MODULE II
INTEGRATED PEST MANAGEMENT CONTROL TACTICS

Training Course on Principals and Application of Integrated Pest and Diseases Management for African Countries

Dewi Melani
PLANT PROTECTION DEPARTMENT

INDONESIAN CENTER FOR AGRICULTURAL TRAINING KETINDAN
AGENCY FOR AGRICULTURAL EXTENSION AND HUMAN RESOURCE DEVELOPMENT
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Field crops are vulnerable to attack by pests. Pest damage can range from slight damage that has no effect on the value of the harvested product to severe damage that kills plants, significantly reduces yield of the crop, or reduces its market value. Field crop pests include insects and mites, weeds, diseases, and nematodes. Effective management of pests is based on thorough consideration of ecological and economic factors. The pest, its biology, and the type of damage are some of the factors that determine which control strategies and methods, if any, should be used. Pest management decisions largely determine the kind and amount of pesticides used. Pest management decisions represent a compromise between the value of the product, the extent of the pest damage, the relative effectiveness and cost of the control measures, and the impact on the environment (Hines, 2015).

The key to crop management in any farming system is the prevention of anything that will decrease the amount of crop harvested. Pest insects feeding on plants, for example, can reduce harvests or destroy crops. The key to prevention is healthy plants and the key to healthy plants is in the soil. Research has shown that healthy plants are not attacked as often by pest insects as less healthy plants. Removing infested plant material including crop residues from the field reduces carryover of pests from one planting to the next and thus prevents reinfestation.

According to the Food and Agriculture Organization (FAO) of the United Nations, Integrated pest management (IPM) means considering all available pest control techniques and other measures that discourage the development of pest populations, while minimizing risks to human health and the environment. For farmers, IPM is the best combination of cultural, biological and chemical measures to manage diseases, insects, weeds and other pests. It takes into account all relevant control tactics and methods that are locally available, evaluating their potential cost-effectiveness. IPM does not, however, consist of any absolute or rigid criteria. It is a flexible system that makes good use of local resources and the latest research, technology, knowledge and experience. Ultimately, IPM is a site-specific strategy for managing pests in the most cost-effective, environmentally sound and socially acceptable way. Implementation of IPM lies with farmers, who adopt practices they view as practical and valuable to their activities

Integrated pest and disease management (IPM) is also defined as a farmer-based and knowledge intensive management approach that encourages natural and cultural control of pest populations by anticipating pest and disease problems and managing their numbers to reduce losses, while permitting safer pesticide uses where justified and permitted. Many indigenous, as well as newly-developed, nonchemical techniques are available for use. These include combinations of biological control, habitat manipulation, soil health management, use of resistant varieties, and modification of cultural practices (expanded upon below). IPM focuses on long-term prevention of pests and their damage. Pesticides are considered curative, and generally should be used as a last resort. The goal of IPM is to use all appropriate tools and tactics to keep pest populations below economically damaging levels and to avoid adverse effects to humans, wildlife, and the environment. Management decisions are based on information gathered about the pest problem and crop. Then you use a combination of control measures that best suits the problem. insect and disease problems.

Figure 2.1 : Concept of Integrated Pest Management
(www.croplife.org)

The demands of a growing world population for food and fiber require farmers to produce more crops on existing farmland. To increase these yields requires continuous improvement of agricultural technologies to minimize crop losses. The challenge is to do this while protecting the environment. IPM is a big part of the solution. Increasingly it is being adopted in both developed and developing countries for long-term, sustainable agriculture that achieves adequate, safe and quality food production, improves farmer livelihoods and conserves non-renewable resources.

IPM provides multiple benefits for society and the environment. It is vital for the long-term future of the plant science industry.

a) Improved crop profitability due to better pest control measures and appropriate use of crop protection products;
b) Stable, reliable and quality crop yields;
c) Decreased severity of pest infestations;
d) Reduced potential for problems of pest resistance or resurgence;
e) Increased consumer confidence in the safety and quality of food and fiber products.

Crop protection companies that integrate IPM principles into marketing and customer support for their products also stand to benefit from:

a) Sustained market share and access
b) Less risk of restrictions or deregistration
c) New opportunities for established and novel products, techniques and services
d) Longer product life cycles
e) Decreased resistance of pests to crop protection products and biotech plants
f) Increased public confidence in, and credibility of, the crop protection industry

2.1 A Brief Sketch of Insect Natural History

The number of insect species is greater than the number of all other species of organisms combined (excluding prokaryotic organisms-bacteria). The number of taxonomically described beetles (only one of 31 orders of insects) is more than 250,000 species, more than all the species of flowering plants. Estimates on the number of species of insects not yet discovered range from between 2 - 100 million species. Insects have been around for more than 350 million years. Except for marine habitats, insects have adapted to almost every environment possible. The reasons for their success include the following factors:

a) Short generation times and high numbers of offspring result in populations that are highly adaptable under the stress of environmental changes.
b) A highly efficient body plan and construction: The insect "exoskeleton" is a light-weight, but incredibly strong "suit of armor" whose external waxy coating protects against moisture loss. Outwardly directed ridges and spines serve to protect or hide the insect

from enemies, or are colored and modified to attract mates, while inward protruding ridges and spines serve as points of attachment for muscles.

c) The ability to fly: Active flight was first to evolve in the insects, aiding dispersal to new and potentially favorable environments

d) The development of "complete metamorphosis" in some orders, allowing the juvenile stages to no longer compete with the adults for space or resources. Body forms could be solely adapted to a specific and independent role or function.

Pests are defined here as organisms that cause damage or destruction to crops, forest plantations, and domestic animals. They include viruses, bacteria, fungi, plants, insects, mites, nematodes, birds, rodents and other animals. Field and post-harvest crop losses due to pests range from 25 percent to 50 percent worldwide, and may be higher in the developing world. Pests responsible for animal diseases may also infect humans; chronic diseases transmitted by insects inflict pain and suffering and diminish people's ability to work.

Not all insects are harmful. Identification is essential to distinguish the harmful from the beneficial insects.

a) Pollination: Many species of native bees and flies pollinate crops

b) Organic matter decomposition: Mold mites, springtails, wolf spiders, centipedes, sow bugs, ground beetles exist at different trophic levels and serve to break down organic matter into its constituent parts. They feed directly on organic matter or prey on those that do.

c) Natural or intrinsic levels of pest suppression: Some insects feed on other harmful insects. The great diversity of insects includes predaceous, parasitic and parasitoid adaptive strategies and are "natural enemies" of agricultural pests.

These "beneficial insects" may serve to effectively suppress the development of pest populations if the habitat for these species is effectively managed.

2.2 Monitoring (Field Scouting)

Observing crops determines if, when and what action should be taken to maximize crop production and quality. Decision-making tools range from pegboards to computers and trained local experts to remote-sensing technologies. Getting real-time information on what is happening in the field is ideal. Management of any crop requires routine inspections to assess how well plants are growing and what actions need to be taken from seeding to harvest. Walking through a field involves scouting for pests and distinguishing them from non-pests and beneficial insects. Tools like pheromone traps, diagnostics and forecasting systems can assist with such monitoring in a timely and accurate way.

IPM often requires collaborative decisions within a specific geography to provide effective control of pests. Some of these decisions need to be taken by national governments in relation to quarantine regulations and legislation, provision and training of advisory services and strategies for control of highly mobile pests like locusts. Geographic information systems and remote-sensing techniques can also assist in area-wide management.

Field scouting also is an important part of any IPM program because it helps define the pest problems. Correct identification and location of each pest in a crop are necessary for a successful pest management program. These can be accomplished by regularly scouting fields. A scouting trip through a field reveals what pests are present, the growth stage of the pests and the crop, the location of the pest in the crop, whether the pests are parasitized or diseased, the pest population, if the population is increasing or decreasing, and crop condition. A scouting program should include accurately written records of field locations, field conditions, previous pest infestations, and control measures. Using this information, you can decide what control measures are needed and will be the most effective.

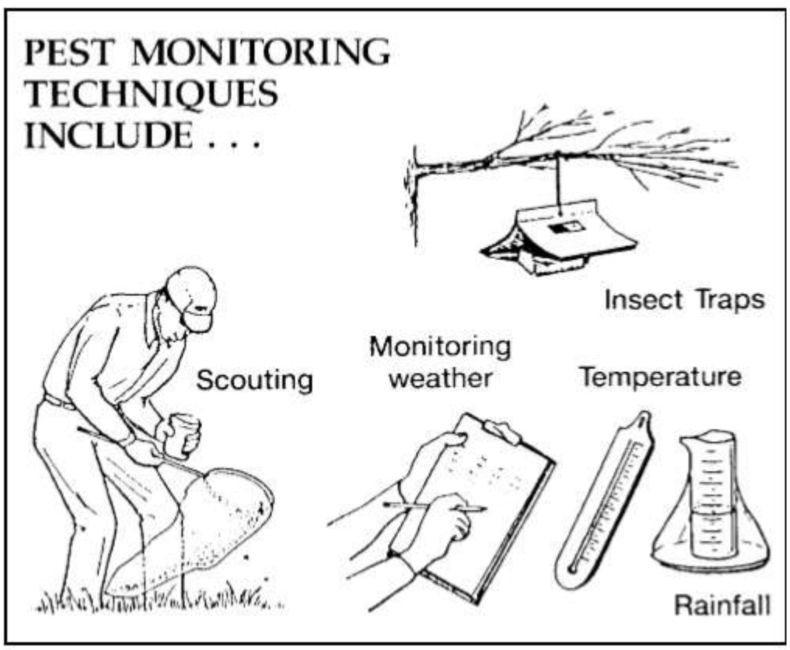

Figure 2.2 : Pest Monitoring Techniques
(Hines, 2015).

Remember the following basic principles when scouting:

a. Take samples from several areas of the field.
b. Select sample sites at random unless field conditions suggest uneven pest distribution.
c. DO NOT sample in border rows or field edges unless indicated to do so for a particular pest.

Insect pests can be monitored in several ways. The most common methods are directly counting the number of insects present and/or estimating the amount of insect damage. Insect counts are usually expressed as the number of insects per plant or plant part (e.g., number of insects per leaf); insect crop damage is often expressed as percentage of the plant damaged (for example, percent leaf defoliation).

