequent global trade, transport and human travelling makes the introduction of insects and diseases into a new area more frequent and can lead to serious damage of local forest ecosystems. These kind of introductions will continue to be a major factor in the health and productivity of global forests, and are expected to increase in future.

Establishment of multi-species forest plantations helps to restore biodiversity and sustain the services that humans rely on. However, most new plantations are monocultures or have low species diversity, and are thus more easily susceptible to pest outbreaks. Such outbreaks may spread to adjoining forests and continue to cause widespread damage. It is important to implement pest monitoring and management systems from the onset of plantation establishment to detect pest activity and prevent spread of damage. Since BSOs are monoculture plantings, they are easily exposed to insects and diseases.

Apart from insects and diseases, there are several abiotic factors that have a negative impact on the growth, development, yield and seed quality of forests and plantations. These comprise both physical and chemical factors such as drought, floods, salinity, temperature, sunlight, mineral toxicity, etc.

Abiotic and biotic factors can interact in plants to produce negative impact. For example, abiotic conditions can make the impacts and dynamics of non-native insects and diseases more severe.

Trees can recover from injuries, if the stress is mild or short-term. However, severe or long-term stresses hinder flowering and seed formation, induce senescence and lead to death of plants.

This practical guide provides insights into health monitoring and management of tree seeds through the process of BSO establishment to ensure their optimal establishment, sustainable development and maximum production of quality seed.

2. Principles of health management of BSOs

The guiding principle in BSO health management is to understand how tree health is damaged by insects and diseases, and how to prevent and treat it.

There are numerous potential insects and diseases in BSOs/forest plantations. Several specific management options have been described for particular insects or diseases, but this publication will focus on integrated pest management (IPM).

"Prevention is better than cure". This is the first general rule in any production system. IPM is an approach that combines biological, cultural and chemical practices to control insects and diseases effectively. It can be used to manage most kinds of pests in any BSO/plantation. IPM focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices and use of resistant varieties, while minimizing risks to people and the environment.

The general principles of IPM include:

- Cultural control – use practices that reduce pest establishment, reproduction, dispersal and survival. For example, changing irrigation practices can reduce insect problems. Too much water can increase root disease and weeds, and consequently kill the plants.
- Mechanical and physical control – kill insects directly by hand, and remove weeds to make the environment unsuitable for insects and diseases. Steam sterilization of the soil for soil-borne disease control or physical barriers such as meshes to keep insects and animals away from the plants/trees.
- Chemical control – use of pesticides. In IPM, pesticides are used only when absolutely necessary and often in combination with other approaches for more effective, long-term control. Pesticides are carefully selected and applied in a way that minimizes harm to people, non-target organisms, air, soil and water. It is preferable to use pesticides in bait stations rather than around entire planting/BSO areas.
- Biological control – use of natural enemies and competitors of pests, such as predators, parasites and microorganisms, to control their damage.

The specific activities of IPM programmes/strategies include:

- Pest identification
- Monitoring and assessing of pest numbers and their damage
- Guidelines for when management action is needed
- Preventing pest problems
- Using a combination of biological, cultural, physical/mechanical and chemical management tools
- After action is taken, assessing the effect of pest management.

3. Principles of health management of BSOs

3.1 Seed collection and seed storage

The basic principle of seed collection is to allow the seed to reach optimal physiological maturity on the tree to ensure viability of the seed and to ensure that they are 'ready' for storage.

Seed collection

Each type of tree and plant has a physiological optimal time for collecting the seed. However, during this period, the seed is exposed to the external environment and is under threat from diseases, insects, birds and predatory mammals. It is advisable to collect the seed earlier than the physiological optimal time and allow it to continue maturing and drying after collection. Thus, it is essential to ensure that seed is harvested in good physiological quality and right moisture content before storing.

When making a decision on the best time to collect seed, ideal weather conditions are low temperature and low relative humidity (RH). Be careful not to drop the seeds on the soil. This will minimize the possibility of pathogen and insect contamination, thereby reducing pest damage to the seed during storage.

It is very important to collect seeds from healthy mother trees. Do not collect seed from trees that have undergone a lot of insect attacks, look suppressed, diseased or generally unhealthy. There is a higher possibility that seed collected from unhealthy trees would carry diseases and insects. The seedlings produced from such seeds will most likely be damaged. One should also be very careful when collecting seeds that have already fallen from the tree. These could be old and contaminated by soil-borne pathogens.