2.2.1 Arthropod Monitoring and Management Procedures

Monitoring is the systematic scouting of crops for pests and natural enemies, either regularly or at susceptible times to understand if the self-regulatory regulation of pests is still intact or if additional measures need to be taken. Typical aids for monitoring are sweeping nets, sticky traps, and pheromone traps. Observations need to be made on a daily basis to monitor pest types and numbers to determine when to intervene. This is important because any type of intervention costs time and money.

Figure 2.3 : Sweeping nets and sticky traps for monitoring pests and natural enemies (https://www.entosupplies.com.au and https://www.gardeningknowhow.com)

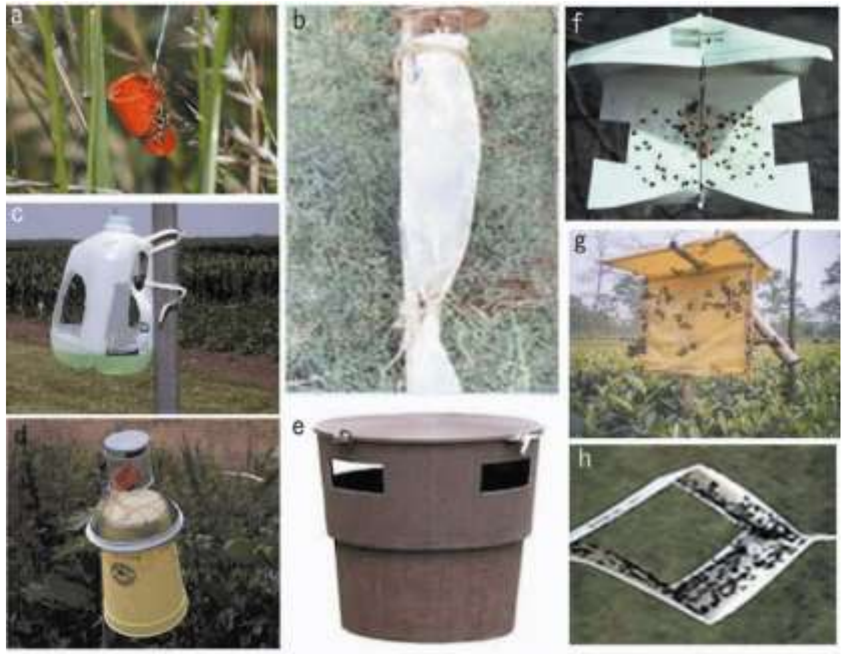

Figure 2.4 : Different types of pheromone traps used in field; traps used in crop field (a-e), traps with trapped pest insects (f-h). a. one lure septum hanged with crop plant, b. net trap, c. water trap, d. bucket trap, e. bucket with window trap, f. delta trap, g. Yellow sticky trap, h. wing trap (Islam, M.A, 2012)

2.2.2. Monitoring methods commonly used

1) Visual inspection/observation: Regular visual inspection and observation of plant parts in field and lab is the most effective
   - Monitoring protocol for in-field visual inspections
     - ❖ Survey crops systematically and on regular basis
     - ❖ Frequency: 1x/week; 2x/week during peak growing season
   - Vegetable crops:
     - ❖ Walk furrows and check both sides of leaves on every few plants
     - ❖ Remove wilted plants and examine root system for indications of soil borne insects, pathogens
   - Root crops:
     - ❖ Check the soil before you plant from the soil level to 4 inches down by running your fingers through the soil looking for small insects. Collect and identify samples.

2) Arthropod sampling techniques for the garden and small farm

- Traps: Less effective as they tell what is on the farm and not necessarily what is affecting the crops. Traps may also catch arthropods that come from outside the farm or garden.
    - ❖ Pheromone traps: Attract insects by chemical lure
    - ❖ Sticky traps: Capture flying adult insects
    - ❖ Light traps: Select for nocturnal insects
    - ❖ Pit fall traps: Capture ground-dwellings arthropods and spiders
- Catching: Most effective in determining abundance and corollating arthropods with damage
- Sweep nets: Use to capture insects on vegetation
- Aspirators: Use to capture very small insects on vegetation
- Shaking plants: Shaking or beating plants or branches onto paper for later sampling is a useful way to gather insects for identification that might normally go unseen
- Degree-day monitoring: For some pests and beneficial insects researchers have developed temperature development thresholds at which time management actions may best be taken

2.2.3 Identification and Understanding Life Cycles.

Another important tool in pest and disease control is identification and understanding of the life cycles. The accurate identification of the species, life cycle, habitat requirements, time and location of occurrence, damage pattern, susceptible time for control form an important part of the knowledge of pests and natural enemies and are indispensable for a successful long-term pest management strategy. Identification can be done using field manuals or by collecting a specimen or diseased tissue and pest is identified, a study of its life cycle will reveal when it is the most vulnerable to existing controls. Climate and weather conditions also influence the pest activity and rate of reproduction. Knowledge of these can help to predict the likelihood of disease infections and thus aid in the designing of appropriate preventive measures.

2.3 Economic Thresholds

An economic threshold is defined as the pest density at which action must be taken to prevent the pest population from increasing and causing economic damage. Economic thresholds are constantly changing. They vary between fields, varieties, and crop growth stages. Economic thresholds are a function of crop value and cost of control. In general, a high-value crop will have a lower economic threshold; less pest damage will be accepted and control measures must be taken sooner. If the control measures are expensive, the economic threshold is usually high. High control costs mean it takes more crop loss to justify the control action. Economic thresholds are often referred to as action thresholds. When the pest population reaches the threshold, action is taken to reduce the population. For insects, an economic or action threshold is typically expressed as the number of insects per plant or the amount of crop damage.

2.4 Control Strategies

Reducing economically damaging pests to acceptable levels may involve cultural, physical, biological and chemical control measures individually or in combination. Costs, benefits, timing, labor force and equipment as well as economic, environmental and social impacts all have to be taken into consideration.

2.4.1 Cultural Control

Cultural control uses farming practices to reduce pest populations. Implementing a practice such as tillage or crop rotation at the correct time can kill or reduce pest numbers or slow pest development. Like all other control strategies, cultural control requires an understanding of the pest and the crop. Cultural control measures are usually applied at the weakest stage of the pest’s life cycle. Generally, cultural control methods are preventive actions rather than curative actions. Cultural control methods work in three ways:

1. Prevent the pest from colonizing the crop or commodity.
2. Create adverse conditions that reduce survival of the pest.
3. Reduce the impact of pest injury.

2.4.1.1. Preventing Colonization

Control measures that prevent colonization physically exclude the pest, reduce pest populations, prevent the pest from finding the crop, or disrupt the timing between the pest and the crop and Help provide habitat for beneficial insects.

a. Trap crop—planting a small area with a preferred host to attract the pest away from the crop. Once in the trap crop, the pest can be destroyed or controlled. Protecting natural habitats near farmland is the best way to conserve biodiversity, including many natural pest enemies. Careful management of farmland edges, including trees and hedges, is important for wildlife habitats, providing cover and refuge for beneficial insects and Intentionally planted alternative food sources for pest organisms.
   - A trap crop is one the bugs prefer to the main crop. It is planted to "trap" the pests and keep them away from the main crop.
   - Trap crops are used to protect the main crop from a pest or a variety of pests.
   - The trap crop can be a different plant species, variety, or just a different growth stage of the same species as the main crop, as long as it is more attractive to the pests when they are present. If given a choice, cucurbit pests such as squash bugs and striped and spotted cucumber beetles prefer squash and pumpkins to watermelons, cantaloupes, cucumbers, and gourds—in that order.
   - The required trap crop planting size depends upon the intensity and direction of the pest attack expected, as well as the mobility of the target pest insect
   - Usually, planting a trap crop around the perimeter of a crop area will be effective against insects of intermediate mobility.
   - Trap cropping tends to work best for insects of intermediate mobility rather than those, like aphids, that are passively dispersed by air currents, or insects that are strong fliers.
   - Trap crops are more economical to use if the system is easily planted and maintained and if they have some other use, such as supporting beneficial insects or if they can also be marketed. If they require a small amount of space relative to the main crop, they will be more economical.
   - The type of plants to use as trap crops varies according to the intended primary crop and expected types of pest insects. These will also vary due to the differences in climate within the state. One plant that is commonly used as a perimeter trap is collard greens to protect cabbage.

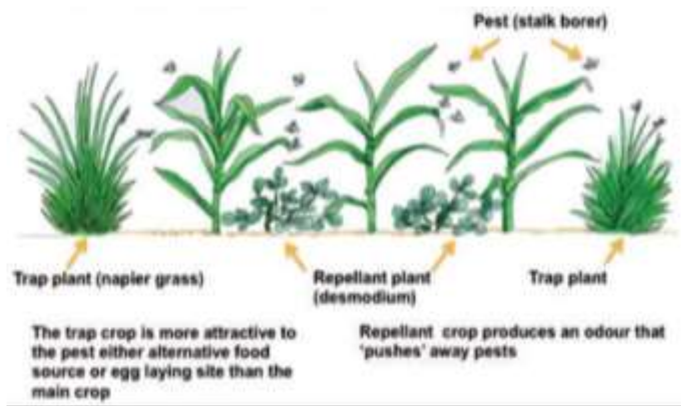

Figure 2.5 : Trap cropping (push-pull) strategy in Maize
https://teca.apps.fao.org/teca/en/technologies/8372

a. Physical barriers—separating a pest and host with an object such as a wall to stop the pest from infesting. Example: in grain bins, it is extremely important to fill in all cracks and crevices with approved caulking material to prevent colonization by pests such as insects and rodents.
b. Crop rotation—a cycle in which different crops are planted in a field every year; the longer the rotation, the better the pest control. A crop rotation system helps control host-specific pests. Planting similar crops alongside each other can substantially increase pests and should be avoided if possible. Traditionally, some farmers sow different crops in alternate rows or undersow a crop like maize with a legume such as cowpea to help improve soil fertility and reduce weeds. Such systems can help reduce pests. A classic example of crop rotations is a corn-soybean rotation to control corn rootworms.
c. Delayed planting (timing)—changing the planting date so that the host is not available when the pest is present. Example: changing the planting date of winter wheat can control the Hessian fly. The adult fly is shortlived and requires wheat at a specific vegetative state for egg laying. Delaying the fall planting of winter wheat until after the Hessian fly adults have died offers yearround control of this pest. Another example is planting oats before May 15 to reduce the crop's exposure to aphids carrying barley yellow dwarf virus when the plants are young and more susceptible.
d. Companion planting

   Plants intentionally planted adjacent to cash crops that repel pests. The use of resistant crop varieties: Certain crop species have undergone extensive selective breeding in order to develop greater resistance and resilience to common agricultural pests. Such varieties should be used where appropriate.