Seed storage

Seed storage is the preservation of seed under controlled environmental conditions. This serves to preserve its genetic integrity and maintain seed viability for a long period of time. Broadly speaking, storage begins when the mature seed is collected from the field to the time when it germinates and begins to produce seedlings. This publication focuses on postharvest storage.

Temperature and relative humidity are the two most important factors during seed storage. Infestation by insects, mites and storage fungi, damage the quality of seeds, and their development is directly influenced by temperature and moisture. In general, seed with lower moisture content (MC), and stored in cool, dry conditions can be kept for a longer time than those in a wet and warm environment.

Always use sealed containers for seed storage to avoid re-absorbing moisture. Besides, the incidence of other conditioning factors (e.g., rodents and birds) depend on the quality of the storage containers/bags and their actual condition.

Storage insects

The most significant bio-cause of seed loss during storage is by far infestation by storage insects. Many storage insects eat embryos of the seed, thereby reducing the germination percentage of the seed lot. In addition, they could transmit pathogenic fungi and bacteria, particularly storage fungi, which damage the seed. Insects can survive from one season to the next within infested residues in the field, in storage structures/containers and in natural habitats. Thus, newly collected seed can become infested by the active migration of insects to the seed in the field or in the store room.

The insects can be divided into primary and secondary insects. Primary insects attack whole, unbroken seeds, while secondary pests attack only damaged seeds, dust and milled products. Primary insects are usually more destructive than secondary insects, especially in short-term storage. Majority of storage insects are beetles (Coleoptera) and moths (Lepidoptera).

It is important to first identify the insects before making a decision on the most appropriate methods that could prevent damage to the stored seed.

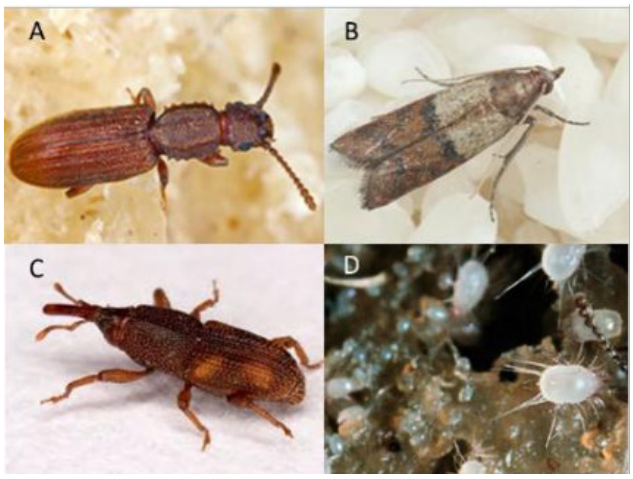

Figure 1. Common storage insects in seeds (A) beetles; (B) moths; (C) weevil; (D) mites (not insects but arachnids)

Control measures for storage insects

- Select a storage site that is far from the field.
- Keep the surroundings of the threshing/store clean. Get rid of weeds and plants which could serve as potential sources of insects.
- Pre-treat all the wood that will be used for construction of temporary storage facilities with insecticides, wood preservatives or fumigation to get rid of any insects or eggs.
- Clean the threshing/storage facilities and area before and after use by spraying bleach on the floor/ground, walls and ceiling to get rid of insects and insect eggs. Remove any plant, seed, food residues and unnecessary items in the platform/ room.
- Repair all cracks and holes in the store immediately to avoid harbouring insects.
- Collect and store only healthy seeds. Remove any damaged seeds during threshing and cleaning to minimize the possibility of insect infestation. If one batch/lot of seeds is even slightly infested, store them separately in a sealed container for further treatment. If the lot is severely infested, the whole batch of seeds should be destroyed immediately to protect the other seeds.
- Dry all the seeds to a low and species-wise recommended moisture content without affecting the viability.
- Keep the temperature of the storage area below 15°C, and relative humidity below 25% to inhibit growth of storage insects.
- Inspect the store regularly and remove any infested materials.
- Fumigation is an effective method of killing insects at all life stages in the storage room and in the seed, especially for large amount of seeds or to treat infested seed. The most common fumigant is phosphine gas. Note that only experienced staff are allowed to carry out this activity.
- Spraying broad spectrum or selective insecticides in the storage room or on seeds directly is also an effective way of controlling storage insects.
- Material from plants with strong odours can be mixed with seeds to repel the insects, e.g., Eucalyptus leaves, neem leaves and dry chilli pepper pods or powder. Ensure that you select healthy plant materials.
- Wood ash can be mixed with seeds for storage of small amounts of seed.
- If seeds are imported from abroad, make sure that they meet the quarantine requirements of the receiving country to prevent entry of invasive pests; remember to obtain the required phytosanitary certificate from the exporter.