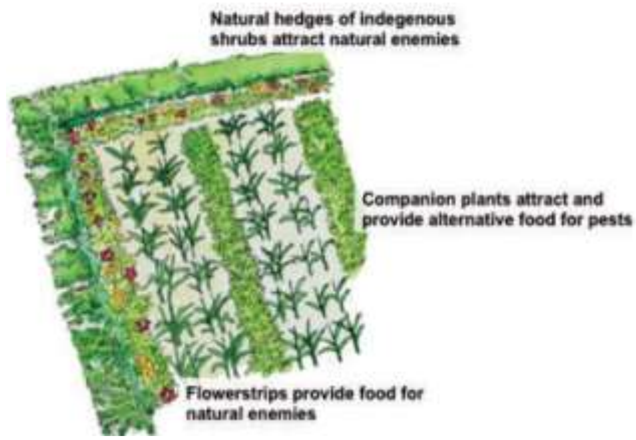

Figure 2.6 : Enhancing biological control using Companion Plant
https://teca.apps.fao.org/teca/en/technologies/8372

e. Cover crops— utilizing plant competition by planting a secondary crop to prevent weeds from becoming established. Example: cereal grain cover crops provide a suitable environment for soybean seedling establishment while suppressing weeds.

2.4.1.2. Creating Adverse Pest Conditions In The Crop

Pests require specific living conditions. Cultural control methods can disrupt ideal pest conditions and so decrease pest pressure. Adverse pest conditions can be created by destroying the host plant, physically moving the soil, changing water management practices and spatial arrangement, and the plant's natural defense mechanisms.

a. Destroy crop residue, alternate hosts, and volunteer crops—eliminating the pest or pest habitat found in crop residue, or destroying alternate hosts of the pest found near or in the crop. Example: planting wheat into corn residue increases the risk of wheat scab because the pathogen infects both hosts. Pests, particularly plant pathogens, can survive in a field on volunteer crops and alternate hosts. The survival of these pathogens provides a source of inoculum for the field. For example, wheat streak mosaic virus and its mite vector survive on volunteer wheat. Many fungi and bacteria build up on volunteer crops early in the season and surround and infect the crop later in the season.
b. Tillage—physically moving the soil around the crop. Tillage can destroy an insect, create physical and chemical changes in the soil that reduce pathogens, and destroy a

weed's roots and disrupt nutrient uptake. All of these factors can reduce pest populations.

c. Water management—manipulating water to control a pest. Supplying water to crops is essential to plant health but it can greatly influence pest incidence and impact. Irrigation may be required, especially in dry areas or with crops that require a lot of moisture. But while flood irrigating some crops, such as lowland rice, can control weeds, it is wasteful of water and can adversely affect beneficial soil organisms. Methods to combat these risks and conserve water include drip irrigation or growing crops on ridges or raised beds. Water management can also be used to promote healthy crops, which are better able to compete with weeds. Overwatering can increase the potential for plant diseases.

d. Soil Management

   Mechanical, physical and cultural crop protection methods prevent or minimize pests as well as reduce their build-up and carryover from one crop to another. For example, traditional ploughing ("tillage") turns the soil and buries crop residue and weeds before the seed bed is prepared for the next crop. However, tillage has led to increased erosion as well as loss of soil moisture and organic material. In many countries, there has been a trend towards reducing tillage and using herbicide-tolerant biotech crops. Regular additions of organic matter (e.g., compost, cover crops, and/or manure) stimulates soil biological activity and diversity, which may prevent certain pest populations from increasing beyond economic thresholds. Different soil types contain varying amounts of nutrients. At harvest, nutrients are removed with a crop from the soil. In order to maintain or improve soil fertility, these nutrients have to be replaced with mineral and/or organic fertilizers. These products must be applied at the right time in the correct amounts to optimize soil health. New plant varieties with more efficient uptake of nutrients should be considered.

e. Spatial arrangement (seeding rate and row spacing)—changing the spatial arrangement of the crop to reduce pest populations. Example: when plant spacing and row width are reduced, soybeans outcompete weeds. On the other hand, close spacing may provide a favorable environment for disease to develop—for example, white mold in soybeans and dry beans.

f. Allelopathy—one plant species eliminates a competing plant species through the release of toxic chemical agents. Allelopathy has great potential in weed management. For example, in a conservation tillage system, leaving rye residues can reduce the number of weeds.

2.4.1.3 Reduce Pest Injury To Crop

Cultural controls also utilize a plant's defense mechanisms to minimize pest damage. Planting pest-resistant crops, maintaining a healthy crop, timing harvest to reduce pest damage, and practicing pest-reducing storage techniques can reduce pest injury.

a. Host-plant resistance—the host plant's ability to tolerate pest pressure. Plants have defense mechanisms that allow them either to affect the pest or withstand the pest's damage. Choosing beneficial crop varieties, such as those with disease and pest resistance, has always been a cornerstone of IPM. These varieties can be derived from traditional cross-breeding or modern biotechnology: pest-resistant and herbicide-tolerant varieties, for example, may reduce the need for other crop protection measures. Biotech crops can also facilitate reduced or no-till practices, helping to maintain soil health and prevent erosion.
b. Plant health—maintaining strong, healthy plants that are better equipped to out-compete weeds, fight disease, and withstand insect damage.
c. Harvest timing—changing the time when a crop is harvested to reduce pest impact on yield. For example, cutting alfalfa early can reduce the effects of alfalfa weevil or leafhopper damage. Cutting too early, however, weakens the roots and can make the plant more susceptible to root diseases.
d. Storage practices—handling, curing, and storage practices to prevent the spread of disease during storage. For example, low temperature and good ventilation are essential to minimize losses in potatoes.

2.4.2 Physical Control

Physical control methods in crop protection comprise techniques that limit pest access to the crop/commodity, induce behavioral changes, or cause direct pest damage/death. The primary action may have a direct impact, for example, when insects are killed immediately by mechanical shock. In other instances, the desired effect is attained through stress responses.

With the rapid advances that have occurred in the physical, chemical, and biological sciences since the late 19th century, agriculture has been transformed from a strictly empirical activity, largely based on tradition and aimed primarily at staying off famine, to a quantitative form of agriculture focused on producing large quantities of food. During this transition, which has been sustained at an increasing rate over the past 50 years, physical control methods have been set aside because of the tremendous success of chemical control. It is only natural that some people should view the use of physical control methods as a step backward to those distant, ancestral practices.

Thanks to technological advances and greater precision in the implementation of such methods, physical control now has all the necessary attributes for incorporation into IPM strategies. Generally physical control methods are also preventive actions like remove/kill pest by hand (hand picking), cultivation, introduction pest traps (sticky / pheromone traps), irrigation practices, row covers, mulching, solarization, field sanitation, netting,reflective mulches, and petroleum oil barriers (Vincent et al., 2009).

2.4.1 Modes of Action and Classification

Passive methods cause changes in the immediate environment and have a more lasting effect; although with no residual action after they are removed. For example, there are a wide variety of physical barriers in use which can be applied in the fi eld, screenhouse or food storage area. Barriers used in the fi eld can take several forms (trenches, exclusion nets, etc.) and can be deployed on a range of scales to protect a complete field, a crop row, or a group of plants. Passive methods should be used whenever possible, because they extend the length of the treatment. For example, plastic-lined trenches along field boundaries trap *Colorado potato beetles* during the whole migration period; screening windows and doors in food storage prevent fl ying insects from entering. Physical barriers used to keep pests out, combined with suppression techniques, are the cornerstone of the approach adopted by industrialized countries to replace methyl bromide. Other techniques such as diatomaceous earth, hydrophilic particle films, sticky traps, and oils also are also passive techniques.

Active methods are used to destroy, injure, or induce stress in crop pests or to remove them from the environment, and can be classified according to the mode of energy use ex : thermal shock (heat), electromagnetic radiation (microwaves, infrared, and radiofrequencies), mechanical shock, and pneumatic control (blowing or vacuuming tools).

In an IPM context, the decision to use a physical control tactic must therefore be made on a case-by-case basis according to the same criteria as in decision-making regarding the appropriateness of pesticide applications: efficacy, cost-effectiveness, and undesirable effects. In addition, no physical control technique is sufficient on its own for all pest control treatments in a given crop (Vincent et al., 2009).

a. Pheromones defined: The chemical sex attractant used by many insect species to draw mates

- Trapping out: The use of pheromone traps to trap and kill
- Mating disruption: The timed mass release of synthetic pheromones with the mating times of agricultural pests resulting in the inability of mating pairs to form.

Finally, the development and availability of insect sex pheromones and other behavior-modifying chemicals offer farmers the possibility of:

- Selective trapping techniques to monitor the movement of pests or changes in their populations during the season
- “Lure and kill” strategies to attract the pest to insecticide deposits and reduce the need for overall crop spraying
- Mating disruption that slows population build-up to delay or reduce the need for control treatments

b. Repellants

A way to prevent pest insect damage is to repel them with a substance that can be sprayed on the plants. This is usually done with garlic oil that is commercially available in large quantities. It has a small quantity of soap that doesn't harm plants mixed in to make it soluble in water. This mix of garlic oil and soap is diluted in water and applied directly to the plants. Another substance used to repel pests is an herb commonly called tansy. Cuttings from the plant can be boiled in water to make a tea. This can be diluted and applied. These and other mixtures have the effect of making the plants unpalatable to the pests, resulting in little or no damage to the crops. These repellants should be reapplied on a regular basis or after a rain. Application should be stopped enough ahead of harvest for the repellents to be washed off.

2.4.3 Biological Control

Biological control is the use of living organisms to reduce a pest population. These beneficial (good) organisms are referred to as natural enemies. Predators, parasitoids, and pathogens are the most common natural enemies.

a. Predators—other organisms that eat the pest. Predators are usually not specific about what they eat—they will eat a variety of pests.
b. Parasitoids—organisms that must live in or on another organism to develop. A parasitoid is usually an insect that develops and feeds inside another insect. An adult parasitoid lays an egg in or on a host insect. When the parasitoid egg hatches, the larva feeds on the host insect. Eventually, the developing parasitoid kills the host insect by eating it from the inside out. Common parasitoids include tiny wasps and flies. They are usually host specific.