Storage fungi

These are fungi that invade seed during the storage period. These microorganisms cause distinct problems in storage grains – decreased viability, discolouration, reduced storability. They occur as spores in air, soil and decayed plants together with seeds before, during and after collection. Storage fungi do not occur only as contaminants, but also as dormant mycelium within the tissues of pericarps or seed coats. Seed predisposed to environmental stress such as drought or damage by insects, diseases or harvest equipment are more easily invaded by fungi/spores.

In contrast to the plant pathogenic fungi in the field, storage fungi can grow in conditions with low moisture and temperatures

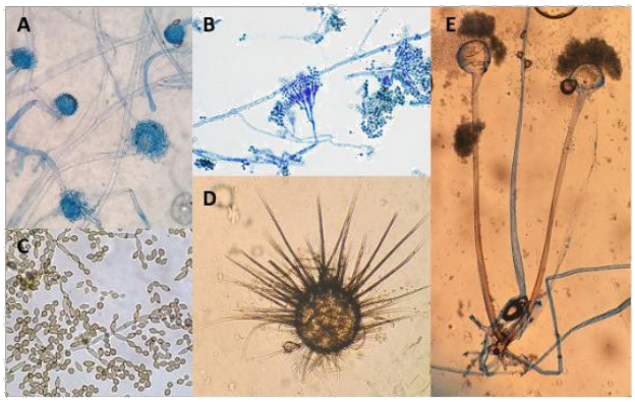

Figure 2. Common storage fungi in seeds. (A) Aspergillus; (B) Penicillium; (C) Cladosporium; (D) Chaetomium; (E) Rizopus

Control measures for storage fungi

- Keep storage area clean and hygienic. Clean the storage room and seed containers, before and after use, with 1% bleach. Get rid of dust, spider webs and plant debris. Sweep floor and spray walls, crevices, shelves using 1% bleach.
- Avoid damaging seeds during and post collection.
- Dry the seed to the recommended moisture content as soon as possible after harvest.
- For storage at ambient temperatures, keep the storage area temperature below 20°C, and moisture content below 15%.
- Keep the storage area well ventilated through natural air flow.
- Eliminate all storage insects and mites.
- Inspect the stored seeds at least once every two weeks for signs of fungi infection.
- Soak seeds in 1% sodium hypochlorite solution for 2 minutes and dry again to remove any fungi spores that may be attached to the surface.

Adopting the above measures will significantly reduce damage to the seed from storage fungi. However, if the fungi has grown rapidly, fungicides should be applied to prevent further damage.

3.2 Seed germination and nursery management

Seed germination

Seed is the beginning of a new seedling. Use of high quality seeds is the basis for growing quality trees. Therefore, it is critical to collect and store quality seeds in a proper way until seed germination and planting.

Good quality seeds should be of:

- High genetic quality – optimal capacity for trees to produce the desired outputs when planted in the right location.
- Good physical quality – seed that is not damaged, with high purity and free of dust, weed, stone, etc.
- High physiological quality – good shape, size, colour, no damaged or empty seed.
- High germination capacity (%).
- Free from insect pests and diseases.

Besides, always using healthy seed, and applying biological, physical and chemical agents and techniques to the seed can ensure protection from insects and diseases. Good nursery practices result in healthy and robust seedlings, which in turn leads to establishment of healthy and robust BSOs.

Seed treatment is one of the most economical and effective methods of eliminating or reducing insects and diseases without affecting the germination capacity of seed. It includes physical, chemical and biological treatments and techniques to provide and improve the germination and establishment of healthy plants.

Compared to seed without treatment, the treated seed has:

- Reduced seed borne insects and pathogens
- Continued protection against soil insects and diseases until seedlings are ready for transplanting in the field
- Potential for easier, uniform and cheaper establishment of seedlings/trees in BSOs

Common methods of seed treatment in nursery management

- Hot water treatment. It is a very old practice, which is affordable, safe and time-saving. Usually 50-55°C for 10-30 minutes has a good phytosanitary effect in the majority of cases. However, it is recommended that tests be conducted and specific recommendations followed for each individual species.
- Heat treatment. It is a common physical treatment for seed which can be done in the oven – usually 60-70°C for 30 minutes-7 days. It is suitable for seed which will be stored for a long time because it does not increase moisture content.
- Chemical treatment. Application of insecticides, fungicides, or a combination of both to control insects and diseases in seed and soil. Broad spectrum chemical products like thiophanate methyl and thiram are recommended. Soaking for one hour in 30% hydrogen peroxide can also effectively remove fungi in seed and improve germination of low vigour lots.
- Biological treatment. Applying beneficial microorganisms, for example, mycorrhizal fungi and Bacillus spp. on seed can promote shoot and root growth, increase nutrient uptake, enhance resistance to environmental stress, suppress diseases especially soil borne pathogens, and improve soil fertility.
- Aerated steam treatment and radiation treatment have been used in some places. They are not common due to the requirement of specialized and expensive equipment.