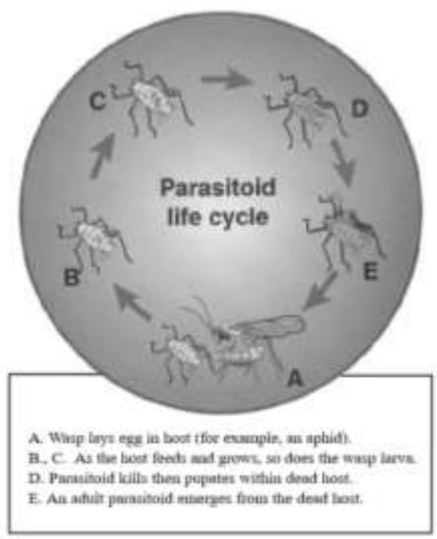

Figure 2.7 : Parasitoid Life Cycle
(Hines, 2015)

c. Pathogens—disease-causing organisms such as bacteria, viruses, and fungi that infect and kill the pest. Environmental conditions such as high humidity or high pest abundance allow naturally occurring pathogens to multiply and cause disease outbreaks (epizootic) that reduce a pest population. Some insect pathogens are manipulated to control specific pests. For example, the soil bacterium Bacillus thuringiensis (commonly known as Bt) can kill a variety of insects, including many caterpillars and mosquito and beetle larvae.

Examples of insect biological control agents (natural enemies).

Natural Enemy	Pests Controlled
PREDATORS	
lady beetles	aphids, scale insects
green lacewings	aphids, mites, others
spined soldier bug	Colorado potato beetle, Mexican bean beetle corn
minute pirate bug	earworm eggs, mites
PARASITOIDS	
tachinid flies	beetles, caterpillars
ichneumonid wasps	caterpillars, leafrollers, weevils, others
braconid wasps	caterpillars, beetles, aphids
Trichogramma wasps	eggs of moths, such as European corn borer
PATHOGENS	
Bacillus thuringiensis	caterpillars, some beetle larvae
nuclear polyhedrosis viruses (NPV)	Caterpillars
Beauveria bassiana (fungus)	caterpillars, grasshoppers, aphids
Nosema (protozoan)	caterpillars, beetles, grasshoppers

Using beneficial insects to control pests works best when crops are grown in controlled environments like greenhouses and plastic tunnels. There are cases when control techniques with living organisms are successful in open field conditions, such as using predatory mites against spider mites. However, biological control products are usually only efficient at low pest intensities and other interventions are often required. Bacteria, fungi, nematodes or viruses have also been mass produced to control some pests. The most common and successful is Bacillus thuringiensis (Bt), a naturally occurring bacterium, which has been used to control several important pests (e.g., caterpillar pests in vegetables, vineyards and orchards). With modern biotechnology, crops like corn and cotton can now express the insect toxin produced by this natural control agent, delivering it more effectively.

Biotechnology also has considerable potential to contribute to IPM. One focus of research has been on mass production of micro-organisms that cause disease in insect pests and weeds or compete with plant disease-causing organisms. The second and most rapidly expanding area of biotechnology for pest control has been the development of crop varieties resistant to pests and diseases and/or tolerant to herbicides. These varieties incorporate insect or disease resistance within the plant for accurate and timely delivery of an active ingredient.

2.4.4 Chemical Control

Chemical control reduces a pest population through the application of pesticides. The decision to use a pesticide as part of an IPM program should be based on a scouting program, pest identification, economic thresholds, and the crop/pest life stage. When used properly, pesticides provide effective and reliable control of most pest species. When pest insect populations reach the critical point where crop damage is unacceptable, some type of intervention is needed. This can be done using insecticides that target only the pests. If there is no target insecticide available, a broad- spectrum insecticide that is acceptable under the organic rule can be used. In small- scale operations or small numbers of specialty crops, techniques like hand picking are effective.

Chemical crop protection products (pesticides) are biologically active chemicals that control a range of insect and vertebrate pests, diseases and weeds. They are often the most cost-effective way of controlling infestations as part of an IPM strategy. Today's crop protection products are the result of more than 50 years of research, development and field experience around the world by the plant science industry. Before crop protection products are released in the market, they are thoroughly tested for their safety, usefulness and effectiveness. When sold, they are labeled with explicit use instructions. To get the most out of these products, they must be applied correctly. Responsible use and good handling practices limit potential pesticide residues in crops and the environment as well as help avoid pest resurgence and resistance. Improved application techniques and equipment, such as reduced drift nozzles and spot spraying, help farmers protect untreated refuges (e.g., hedgerows and field margins) and natural habitats for wildlife and pest enemies. The timing of treatment (season and time of day) as well as the types of products used are also critical factors.

An insecticide that targets the pest insects and does not kill the beneficials can be effectively used. However, some understanding of the life cycles of the pests and the insecticides used is necessary. One product that targets soft-bodied insects is insecticidal soap. This is effective in controlling aphids by dissolving the waxy coating on the outside of their bodies and causing them to dehydrate. Because of the way it works, the pests must be drenched in the soap solution. This requires direct contact with the solution so that it covers the pests. Another insecticide that targets specific pests is ultra-refined vegetable oil. This is prepared so it is soluble in water and can be diluted. A solution of this oil can be sprayed on larval forms of insects to kill them. When the solution dries, the oil turns into a paraffin-like coating that smothers the larvae. Again, the pests must be drenched with the solution for it to be effective, unlike the broad-spectrum insecticides.

All of these insecticides take some time to kill the pests- from hours for soap and oil, to days for the Bt. But they do not need to be reapplied unless rain or overhead irrigation washes the insecticide off the pests' bodies or the plant surfaces being eaten.The broad-spectrum insecticides (sometimes called botanicals pesticide) allowed by organic standards are all derived from plant material. These include rotenone, pyrethrum, sabadilla and others. They are called broad-spectrum because they kill almost all of the insects that come in contact with them- pests and beneficials.

These are the only substances known to be effective on the adult stage of most insects. Since they kill most of the insects they should be used only as a last resort and to save a crop that would otherwise be destroyed. There are two cautions about using these insecticides. The first is the misconception that, since these are organic, the dosage must be right so that it does not affect the plants. Another caution is in making sure that a botanical insecticide does not contain any chemical insecticides that may void your organic certification. Botanicals have a much shorter shelf life than chemically produced insecticides. They should be stored carefully to maintain potency and avoiding moisture.

2.4.4.1 Botanical pesticides

Botanical pesticides are naturally occurring chemicals extracted from plants. Natural pesticidal products are available as an alternative to synthetic chemical formulations but they are not necessarily less toxic to humans. Some plants contain components that are toxic to insects called secondary metabolites. Secondary metabolites (SMs) are natural products synthesized mainly by bacteria, fungi and plants. They are molecules of low molecular weight with diverse chemical structures and biological activities. The name secondary metabolite originates from the initial observation that their production is not necessary for the growth and reproduction of organisms, in contrast to primary metabolites which include lipids, amino acids, carbohydrates and nucleic acids. However, SMs are far from being secondary and the term “specialized metabolites” is emerging to describe them. It is now accepted that SMs play key roles in the survival of the organisms that produce them because SMs determine interactions within their environment. When extracted from the plants and applied on infested crops, these components are called botanical pesticides or botanicals. The use of plant extracts to control pests is not new. Rotenone (*Derris* sp.), nicotine (tobacco), and pyrethrins (*Chrysanthemum* sp.) have been used widely both in small-scale subsistence farming as well as in commercial agriculture.

Mode of action refers to the specific biochemical interaction through which a pesticide produces its effect. Usually, the mode of action includes the specific enzyme, protein, or biological step affected. While most other classifications are the pests controlled, physical characteristics, or chemical composition, mode of action specifically refers to which biological process the pesticide interrupts. Most botanical pesticides are contact, respiratory, or stomach poisons. Therefore, they are not very selective, but target a broad range of insects. This means that even beneficial organisms can be affected. Yet the toxicity of botanical pesticides is usually not very high and their negative effects on beneficial organisms can be significantly reduced by selective application. Furthermore, botanical pesticides are generally highly biodegradable, so that they become inactive within hours or a few days.This reduces again the negative impact on beneficial organisms and they are relatively environmentally safe compared to chemical pesticides. Knowing the mode of action is integral for scientists to improve the quality and sustainability of a product. To understand how pesticides work (their mode of action), it is necessary to understand how the pests' targeted systems normally function. It is also helpful to understand how human systems function in order to know similarities and differences between humans and the pests we try to control. Another reason, it is important to understand the modes of action of the pesticides we use is to prevent development of pesticide resistance in the target pest. Using pesticides with the same mode of action contributes to this problem by killing the susceptible pests and leaving only those with resistance to the entire class of pesticides that work through similar mechanisms.

Factors Affecting Use of Botanical Pesticides

1. Raw material availability
2. Standardization of botanical extracts containing a complex mixture of active constituents
3. solvent types, plant species and part of plant
4. Rapid degradation
5. State registration
6. Market opportunities for botanical pesticides
7. Weather conditions

There are other factors affecting on synthetic botanical pesticide uses, such as the formulation of the pesticide, the active ingredient, the time of exposure, the direct or indirect contact, the quantity used the pesticides mixtures, the climate and season of the year when it's applied, and the person's age, amongst others. ge, amongst others. There are environmental indicators, health indicators, and other elements that help determine the exposure risk, such as the person residence and occupational history, the clinical history, as well as the presence of the pesticides studied in drinking water, in the ground, in the atmosphere, and in the fresh or processed foods in the region where the studied populations inhabit. The exposure can be increased with the daily time dedicated to the activity, as well as the years of work, the exposure form, the use of protective gear, and/or the physical proximity of the housing to agricultural fields

Resources of Botanical Pesticides

At present there are four major types of botanical products used for insect control (pyrethrum, rotenone, neem, and essential oils), along with three others in limited use (ryania, nicotine, and sabadilla). Additional plant extracts and oils (e. g. garlic oil, Capsicum oleoresin) see limited (low volume) regional use in various countries, but these are not considered here, as shown in the following Tables 1 and 2.