Raising seedlings in the nursery

After germination, the seedlings must be raised to a suitable size and quality under favourable conditions in the nursery, before being planted in the field. The seedlings are fragile and can be easily attacked by insects and diseases. Special attention and protection is required during the seedling's growing phase in the nursery.

Common methods used to control insects in the nursery

- Keep the nursery site and surrounding areas clean. Remove weeds and plants.
- Clean and sanitize the nursery area. If it is a greenhouse, clean the floor/ground, walls and ceiling using 1% bleach regularly.
- Control temperature and humidity inside the greenhouse.
- Control the sunshine reaching the seedlings by using nets or straw. Make sure that the straw is pretreated with insecticides and fungicides to avoid introduction of insects and diseases.
- Hand pick larger insects.
- Inspect the seedlings regularly. If there is an outbreak, spray insecticides to control it.

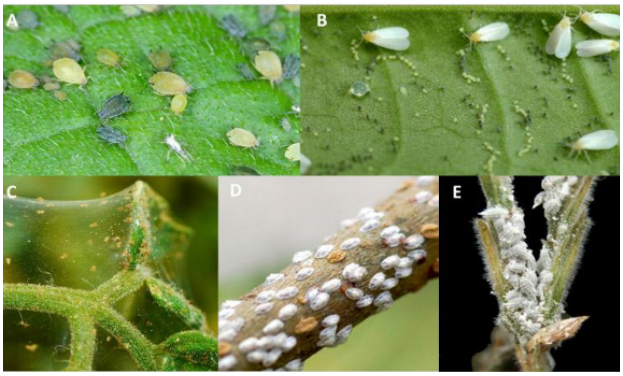

Figure 3. Common insects and mites of seedlings in nursery. (A) Aphids; (B) White flies; (C) Spider mites; (D) Mealybugs; (E) Scales

Control methods used to control diseases in the nursery

- Sterilize or fumigate the seedling beds.
- Use sterilized tools (pot, knife, secateurs, etc.); clean the tools with 70% ethanol or 1% bleach before and after each use.
- Keep the seedlings under correct sunlight, and in a clean environment. Ensure proper watering and avoid flooding the plants; this could damage the root and cause diseases.

- Inspect the seedlings regularly and remove unhealthy plants immediately to avoid disease transmission.
- Spray broad-spectrum fungicides/bactericides, like Azoxystrobin, Boscalid and Carbendazim, at regular intervals, or narrow-spectrum fungicides/ bactericides for certain disease if any symptom is observed.

Figure 4. Common diseases of seedlings in nursery.(A) Damping –off; (B) Root dieback/root rots; (C) Powdery mildew; (D) Leaf spot; (E) Rust; (F) Wilt

3.3 Post-planting measures in BSOs

The natural ecosystem is much more complex than the relatively closed and controlled environment of the nursery area. The trees will face numerous threats by both biotic and abiotic factors, especially pests and diseases.

The most important principle in BSO protection is preventing attacks or avoiding further development of pest problems. This is far more effective than attempting to stop the damage of already developed pest problems. One of the most effective and economical ways is monitoring of insects and diseases soon after the BSO has been established.

In general, there are three basic patterns of insects and diseases spatial dispersion: random, clumped and mosaic.

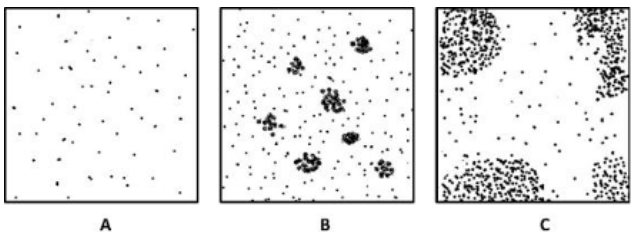

Figure 5. Basic patterns of insects and diseases spatial dispersion. (A) Random; (B) Clumped; (C) Mosaic

The most common type of dispersion in nature is clumped distribution. Random distribution is less common, while mosaic distribution is the least common pattern.

Field check/monitoring of insect attacks and diseases

For random distribution, five point sampling, diagonal sampling or checkerboard sampling is most suitable; parallel line sampling is better for clumped distribution; while for the mosaic pattern distribution, the zigzag sampling method is more appropriate.

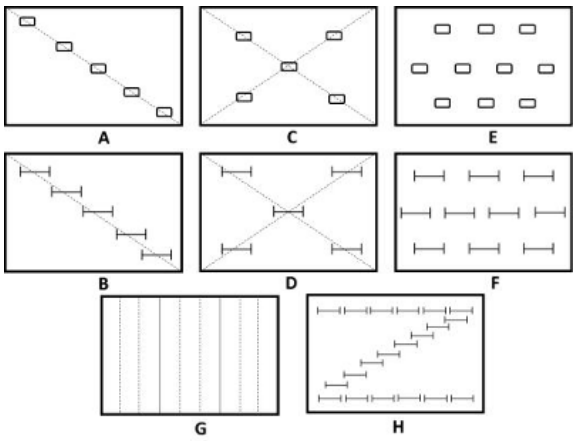

Figure 6. Sampling patterns for insects and diseases in the field. (A)-(B) Diagonal sampling; (C)-(D) Five point sampling; (E)-(F) Checkerboard sampling; (G) Parallel line sampling; (H) Zigzag sampling

Surveillance of insects and diseases in BSOs

- Prepare a map of the orchard, including details such as the number of trees, distance between trees and planting date.
- Decide how many trees should be sampled in the BSO. This will vary depending on the size of the BSO, number of trees and amount of time available for sampling. Normally sample 15 trees per 1000, i.e., 35-40 trees in a BSO of 1 ha and with 2500 trees.

Morning is the best time to monitor for insects, as this is when they are least active and most likely to be seen. As the day warms up, most of the insects will

move into the trees, e.g., weevils. Diseases can be monitored at the same time with the same samples.

- Conduct monitoring in the BSO at least every 14 days in the first months after planting the seedlings.
- Select the suitable sampling method and collect samples randomly.

Effective management of pest problems in a BSO

- Only plant healthy seedlings.
- Transplant seedlings after root dip for 3-5 min in 0.02% Carbendazim solution.
- Irrigate only on the ground and avoid watering the parts of the seedlings above ground as much as possible.
- Avoid any mechanical or other types of injury to the seedlings/trees.
- Remove branches and seedlings/trees killed by diseases or insects.
- Control weeds, especially grasses, in the BSO.
- Use appropriate cultural practices that will prevent or delay pests from reaching damaging levels.
- Ensure early detection of pests and/or environmental conditions that regulate pests before serious damage occur.
- Ensure correct diagnosis of the problem and correct identification of the pest causing it.
- Evaluate the pest population densities to determine if economic damage is likely to occur and if additional control measures are needed.

The insect trap is an efficient tool for monitoring and killing many insects in a large area within a limited amount of time and with minimal labour and financial resources. It can provide an accurate picture of presence and stage of various insects, which can then be used to predict optimal timing of treatment.

Common insect traps include:

- Delta trap: Consists of a single sheet of stiff, white cardboard folded into a triangular “tent”. The specific pheromone lures the insects. Other attractants can be placed on the sticky interior surface. The trap is suitable for use in detection of BSO and nursery insects like moths, mealybugs, etc.
- Tree band trap: Weather-resistant paper coated with a light adhesive. Insects that walk up and down trees become entangled in the glue and are collected.
- Bottle trap: Also known as Sugar-Bait Trap. A plastic container is hung from a tree and baited with sugar or other sweetener, a pheromone lure, volatile plant or chemical compounds, or a combination of any of these, along with a dispatching agent and/or preservative, such as ethyl alcohol.
- Pan trap: Used to collect visually-oriented flying insects which are often attracted by colour. The pans are usually white, yellow or blue, and filled with water and a mild, biodegradable detergent, which is used to break the water’s surface tension. These traps are set out in series of one or more bowls of each colour in open areas, and remain up for eight to 24 hours at a time.