Table 1. Medicinal and aromatic plants, which can be used as botanical pesticides

English name	Scientific name	Family name	Arabic name	Used part(s)
Lantana	*Lantana camara* L.	Verbenaceae	اللانتانا	Leaves + flowers
Eucalyptus	*Eucalyptus globulus* Lab.	Myrtaceae	الكافور	Leaves
Lemon grass	*Cymbopogon citratus* Stapf	Gramineae	حشيشة الليمون	Leaves
Datura	*Datura stramonium* L.	Solanaceae	الداتورا	Leaves + frutis
Nerium	*Nerium oleander* L.	Apocynaceae	الدفلة	Leaves
Althea	*Althaea officinalis* L.	Malvaceae	الخطمية	Roots + leaves
Neem	*Azadirachta indica* A. Juss.	Meliaceae	النيم	Leaves + frutis
Visnaga	*Ammi visnaga* L.	Apiaceae	الخلة البلدي	Frutis
Basil	*Ocinum bacilicum* L.	Lamiaceae	الريحان	Leaves
Pipermint	*Mentha pipermita* L.	Labiatae	النعناع الفلفلي	Leaves + flower tops
Spearmint	*Mentha spicata* L.	Lamiaceae	النعناع البلدي	Leaves + flower tops
Acacia	*Acacia arabica* Lam.	Fabaceae	السنط العربي	Flowers + frutis
Capsicum	*Capsicum frutescens* L.	Solanaceae	الشطة السوداني	Frutis
Garlic	*Allium sativum* L.	Lilliaceae	الثوم	Cloves
Castor beans	*Ricinus communis* L.	Euphorbiaceae	الخروع	Frutis
Thymue	*Thymus vulgaris* L.	Lamiaceae	الزعتر	Leaves
Marjoram	Majorana hortensis L.	Lamiaceae	البردقوش	Leaves
Chamomile	*Matricaria chamomile* L.	Asteraceae	البابونج	Flwoers
Pelargonium	*Pelargonium graveolens* L'Her.	Geraniaceae	العتر	Herbs
Pomegranate	*Punica granatum* L.	Punicaceae	الرمان	Pomegranate peel
Melissa	*Melissa officinalis* L.	Lamiaceae	المليسيا	Herbs

Table 2. List of plants and their parts used for evaluation of pesticide activities in Thailand (cited from Bussaman et al. 2012a, b)

Scientific name	Family	Common name	Parts
Boesenbergia pandurata Schltr.	Zingiberaceae	Fingerroot	Rhizome
Kaempferia parviflora Wall.	Zingiberaceae	Belamcanda chinensis	Rhizome
Kaempferia pulchra (Ridl.) Ridl	Zingiberaceae	Peacock ginger, resurrection lily	Rhizome
Zingiber zerumbet (L.) Smith.	Zingiberaceae	Wild ginger, Martinique ginger	Rhizome
Zingiber officinale Roscoe.	Zingiberaceae	Ginger	Rhizome
Zingiber montanum (Koenig) Link	Zingiberaceae	Phlai, cassumunar	Rhizome
Alpinia galanga (L.) Swartz.	Zingiberaceae	Kha, galingale, galangal	Rhizome
Curcuma longa Linn.	Zingiberaceae	Turmeric	Rhizome
Curcuma xanthorrhiza Roxb.	Zingiberaceae	Curcuma	Rhizome
Cymbopogon citratus Stapf.	Gramineae	Takhrai, lemongrass	Leaf
Citrus hystrix DC.	Rutaceae	Leech lime	Leaf
Ocimum basilicum Linn.	Labiatae	Ho-ra-pa, sweet-basil, basil	Leaf
Ocimum canum Linn.	Labiatae	Hairy basil	Leaf
Ocimum sanctum Linn.	Malvaceae	Holy basil, sacred basil	Leaf
Moringa oleifera Lam.	Moringaceae	Horse radish tree	Leaf
Annona squamosa Linn.	Annonaceae	Sugar apple	Leaf
Psidium guajava Linn.	Myrtaceae	Guava	Leaf
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Red river gum, Murray red gum	Leaf
Artocarpus heterophyllus Lam.	Moraceae	Jackfruit tree	Leaf
Piper sarmentosum Roxb.	Piperaceae	Cha-plu	Leaf
Murraya paniculata (L.) Jack.	Rutaceae	Orange jessamine, satin-wood	Leaf
Melissa officinalis L.	Lamiaceae	Kitchen mint, marsh mint	Leaf
Cassia siamea (Lam.)	Fabaceae	Kassod tree, siamese senna	Leaf

Table 3 Examples of functional and/or biologically active plant ingredients (Bakkali et al. 2008)

Ingredient type/function	Examples
Antioxidants	Lycopene, resveratrol, α-carotene, β-carotene, catechins, vitamin C, vitamin E, green tea, soy isoflavones, curcumin, pomegranate extracts (anthocyanins, delphinidin, cyaniding, pelargonidin), grape seed extracts, polyphenols, essential oils, kojic acid
Anticarcinogens	Resveratrol, lycopene, green tea, genistein, pycnogenol, curcumin, lycopene, pomegranate seed oils, polypodium extracts, vitamin E, silymarin
Antiinflammatory/anti-irritant	Vitamin C, pycnogenol, oatmeal, curcumin, avenanthramides, salicylic acid, polyphenols
Natural colorants	Henna, lawsone, indigo, camomille, lycopene, crocin, carmine, anthocyanidins, carotenoids
Fragrances	Essential oils terpenes, terpenoides, aldehydes, alcohols, esters, ketones, phenols, methoxyphenols
Preservatives, antiseptics	Saponins, essential oils, benzoic/salicylic acids and derivatives, organic acids and esters, phenols, usnic acid, thymol, bacteriocins
Hydration/moisturizing	Silymarin, lipids, sterols, omega-3 fatty acids
Surfactants	Saponins, phospholipids
Thickening agents	Carrageenan, starches, carbohydrates
Skin whitening	Kojic acid, arbutin, soy proteins, aloesin, vitamin C
Anti-ageing/free radical scavenging	Lycopene, genistein, vitamin C, vitamin E, pomegranate extracts, grape seed extract, silymarin, soy proteins, anthocyanins, green tea extracts, Polypodium leucotomos extract, polyphenols, resveratrol, curcumin, pomegranate seed oils, soy isoflavones
Photo-protection	Pomegranate seed oils, genistein, green tea extracts, Polypodium leucotomos extract, polyphenols, avenanthramides

Advantages and Disadvantages of Botanical Pesticides

Advantages

1. Plants producing the above mentioned compounds are known by the farmer because most of the time they grow in the same general area
2. Often these plants also have other uses like household insect repellents or are plants with medicinal application, the rapid degradation of the active product may be convenient as it reduces the risk of residues on food.
3. Some of these products may be used shortly before harvesting.
4. Many of these products act very quickly inhibiting insect feeding even though long term they do (will?) not cause insect death.
5. Since most of these products have a stomach action and are rapidly decomposed they may be more selective to insect pests and less aggressive with natural enemies.
6. Most of these compounds are not phytotoxic.
7. Resistance to these compounds is not developed as quickly as with synthetic pesticides.

Disadvantages

1. Most of these products are not truly pesticides since many are merely insect deterrents and their effect is slow.
2. They are rapidly degraded by UV light so that their residual action is short.
3. Not all plant pesticides are less toxic to other animals than the synthetic ones.
4. They are not necessarily available season long.
5. Most of them have no established residue tolerances.
6. There are no legal registrations establishing their use.
7. Not all recommendations followed by growers have been scientifically verified.

Plant as Botanical Pesticides

a. Neem (*Azadirachta indica*)

Two types of botanical pesticides can be obtained from seeds of the Indian neem tree, Azadirachta indica (Meliaceae) (Schmutterer 1990, 2002). Neem oil, obtained by cold-pressing seeds, can be effective against soft-bodied insects and mites but is also useful in the management of phytopathogens. Apart from the physical effects of neem oil on pests and fungi, disulfides in the oil likely contribute to the bioactivity of this material (Dimetry et al. 2010; Dimetry 2012). More highly valued than neem oil are mediumpolarity extracts of the seed residue after removal of the oil, as these extracts contain the complex triterpene azadirachtin (Fig. 2.8). Neem seeds actually contain more than a dozen azadirachtin analogs, but the major form is azadirachtin and the remaining minor analogs likely contribute little to overall efficacy of the extract. Seed extracts include considerable quantities of other triterpenoids, notably salannin, nimbin, and derivatives thereof. The role of these other natural substances has been controversial (El-Sayed 1982– 1983a, b), but most evidence points to azadirachtin as the most important active principle (Isman et al. 1996). Neem seeds typically contain 0.2–0.6% azadirachtin by weight, so solvent partitions or other chemical processes are required to concentrate this active ingredient to level 10–50% seen in the technical grade material used to produce their products (Sallena 1989; Schmutterer 1990). Azadirachtin has two profound effects on insects. At the physiological level, azadirachtin blocks the synthesis and release of molting hormones (ecdysteroids) from the prothoracic gland, leading to incomplete ecdysis in immature insects. In adult female insects, a similar mechanism of action leads to sterility. In addition, azadirachtin is a potent antifeedant to many insects. The discovery of neem by western science is attributed to Schmutterer (1990), who observed that swarming desert locusts in Sudan defoliated almost all local flora except for some introduced neem trees (National Research Council 1992). Indeed, azadirachtin was first isolated based on its exceptional antifeedant activity in the desert locust, and this substance remains the most potent locust antifeedant discovered to date. Unlike pyrethrins, azadirachtin has defied total synthesis to this point. In USA, Neem rapidly became the modern paradigm for development of botanical pesticides (Weinzierl 2000).

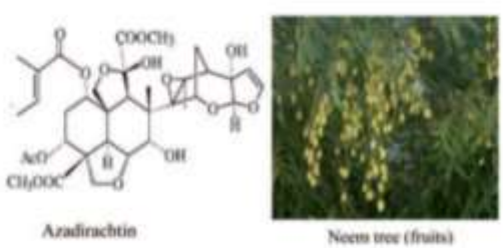

Fig. 2.8 Active constituents of neem (Azadirachtin) and neem tree

The preparation and use of botanicals requires some know-how, but not much material and infrastructures. It's a common practice under many traditional agricultural systems.

Neem contains several insecticidal compounds.The main active ingredient is azadiractin, which both deters and kills many species of caterpillars, thrips and whitefly. Both seeds and leaves can be used to prepare the neem solution.

Neem seeds contain a higher amount of neem oil, but leaves are available all year. A neem solution looses its effectiveness within about eight hours after preparation, and when exposed to direct sunlight. It is most effective to apply neem in the evening, directly after preparation, under humid conditions or when the plants and insects are damp.

Recommendations for farmers for the preparation of neem pesticides :

- In Ghana, Africa, neem seed kernel extract was tested on cabbage in farmer trainings and had a very good repelling effect on diamondback moth (Plutella xylostella).
- Pound 30 g neem kernels (that is the seed of which the seed coat has been removed) and mix it in 1 litre of water.Leave overnight. The next morning, filter the solution through a fine cloth and use it immediately for spraying. It should not be further diluted.
- Neem cake (ground neem seed or neem kernel powder) has also a considerable potential as a fertilizer and at the same time it will hinder nematode attacks of the crop roots (e.g. tomato). Put neem cake in the planting pit (200 g per m2) and mix it with substrate. The neem cake will repel and even kill nematodes and other root pests.

  Insecticidal agents (azadirachtin) will be translocated to above-ground parts of the plant and help to get rid of pests there.

b. Melia Extracts

The remarkable bioactivity of azadirachtin from the Indian neem tree (*Azadirachta indica)* led to the search for natural pesticides in the most closely related genus, Melia. Seeds from the chinaberry tree, *Melia azedarach*, contain a number of triterpenoids, the meliacarpins (Fig. 11), that are similar but not identical to the azadirachtins, and these also have insect growth regulating bioactivities (Kraus 2002). But in spite of the abundance of chinaberry trees in Asia and other tropical and subtropical areas to which they were introduced, development of commercial pesticides has not paralleled that of the neem pesticides. The main reason is the presence, in chinaberry seeds, of additional triterpenoids, the meliatoxins, that have demonstrated toxicity to mammals (Ascher et al. 2002). However the chemistry of chinaberry varies considerably across its natural and introduced range, and seeds of *M. azedarach* growing in Argentina lack meliatoxins but produce triterpenoids (most notably meliartenin) that are strong feeding deterrents to insect pests and could prove useful for pest management (Carpinella et al. 2003). Similar results have been obtained from South Africa using aqueous extracts of chinaberry leaves, presumably lacking meliatoxins but efficacious against the diamondback moth (Charleston 2004). In the early 1990s a botanical insecticide produced in China was based on an extract of bark of Melia toosendan, a tree considered by most taxonomists to be synonymous with M. azedarach. The extract contains a number of triterpenoids based on toosendanin (Fig. 2.9), a substance reported to be a stomach poison for chewing insects (Chiu 1988)

Fig. 2.9 Active constituents of some botanical insecticides (toosendanin)

Later studies suggest that this substance acts primarily as a feeding deterrent but can also serve as a synergist for conventional insecticides (Chen et al. 1995; Feng et al. 1995). Although relatively nontoxic to mammals, it is unclear whether this material remains in production or whether it is sufficiently efficacious as a stand-alone crop protectant. When M. toosendan came under scientific scrutiny, investigation of the east African M. volkensii demonstrated bioactivity in insects from seed extracts of this species. The active principles in M. volkensii include the triterpenoid salannin, also a major constituent of neem seed extracts, and some novel triterpenoids such as volkensin (Fig. 13). Collectively these function as feeding deterrents and stomach poisons with moderate efficacy against chewing insects and as a mosquito larvicide. Although a standardized seed extract has been made in quantities sufficient for research (Rembold and Mwangi

2002), commercial production appears unlikely owing to a lack of infrastructure for harvesting seeds in addition to regulatory impediments (Weinzierl 2000; Isman 2006).

Mode of Action Neem products are complex mixtures of biologically active materials, and they are difficult to pinpoint the exact modes of action of various extracts or preparations. In insects, neem is most active as a feeding deterrent, but in various forms it also serves as a repellent, growth regulator, oviposition (egg deposition) suppressant, sterilant, or toxin. As a repellent, neem prevents insects from initiating feeding. As a feeding deterrent, it causes insects to stop feeding. As a feeding, either immediately after the first “taste” (due to the presence of deterrent taste factors) (Salama and Sharaby 1988), or at some point soon after ingesting the food (due to secondary hormonal or physiological effects of the deterrent substance). As a growth regulator, neem is thought to disrupt normal development interfering with chitin synthesis. Susceptibility to the various effects of neem differs by species

c. Annonaceous (Acetogenins)

Botanical pesticides have been traditionally prepared from the seeds of tropical Annona species, members of the cus tard apple family (Annonaceae). These include the sweetsop (A. squamosa) and soursop (A. muricata), important sources of fruit juices in Southeast Asia. Detailed investigations in the 1980s led to the isolation of a number of long-chain fatty acid derivatives, termed acetogenins, responsible for the insecticidal bioactivity. The major acetogenin obtained from seeds of A. squamosa is annonin I, or squamocin, and a similar compound, asimicin (Fig. 2.10), was isolated from the bark of the American pawpaw tree, Asimina triloba (McLaughlin et al. 1997; Johnson et al. 2000). Mikolajczak et al. (1988) hold a US patent on insecticides ased on acetogenins from A. triloba; Bayer AG (Germany) holds a similar patent based on Annona acetogenins for Moeschler et al. (1987). These compounds are slow acting stomach poisons, particularly effective against chewing insects such as lepidopterans and the Colorado potato beetle (Leptinotarsa decemlineata). Further investigations revealed that the acetogenins have a mode of action identical to that of rotenone, i. e., they block energy production in mitochondria in both insects and mammals (Londershausen et al. 1991). In purity certain acetogenins are toxic to mammals (LD50 is

(Nature’s Sunshine Products, Inc., United States). Annona seed extracts may prove more useful in tropical countries where the fruits are commonly consumed or used to produce fruit juice, in which case the seeds are a waste product. For example, Leatemia and

Isman (2004a, b) recently demonstrated that crude ethanolic extracts or even aqueous extracts of seeds from A. squamosa collected at several sites in eastern Indonesia are effective against the diamondback moth (Plutella xylostella) (Isman 2006).

The Insecticidal Mode of Action of Asimicin It reduced the rate of oxygen consumption by fourth instar Ostrinia nubilalis as measured with a constant volume manometer. Further examination of the respiratory effect of asimicin was carried out on mitochondria isolated from the midguts of fifth instar O. nubilalis and in which O2 was measured polarographically. The results of these studies indicate a significant reduction in state 3 respiration using malate and pyruvate as substrate, caused by asimicin (concentration for 50% inhibition = 0.55 nmol/mg protein) (Lewis et al. 1993)

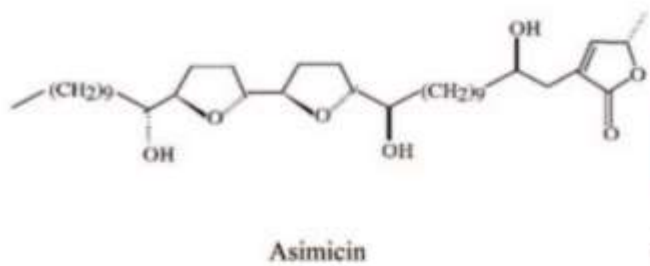

Fig. 2.10 Active constituents of Annona species (asimicin) and Annona squamosa plant

d. Pyrethrum

Pyrethrum is a daisy-like Chrysanthemum. In the tropics, pyrethrum is grown in mountain areas because it needs cool temperatures to develop its flowers. Pyrethrins are insecticidal chemicals extracted from the dried pyrethrum flower. The flower heads are processed into a powder to make a dust. This dust can be used directly or infused into water to make a spray. Pyrethrins cause immediate paralysis to most insects. Low doses do not kill but have a 'knock down' effect. Stronger doses kill. Pyrethrins break down very quickly in sunlight so they should be stored in darkness. Both highly alkaline and highly acid conditions speed up degradation so pyrethrins should not be mixed with lime or soap solutions.

Recommendations for farmers for the preparation of Pyrethrum pesticides:

- Pyrethrum powder is made with dried ground flowers. Use pure or mix with a carrier such as talc, lime or diatomaceous earth and sprinkle over infested plants.

- To make liquid pyrethrum extract (mix 20 g pyrethrum powder with 10 litres water), add organic soap to make the substance more effective.
- Strain and apply immediately as a spray. For best effects this should be applied in the evening.Pyrethrum can also be extracted by alcohol.

e. Chillipepper

Chillies and capsicum pepper have both repellent and insecticidal effects. Recommendations for the farmers for the preparation of chilli pesticides.

- To make the chilli extract grind 200 g of chillies into a fine dust. Mix it in 4 litres water.
- Add another 4 litres of water and a few drops of liquid organic soap.This mixture can be sprayed against aphids, ants, small caterpillars and snail

f. Garlic

Garlic has antifeedant (insect stop feeding), insecticidal, nematicidal and repellent properties. Garlic is reportedly effective against a wide range of insects at different stages in their life cycle (egg, larvae, adult). This includes ants, aphids, armyworms, diamondback moth, whitefly, wireworm and termites.

Garlic is non-selective, has a broad-spectrum effect and can kill beneficial insects as well. Therefore, it should be used with caution. Recommendations for farmers for the preparation of garlic pesticides.