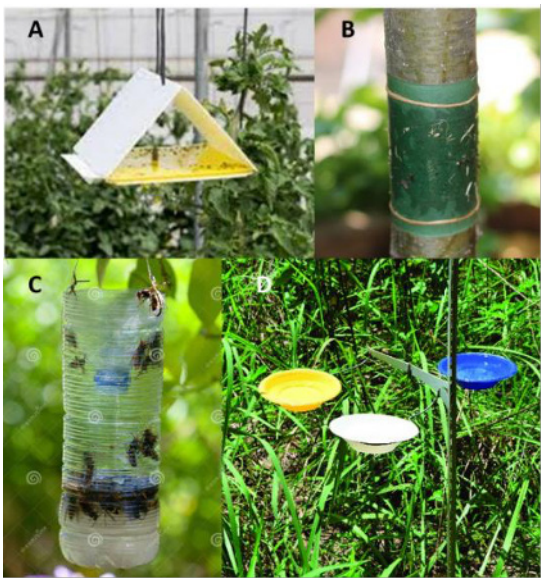

Figure 7. Common insect traps. (A) Delta trap; (B) Tree band trap; (C) Bottle trap; (D) Pan trap

4. Abiotic factors in plant health management

The BSOs not only face threats from biotic factors such as insects and diseases, but also increasing stress from abiotic factors in the environment, usually driven by the changing climate.

Abiotic factors refer to non-living chemical and physical components of an ecosystem that have an impact on living organisms, and the function of the environment such as temperature, light, water, soil, minerals, radiation, humidity, etc.

A stressful life is common among plants and trees in a field. In general, they have the capacity to tolerate or resist unsuitable living conditions if the stress is mild or short-term. However, extreme conditions such as intense flooding during rainy seasons or long-term drought, high temperatures during the day, frost and low temperatures in the night, will have a significant impact on the growth, development, yield and seed quality of plants, and even kill them.

Recently, phytotoxicity was classified as an abiotic factor. It is a toxic effect of a compound on plant growth, and could be the result of misuse or misapplication of a chemical to seed or plants such as insecticides, fungicides, herbicides, fertilizers and salinity. Symptoms include leaf spotting, scorch and dead tissues, which could be easily misdiagnosed as insect or disease damage.

4.1 Effects of abiotic factors in BSO

Effects of water

Water is the most important factor in plant life. It is essential for the germination of seeds and growth of roots, leaves and stems. However, water is also the factor that stresses the plants' physiological functions.

Table 1. Effects of water stress on plants

	Effect
Drought stress	Reduction in photosynthesis
	Reduction in root growth and development, shoot mass, number of leaves and flowering
	Decrease in water and nutrient uptake
	Stunt the growth of plants or kill the plants
	Decrease in seed weight, seed yield and composition
Waterlogging stress	Reduction in root respiration
	Increased root damage and restricted root growth
	Limited water and nutrient uptake by roots
	Reduction in plant growth and yields
Salinity stress	White leaf tip followed by tip burning
	Leaf rolling, browning and death
	Stunted plant growth
	Floral sterility
	Low yield
	Change in the flowering duration
	Poor root growth
	Patchy growth in field

Effects of temperature

Temperature has an important role in plants' physiological functions, such as seed germination, enzyme activity, bud dormancy, growth of plant parts, etc. The upper and lower temperatures at which temperature stress is initiated varies from one tree species to another. Some species grow well under alpine conditions, while others thrive in desert conditions. The general effects of cold and heat stress are presented in Table 2.

Table 2. Effects of temperature stress on plants

	Effect
Cold stress	Reduced plant growth and death
	Surface lesions on leaves
	Abnormal curling, crinkling and chlorosis of leaves
	Water soaking of tissues
	Cracking, splitting and dieback of stems
	Internal discoloration (vascular browning)
	Increased susceptibility to decay
	Failure to ripen normally
Heat stress	Scorching
	Sunburn of leaves, twigs, branches and stems
	Leaf senescence and abscission
	Shoot and root growth inhibition
	Extreme high temperature can kill plants
	Decrease in photosynthesis, resulting in drying off

Effect of nutrients

Mineral nutrients are one of the abiotic factors which play an important role in plant development. There are two types of mineral nutrients: macro elements and micro mineral nutrients. Mineral nutrients are classified based on their biochemical function. The damage that can be caused to plants due to insufficient mineral nutrients are presented in Table 3.

Table 3. Effect of mineral nutrient deficiencies on plant growth

First damage part	**Nutrients**	**Symptoms**
Old leaves	N	Upper leaves are light green, lower leaves are yellow. Bottom or older leaves are yellow and shriveled. Stunted growth.
	P	Leaves are darker green than normal. It promotes leaf fall and delays flowering.
	Mg	Lower leaf tips and edges turn yellow from outside going in but veins remain green. Reduced growth.
	Mn	Yellow spots on leaves and/or elongated holes between veins.
Young leaves	K	Tips and edges of leaves turn yellow, usually in younger leaves. Stalks are turned into very weak, dark necrotic lesions.
	S	Curling of leaves, chlorosis is noted first in younger leaves, stems become hard and woody.
	Fe	Young leaves turn yellow and white with green veins. Mature leaves are normal.
	Ca	The new leaves are misshapen or stunted. Existing leaves remain green.