- Grind or chop 100 grams garlic into 0.5 litre water. Allow mixture to stand for 24 hours. Add 0.5 litre of water and stir in liquid soap. Dilute at 1:20 with water and spray in the evening.
- To improve efficacy, chilli extract can be added.

g. Other extracts of plants

There are many other extracts of plants known to have insecticidal effects like tobacco (*Nicotiana tabacum),* yellow root (*Xanthorhiza simplicissima*), fish bean (*Tephrosia vogelii*), anise, chillies, chives, garlic, coriander, nasturtium, spearmint and marigold are plants known to have a repellent effect on different pest insects (aphids, moths, root flies, etc.) and can be grown as intercrop or at the border of crop fields.Marigold is especially known to deter root nematodes, while neem cake is known to deter mice.

h. Plant Essential Oils

Steam distillation of aromatic plants yields essential oils, long used as fragrances and flavorings in the perfume and food industries, respectively, and more recently for aromatherapy and as herbal medicines (Salama et al. 1970; Sharaby 1988; Coppen 1995; Abd El-Aziz and Sharaby 1997; Abd El-Aziz and El-Hawary 1997; Buckle 2003). Plant essential oils are produced commercially from several botanical sources, many of which are members of the mint family (Lamiaceae). The oils are generally composed of complex mixtures of monoterpenes, biogenetically related phenols, and sesquiterpenes. Examples include 1,8-cineole, the major constituent of oils from rosemary (Rosmarinus officinale) and eucalyptus (Eucalyptus globus); eugenol from clove oil (Syzygium aromaticum); thymol from garden thyme (Thymus vulgaris); and menthol from various species of mint (Mentha species) (Isman 1999) (Fig. 2.11). A number of the source plants have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in southern Asia, but interest in the oils was renewed with emerging demonstration of their fumigant and contact insecticidal activities to a wide range of pests (Abdallah et al. 2004). The rapid action against some pests is indicative of a neurotoxic mode of action, and there is evidence for interference with the neuromodulator octopamine (Enan 2001; Kostyukovsky et al. 2002) by some oils and with GABA-gated chloride channels by others (Priestley et al. 2003; El-Hosary 2011). Some of the purified terpenoid constituents of essential oils are moderately toxic to mammals, but, with few exceptions, other oils had molluscicidal effects for snails (Hussein 2005; Abdelgaleil 2010). The oils themselves or products based on oils are mostly nontoxic to mammals, birds, and fish (Stroh et al. 1998; Isman 2000, 2006). However, as broad-spectrum pesticides, both pollinators and natural enemies are vulnerable to poisoning by products based on essential oils. Owing to their volatility, essential oils have limited persistence under field conditions; therefore, although natural enemies are susceptible via direct contact, predators and parasitoids reinvading a treated crop one or more days after treatment are unlikely to be poisoned by residue contact with pesticides (Dimetry et al. 1993; Ismail et al. 2004; El-Sebai et al. 2005). In the United States, commercial development of pesticides based on plant essential oils has been greatly facilitated by exemption from registration for certain oils commonly used in processed foods and beverages (Quarles 1996). This opportunity has spurred the development of essential oil-based insecticides, fungicides, and herbicides for agricultural and industrial applications and for the consumer market, using rosemary oil, clove oil, and thyme oil as active ingredients. Interest in these products has been considerable, particularly for control of greenhouse pests and diseases and for control of domestic and veterinary pests, with several private companies (e.g. EcoSMART Technologies, Inc., United States) moving toward or into the market place (Khater 2012). Another factor favoring development of botanical pesticides based on plant essential oils is the relatively low cost of the active ingredients, a result of their extensive worldwide use as fragrances and flavorings. In contrast, pyrethrum and neem are used primarily for pesticide production (Khater 2012). On the other hand, plant oils have harmless effects on the predacious mites as reported by Amer and Momen (2002, 2005), who studied effects of some essential oils on Amblyseius swirskii. Mode of Action Contact and fumigant insecticidal actions of plant essential oils have been well demonstrated against stored product pests (Acanthoscelides obtectus) (RegnaultRoger et al. 1993). Knockdown activity and lethal toxicity via contact has been demonstrated in the American cockroach (Periplaneta americana) (Ngoh et al. 1998), the German cockroach (Blattella germanica) and the housefly (Musca domestica) (Coats et al. 1991; Rice and Coats 1994). These studies latter pointed to an obvious neurotoxic siteof-action. Certain essential oil monoterpenes are competitive inhibitors of acetylcholinesterase in vitro (Grundy and Still 1985; Miyazawa et al. 1997), but this action may not be correlated with toxicity to insects in vivo. However, systematic investigation of the antifungal activities of essential oils and their constituents predate those of the pesticidal properties (Kurita et al. 1981). El-Hawary and Sammour (2006) studied the bioactivity and mechanism of action of some wild plant extracts on Aphis craccivora. As well Adel et al. (2010) have several studies on physiological, biochemical and histopathological effects of Artemisia monosperma against the cotton leafworm, Spodoptera littoralis in Egypt. Sammour et al. (2011) had comparative studies on the efficacy of neemix and basil oil formulations on the cowpea aphid Aphis craccivora in laboratory in Egypt. On the other side, Dimetry and ElHawary (1997) conducted some experiments to enhance the synergistic effects of some additives on the biological activity and toxicity of Nem-based formulations against cowpea aphids. The modes of action of limonene and linalool in insects are not fully understood. Limonene is thought to cause an increase in the spontaneous activity of sensory nerves. This heightened activity sends spurious information to motor nerves and results in twitching, lack of coordination, and convulsions. The central nervous system may also be affected, resulting in additional stimulation of motor nerves. Massive over stimulation of motor nerves leads to rapid knockdown paralysis. Adult fleas and other insects may recover from knockdown, however, unless limonene is synergized by PBO. Linalool is also synergized by PBO. Little has been published regarding the mode of action of linalool in insects (Abdelgaleil and El-Aswad 2005; Abdelgaleil et al. 2008; Rattan 2010).

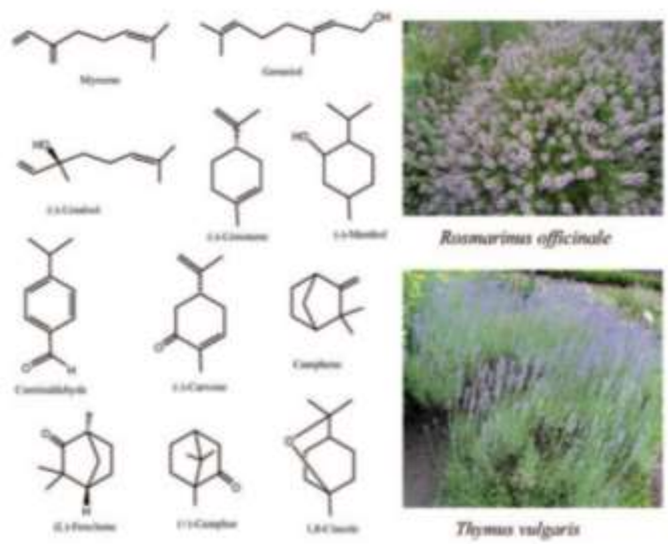

Fig. 2.11 The chemical structures of monoterpenes and Rosmarinus and Thymus plants

Precautions to farmers regarding use of plant extracts. Despite being 'natural' and widely used in agricultural systems, some botanicals may be dangerous for humans and they can be very toxic to natural enemies. Nicotine for example, derived from the tobacco plant, is one of the most toxic organic poisons for humans and other warm-blooded animals. Pyrethrins are not poisonous for humans and warm-blooded animals. However, human allergic reactions are common. It can cause a rash, and breathing the dust can cause headaches and sickness.

Before a new botanical pesticide is applied in a large scale, its effect on the ecosystem should be tested in a small field experiment. Do not just use botanical pesticides as a default option! First understand the ecosystem and how botanicals influence it! Do not have direct skin contact with the crude extract during the process of preparation and application. Contact with plant extracts should be avoided in the eyes. Make sure that you place the plant extract out of reach of children during storage. Wear protective clothing (eyes, mouth, nose and skin) while applying the extract. Wash your hands after handling the plant extract.

Summary of Different Mode of Actions

a. Antifeedant

Botanical pesticides can be grouped according to their mode of action or the way a pesticide destroys or controls the target pest. This is also referred to the primary site of action. For example, one insecticide may affect insect nerves, while another may affect moulting. There are many mode of actions for various botanical pesticides shown in Table 4. Efficiency of Botanical Pesticides on Pests Antifeedants The possibility of using nontoxic deterrents and repellents as crop protectants is intuitively attractive. The concept of using insect antifeedants (= feeding deterrents) gained strength in the 1970s and 1980s with the demonstration of the potent feeding deterrent effect of azadirachtin and neem seed extracts to a large number of pest species. Indeed, considerable literature, scientific and otherwise, touts neem as a successful demonstration of the antifeedant concept. In reality, it is the physiological actions of azadirachtin that appear most reliably linked to field efficacy of neem pesticides (Immaraju 1998); although purely behavioral effects cannot be ruled out, there is hardly any irrefutable evidence or documentation of field efficacy based on the antifeedant effects of neem alone. The antifeedant index (AFI) is calculated from the formula:

$AFI = [(C-T)/(C+T)] \times 100$ (in %)

Where:

C Consumption of control,

T Consumption of treated disks (Pavela et al. 2008)

Table 4.Mechanism of action of pesticides of plant origin (modified from Rattan 2010)

System	Mechanism of action	Compound	Plant source	References
Cholinergic system	Inhibition of acetylecholinestrase (AChE)	Essential oils	*Azadirachtina indica*, *Mentha* spp., *Lavendula* spp.	Grundy and Still (1985); Ryan and Byrne (1988); Miyazawa et al. (1997); Keane and Ryan (1999)
	Cholinergic acetylcholine nicotinic receptor Agonist/antagonist	Nicotine	*Nicotiana* spp., *Haloxylon salicornicum*, *Stemona Japonicum*	Richards and Cutkomp (1945); Kukel and Jennings (1994)
GABA system	GABA-gated chloride channel	Thymol, Silphinenes	*Thymus vulgaris*	Ratra and Casida (2001); Priestley et al. (2003); Bloomquist et al. (2008)
Mitochondrial system	Sodium and potassium ion exchange disruption	Pyrethrin	*Crysanthemum cinerariaefolium*	Casida (1973)
	Inhibitor of cellular respiration(mitochondrial complex I electron transport inhibitor (METI)	Rotenone	*Lonchocarpus* spp.	Yamamoto and Kurokawa (1970); Ware (1988); Khambay et al. (2003)
	Affect calcium channels	Ryanodine	*Ryania* spp.	Copping and Menn (2000)
	Affect nerve cell membrane action	Sabadilla	*Schoenocaulon officinale*	Bloomquist (1996, 2003)
Octopaminergic system	Octopaminergic receptors	Essential oils	*Cedrus* spp., *Pinus* spp., *Citronella* spp., *Eucalyptus* spp.	Nathanson et al. (1993); Kostyukovsky et al. (2002); Enan (2005a)
	Block octopamine receptors by working through tyramine receptors cascade	Thymol	*Thymus vulgaris*	Enan (2005a, b)
Miscellaneous	Hormonal balance disruption	Azadirachtin	*Azadiractina indica*	Copping and Menn (2000)

As an academic exercise, the discovery and demonstration of plant natural products as insect antifeedants has been unquestionably successful. In addition to the neem triterpenoids, extensive work has been performed on clerodane diterpenes from the Lamiaceae (Klein Gebbinck et al. 2002) and sesquiterpene lactones from the Asteraceae (GonzalezColoma et al. 2002). On the other hand, not a single crop protection product based unequivocally on feeding or oviposition deterrence has been commercialized. Two main problems face the use of antifeedants in agriculture (Isman 2002). The first is interspecific variation in response even closely related species can differ dramatically in behavioral responses to a substance limiting the range of pests affected by a particular antifeedant (Isman 1993). Some substances that deter feeding by one pest can even serve as attractants or stimulants for other pests. The second is the behavioral plasticity in insects pests can rapidly habituate to feeding deterrents, rendering them ineffective in a matter of hours. This has been recently demonstrated not only for pure substances like azadirachtin (Bomford and Isman 1996), but also for complex mixtures (plant extracts) (Akhtar et al. 2003). Whereas a highly mobile insect may leave a plant upon first encountering an antifeedant, a less mobile one (larva) may remain on the plant long enough for the deterrent response to wane. Such behavioral changes are important in light of the observation that some plant substances are initially feeding deterrents but lack toxicity if ingested. Azadirachtin is an exception to this rule, as ingestion leads to deleterious physiological consequences, but other compounds with demonstrated antifeedant effects lack toxicity when administered topically (Bernays 1990, 1991).

b. Repellents

For many chemists, an effective alternative to DEET (N, N-diethyl-m-toluamide) for personal protection against mosquitoes and biting flies is the holy grail. In spite of five decades of research, no chemical has been found that provides the degree of protection against biting mosquitoes or persistence on human skin afforded by DEET (Peterson and Coats 2001). Concerns with the safety of DEET, especially to children, have resulted in the introduction of several plant oils as natural alternatives. Some personal repellents in the US marketplace contain oils of citronella, eucalyptus, or cedar wood as active ingredients; 2-phenethylpropionate, a constituent of peanut oil, and p-menthane-3,8-diol (obtained from a particular species of mint) (Fig. 8) are also used in consumer products. All of these materials can provide some protection, but the duration of their effect can be limited (often < 1 h) (Fradin and Day 2002). In tropical areas where mosquito-borne disease is a threat (e.g., yellow fever, dengue, malaria), DEET probably remains the only reliable repellent. Oil of citronella or the constituent citronellal (Fig. 8) is also used in mosquito coils to repel mosquitoes from outdoor areas. Several veterinary products for flea and tick control on domestic pets contain d-limonene (from citrus peels; Fig. 8) as the active ingredient. Other uses for repellents under investigation include perimeter treatments of buildings to exclude termites and the use of essential oils to repel cockroaches from kitchens and flies from dairy barns (Maistrello et al. 2004). Another important use of plant essential oil constituents is in fumigation of beehives to manage economically important honey bee parasites, the Varroa mite (Varroa jacobsoni). In USA, menthol is widely used for this purpose (Delaplane 1992) and in Europe thymol is most used (Floris et al. 2004). Abdel-Khalek et al. (2010) studied repellency and toxicity of extract from Francoeria crispa to Eutetranychus orientalis.

c. Toxicity of Botanical Pesticides

The botanical pesticides are biodegradable and harmless to the environment. Furthermore, unlike conventional pesticides that are based on a single active ingredient, plantderived pesticides comprise an array of chemical compounds which act concertedly on both behavioral and physiological processes. One plant species may possess substances with a wide range of activities; for example, extracts from the neem tree Azadirachta indica are antifeedant, antioviposition, repellent and growth-regulating. In contrast, the toxicity of conventional synthetic insecticides is mainly restricted to neuro-muscular function (Ware 1983). Conventional synthetic insecticides require special safety procedures and equipment during production and application because of the exposure risks for humans, the environment (Schmutterer 1990; Childs et al. 2001).

Summary of Botanicals Used to Control Different Insect Pests

Summary of different botanical pesticides and their effects on various insect pests is appeared in Table 5.

Table 5. Botanical pesticides used to control different insect pests

Botanical pesticides	Insect pests	References
Nicotine	Aphids, thrips, caterpillars	Casanova et al. (2002)
Rotenone	Bugs, aphids, potato beetles, spider mites, carpenter ants	Cabras et al. (2002); Cabizza et al. (2004)
Ryania	Codling moths, potato aphids, onion thrips, corn earworms, silkworms	Copping and Menn (2000); Isman (2006)
Sabadilla	Grasshoppers, codling moths, armyworms, aphids, cabbage loopers, squash bugs	Bloomquist (1996, 2003)
Pyrethrum	Caterpillars, aphids, leafhoppers, spider mites, bugs, cabbage worms, beetles	Casida (1973); Glynne-Jones (2001)
Essential oils	Caterpillars, cabbage worms, aphids, white flies Land sanils	Enan (2005a, b); Abdelgaleil (2010)
Neem products	Armyworms, cutworms, stemborers, bollworms, leaf miners, caterpillars, aphids, whiteflies, leafhoppers, psyllids, scales, mites and thrips	Dimetry et al. (1993, 2010)
Synthetic pyrethroids	Caterpillars, aphids, thrips	Coats (1990); Sallam et al. (2009)

Besides extractions of plants, there are some other natural pesticides, which are allowed in organic farming. Although some of these products have limited selectivity and are not fully biodegradable, there are situations, when their use is justified. However, in most cases, the desired effect is best reached in combination with preventive crop protection methods. Below are some examples:

- Soft soap solutions against aphids and other sucking insects.
- Light mineral oil against various insect pests (harms natural enemies!).
- Sulphur against spider mites (harms natural enemies!). Sulphur should not be used together or after treatments with oil to avoid phytotoxicity
- Plant ashes

  Wood ashes from fire places can be efficient against ants, leaf miners, stem borers, termites and potato moths. Ash should be dusted directly on pest colonies and infested plant parts. The ash will dehydrate the soft bodied pests. Wood ashes are often used when storing grains to deter storage pests such as weevils. In addition, ashes are used against soil born.

- Liquid smoke or wood vinegar, is a result of condensation or condensation from direct or indirect combustion vapors from materials containing carbon compounds. Raw materials for making liquid smoke, in general, are various types of organic waste such as wood, twigs, leaves, coconut shell, rice husk, corn cob, straw, and so on. During the combustion process, the liquid smoke raw material will produce compounds including phenol, carbonyl, acids, furans, alcohols, lactones, hydrocarbons and so on. Liquid smoke has functional properties such as to give flavor and color and natural preservatives because they contain phenol and acid compounds which act as antibacterial and antioxidants, as a latex substitute for formic acid and help the formation of brown color in sit products.

Figure 2.8 : Pirolisator

Liquid smoke can be called biopesticides or biological pesticides, in the agricultural industry, it functions effectively to control pests without causing explosion or phytotoxicity of plants. It's environmentally friendly and free of harmful chemicals that make liquid smoke or biopesticides become one of the products recommended by the Indonesian Ministry of Agriculture for use in the agricultural industry because its usefulness is considered to be able to increase food production in a sustainable manner.

2.4.4.2 Types Of Pesticides

Pesticides used to control field crop pests are applied either to the soil or to the plant foliage.

a. Soil-applied pesticides

   Chemigation—applying a pesticide or fertilizer to the soil by injecting it into the irrigation system.

   Insecticides—applied to prevent insect damage to the roots of corn and other crops. Insecticides can be applied by broadcast soil applications and soil incorporation before planting, applied in the seed furrow at planting, or broadcast before or after crop emergence.

   Herbicides—applied to the soil surface and mixed into the soil before planting (preplant incorporated) or applied after planting but before crop emergence and not incorporated (preemergence).

   Soil fumigants or nematicides—applied to the soil to control nematodes.

b. Foliar-applied pesticides Most foliar applications are broadcast liquid pesticides applied directly to the crop or pest. They can be applied before damage occurs (preventive) or in response to damage (curative).

   Insecticides—generally applied to control insects feeding aboveground on the crop. *Herbicides*—applied to the weed foliage after the crop and weeds have emerged (postemergence).

   Fungicides—can be applied to the crop before the disease appears (protectant) or to remove the disease after it appears (eradicant).

The following are special considerations to remember when using a pesticide to control your pest problem:

a. Preharvest interval—the minimum number of days needed between the last pesticide application and harvest. The Environmental Protection Agency (EPA) requires that all pesticide labels state the preharvest intervals for each crop. The preharvest interval is based partly on how long it takes the pesticide to break down. Observing the preharvest interval reduces pesticide residue on the commodity.
b. Residues—the pesticide that remains on the crop after an application. Ideally, a pesticide is present only long enough to kill the pest and then breaks down. Unfortunately, many pesticides do not break down completely before harvest. Therefore, for each pesticide registered for use on a food or feed crop, the EPA sets the amount of acceptable residue (tolerance) permitted on the harvested crop. The

amount of residue relates to the preharvest interval and the pesticide application rate. Harvesting a crop during the preharvest interval or applying more pesticide than the label stipulates increases the potential for residues to exceed legal tolerance levels.

c. Reentry interval (REI)—the amount of time required after a pesticide application before a person can reenter a field without personal protective equipment (PPE). The reentry interval prevents unnecessary pesticide exposure. Only workers trained for early entry under the Worker Protection Standards (WPS) and wearing proper PPE may enter a treated area during the reentry interval. Refer to the Worker Protection Standards (WPS) for the regulations on informing workers about pesticide applications.

d. Phytotoxicity—when a pesticide damages the crop to which it is applied. Pesticide drift, excessive rates, mixing incompatible pesticides, and improper calibration can all cause phytotoxicity. Weather conditions can increase the degree of damage caused by phytotoxicity. For example, cooler weather followed by a period of bright, hot, dry weather can increase the likelihood of plant damage. Even using pesticides in accordance with the label can result in some phytotoxicity. Applying pesticides within recommended rates and following label instructions for mixing and applying help avoid this problem.

e. Pesticide resistance—the genetically acquired ability of an organism to tolerate the toxic effects of a pesticide (for example, malathion-resistant Indian mealmoths, atrazine-resistant common lambsquarter, and ALS-resistant ragweed). Resistance develops from overuse of the same pesticide or from overuse of a class of pesticides with a common mode of action.

f. Insecticide-induced resurgence

   The rapid expansion of pest populations following a pesticide application resulting from pest populations being "released" from the population-control mechanism of predation by beneficial insects and spiders killed by pesticide exposure.

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