5. Invasive insects and diseases

Healthy forests play a vital role in promoting economic growth and combating climate change. They help maintain a healthy ecosystem to support human life. However, over the past decades, natural, planted and urban forests have faced the rising threats of invasive pests which hinder their capacity to provide sustainable timber, purify air and water, store carbon and maintain wildlife habitat.

An invasive pest is an introduced, non-native organism that spreads from the site of its original introduction, and causes damage to the local ecosystem, economy or human health. These pests include diseases, insects, plants, animals and parasites.

There are several factors that influence the increase of invasive pests: climate, tree species composition and local biodiversity. In particular, frequent global trade and worldwide human travel plays a significant role in introducing exotic insects and diseases. The common sources of introduction include, but are not limited to, movement of live plant materials (seeds, fruits, vegetables, flowers, nursery stock, house plants, scion material for grafting, etc.), logs and lumber, dunnage (wood used to stabilize containers in transit), wood packing materials and soil.

Most of the new insects and diseases are accidentally introduced. However, a few are intentional imports. In the past decades, there has been a changed perspective that insects and diseases have an important ecological role to maintain the diversity of the tree species and health of the forest. Thus, some exotic tree diseases or insects were introduced as biological control tools which diversify uniform plantations of exotic trees. Either means of introduction could drive some local tree species close to extinction through direct or indirect effects and threaten whole ecosystems.

Most of the accidentally-introduced species failed to establish. However, some species are successfully established upon their arrival in the new environment, and a section of them caused severe damage to the local habitat. There are several reasons for the successful establishment:

- Almost nothing is observed about an invasive insect or disease until it establishes in the new habitat and causes severe damage. However, by then it is too late to eliminate the insect or disease.
- Invasive species, particularly insects, usually lack natural enemies in the new habitat. The population could grow rapidly without any suppression and disrupt the eco-balance in the new area.
- The native trees have resistance or tolerance to local insects and diseases following long-term evolution, but they lack defense against invasive species.
- Lack of information about the exotic insect or disease, such as host range, control methods and biological characteristics, which reduces the effectiveness of management. For example, invasive species were not considered pests in the original regions, thus little research was conducted.

It is critical to prevent the invasion, establishment and spread of insects and diseases to protect the forest globally. Meanwhile, it should not disrupt international trade which could result in negative economic impacts. In order to achieve this target, it is important to:

- Follow the national plant quarantine regulations, when importing or exporting products, especially those related to seeds for planting, wood, wood products and wooden packaging materials.

- Early detection and regular surveillance in specific sensitive areas could increase the chances of discovering invasive species in the early stages before they cause irreparable damage.
- Raise public awareness. Involving the public is important for effective and efficient management of invasive species. Through multi-media awareness campaigns like news, posters and apps, people understand the concept of invasive insects and diseases, and the risks that they pose. It will help to educate the public on how to monitor newly introduced species, and to avoid transporting plant materials which have not met the requirement of plant quarantine during international travel.

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Appendix: Examples of diseases and insects in some of the tree species planted as BSOs by PATSPO

Acacia

1. Anthracnose

Pathogen: *Colletotrichum gloeosporioides*

Symptoms: Infected leaves show circular to oval reddish-brown spots of variable size with raised margins and tip necrosis. Drying and cracking of the leaves and premature defoliation can be the result of severe infection.

Prevention and Treatment: Using pathogen-free seeds and implementing strict nursery management are essential to prevent this disease. Remove and destroy infected leaves and branches. Disinfect the tools to prevent spread of the disease. Fungicides with chlorothalonil and copper can be used as preventive treatment in the nursery.

2. Phomopsis leaf spot

Pathogen: *Phomopsis spp.*

Symptoms: The disease usually affects young leaves. It initially forms dark reddish-brown necrotic lesions, which later become large and pale, and can extend the full length of the leaf. It also forms light-coloured necrotic areas with irregular, raised and well demarcated dark brown margins. Lesions gradually spread across the surface and can cover up to half of the leaf.

Prevention and Treatment: Use pathogen-free seeds and seedlings. Implementation of optimal nursery management is essential to prevent this disease. Mancozeb and carbendazim are effective chemicals to control the disease.

3. Pestalotiopsis foliar spot

Pathogen: *Pestalotiopsis spp.*

Symptoms: This disease is commonly found in nurseries. It causes minor damage like small, scattered, dark-brown or reddish-brown, discrete spots. These spots can sometimes have a bleached central region on leaves. Pathogen fruiting bodies can also be found on large necrotic lesions.

Prevention and Treatment: Use pathogen-free seeds and seedlings. Follow optimal nursery management to prevent this disease. Spray prochloraz and chlorothalonil on the plants if the infection is severe.

4. Powdery mildew

Pathogen: *Oidium spp.*

Symptoms: Early symptoms of infection occur as powdery white patches on primary, juvenile, pinnate leaves. Patches increase in size as the infection progresses, often spreading to secondary leaves.

High levels of infection can result in defoliation and, in rare cases, death of seedlings. Heavily infected foliage is coated in a mat of superficial hyphae and spores of pathogen, giving a powdery appearance.

Prevention and Treatment: Remove diseased foliage from the plant and clean up fallen leaves and branches on the ground. Apply sulfur or copper-based fungicides early or at the first sign of disease.

5. Fusarium canker and wilt

Pathogen: **Fusarium spp.**

Symptoms: This disease usually causes rapid and extensive damping-off, leaf drop and lesions on the stems of young seedlings in nursery. Older trees show stem and branch cankers.

Prevention and Treatment: Use pathogen-free seeds and seedlings. Sterilize potting soil and tools in the nursery to prevent this disease. Spray fungicides hymexazol and azoxystrobin to control the disease in seedlings.

Eucalyptus

1. Leaf blight

Pathogen: *Calonectria spp. and Cylindrocladium spp.*

Symptoms: One of the most prominent diseases associated with Eucalyptus trees. Initial infection presents as greyish water-soaked spots on young leaves. These spots develop into extensive necrotic areas, resulting in leaf drop and severe defoliation. In some cases, there are stem cankers and root rot. Shiny white spores can be seen at the margin of lesions, on older necrotic parts of leaves, especially along midribs on the lower surfaces, and on fine shoots. Under high humidity and frequent rainfall conditions, necrotic lesions cover the entire area of the leaf. Pathogen fruiting bodies cover and kill young shoot tips, resulting in leaf and shoot blight symptoms.

Prevention and Treatment: Use healthy seeds and seedlings. Apply carbendazim as a foliar spray or add it directly to the base of plants in the nursery to prevent and treat the disease. Strictly follow optimal nursery and field management. Plant resistant species and genotypes.

2. Mycosphaerella leaf disease (MLD)

Pathogen: *Mycosphaerella spp. and Teratosphaeria spp.*

Symptoms: MLD is an important disease that threatens Eucalyptus plantations worldwide. A great variation in symptom development depends on the Mycosphaerella species and susceptibility of the Eucalyptus. Leaf spots can be single or merge to form larger lesions, often causing leaf crinkles. Small black fruiting bodies of pathogen are often seen within leaf spots, aggregating on leaf veins on the underside or both sides of leaves. Some species of Mycosphaerella can cause defoliation, mostly in the lower crown. Small necrotic lesions develop on young green stem tissue. These lesions merge to form large cankers that exude gum. Epicormic shoots develop below the girdling canker and trees die in severe cases.

Prevention and Treatment: Use healthy seeds and seedlings. Strictly follow the optimal nursery and field management. Plant resistant species and genotypes.

3. Eucalyptus psyllid

Insect: Psyllid

Symptoms: The psyllid nymphs form white lerps composed of solidified honeydew and wax on the surfaces of leaf. The nymphs and adults suck tree juice and cause leaf discolouration/drop. Heavy infestations cause extensive defoliation and weaken the tree, which can increase its susceptibility to other insects and diseases. In addition, the nymphs produce a large amount of sticky honeydew, which results in growth of dark sooty mould on the branches and stem, thereby interfering with harvesting and use of the wood.

Prevention and Treatment: Ensure adequate irrigation, especially during the period of prolonged drought. Inspect regularly to detect problems before they become more serious. Insecticides are not recommended. If necessary, soap, water or horticultural oil can be sprayed.

Cordia

1. Powdery mildew

Pathogen: *Oidium sp.*

Symptoms: Infected leaves are covered with white to gray powder, usually on the upper surface, and become yellow to brown and drop later. The disease is usually not deadly, but weakens the plants. Optimum conditions for powdery mildew development are warm days followed by cool, humid nights. Dry daytime weather allows pathogen spores to spread to other plants via air currents. On a cool evening, they absorb enough moisture from the air to germinate and cause infection.

Prevention and Treatment: Remove diseased foliage from the plant and clean up fallen debris on the ground. Apply sulfur or copper-based fungicides early or at first sign of the disease.

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