Alternatives of Pesticides

Laila Hossain, Rizwanur Rahman, and Mohidus Samad Khan

1 Introduction

Pesticides are widely used in agriculture to control insects, microorganisms, fungi, weeds and other pests. The control of these pests serves to increase crop yield and to decrease manual labor [1]. However, majority of chemical pesticides pose long term danger to the environment and humans through their persistence in nature or in body tissues. Because of the health and environmental hazards, worldwide pest management is facing economic and ecological challenges [2]. To overcome these challenges, regulatory actions have been taken by regulatory and environmental protection agencies of different nations, and synthetic chemical pesticides are being replaced by 'organic' chemicals, such as: biopesticides, which pose lower or no risk to the environment and human health. However, lack of efficacy, inconsistent field performance and high production cost have been relegated them to niche products. Often, the cost of fermentation of microbes is higher than the cost of making a synthetic chemical. It is also required huge funds for research and to develop new products, or to improve existing products.

Biopesticides are often specific to different species of pests; hence, farmers may need to have different biopesticide products to control multiple species of pests. Bioactive products also tend to have shorter shelf lives and are degraded rapidly in sunlight [3]. To use biopesticides effectively, growers need to know a great deal about the lifecycle of the pests or pathogens they are trying to control. Farmers also need to understand the timing and appropriate conditions for application of the biopesticide products. Therefore, it is important to provide sufficient training and protocols to help growers to adopt the broad-spectrum agrochemicals.

In addition to biopesticides options, different cultural societies have adapted and implemented different alternative techniques, such as: cultural tactics, physical,

L. Hossain • R. Rahman • M.S. Khan (✉)
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh
e-mail: mohid@che.buet.ac.bd

M.S. Khan, M.S. Rahman (eds.), *Pesticide Residue in Foods*,
DOI 10.1007/978-3-319-52683-6_9

mechanical and biological tactics, behavioral control tactic using semiochemicals and transgenic crops to address and minimize issues pertaining to pesticides [4]. Cultural control involves regular farm operations and does not require the use of specialized equipment or additional skills. Often, they are considered as the best methods to reduce pests since they combine effectiveness with minimal additional labor and cost [5]. Maintaining optimal growth conditions, altering sowing season and sowing method, reaping secondary host plants, intercropping, crop rotation, and crop sanitation are some common techniques of cultural control method [4, 5]. Preventive, corrective physical and mechanical methods differ from cultural methods since they are intended specifically to control pests and their effectiveness is regarded with temperature, heat, radiation and untrasonic vibrations [6]. Through the actions of living organisms, such as: predators, parasites and pathogens, the reproductive potential of a specific pest organism can be suppressed [4, 6]. Botanical pesticides are extracted from plants and are used as alternatives of synthetic pesticides showing lesser toxicity to humans [2]. To control the pests in most effective way, nowadays, multiple pest control methods are adapted contemporarily. This combined pest controlling method is known as Integrated Pest Management (IPM). IPM involves the selection, integration, and implementation of pest control based on predicted economic, ecological and sociological consequences including weather, disease organisms, predators and parasites [7].

In this chapter, different alternatives of pesticides and pest management techniques are discussed. The basic features of alternative plant protection tactics and their integration are also outlined. The market statistics of biopesticides and their universal consumption information are also illustrated.

2 Global Pesticide Consumption and Pollution

Since the 1990s, the global pesticide sale remained relatively constant, between 270 and 300 billion dollars, of which 47% were herbicides, 79% were insecticides, 19% were fungicides/bactericides, and 5% the others [8]. Over the period of 2007–2008, herbicides were ranked first among three major categories of pesticides (insecticides, fungicides/bactericides, herbicides). Use of fungicides/bactericides was increased rapidly and ranked second [8]. Europe is now the largest pesticide consumer in the world, and Asia is ranked second under this category. As for the countries, China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world [8].

2.1 World Pesticide Trade

Table 1 represents the recent data of pesticide import and export of different major countries [9]. From Table 1 it can be seen that import and export of France, Germany and China are significantly high. Pesticides exported from the United States,

Table 1 Import/export of pesticides of some major countries in recent years [9]

Country	Category	Import (US$Million)				Export (US$Million)			
		2003	2004	2005	2006	2003	2004	2005	2006
USA	Insecticides	96.95	124.74	128.63	117.25	431.47	501.80	373.46	468.55
	Fungicides	179.53	236.76	244.23	152.30	220.98	274.67	258.39	286.20
	Herbicides	310.73	304.71	282.87	298.06	13.68	16.02	22.31	21.86
	Disinfectants	43.25	46.54	45.03	55.70	157.94	167.47	152.18	168.29
Germany	Insecticides	91.35	91.88	100.06	85.38	270.77	286.10	289.01	339.15
	Fungicides	240.26	243.19	335.76	309.14	595.34	738.60	737.90	745.52
	Herbicides	275.64	359.26	417.92	436.31	614.29	434.82	507.69	833.75
	Disinfectants	105.52	145.99	146.56	144.54	325.17	363.04	373.49	436.89
France	Insecticides	268.21	294.94	288.45	262.50	397.70	536.94	492.16	416.59
	Fungicides	571.39	590.38	712.55	459.20	554.13	767.75	885.30	779.65
	Herbicides	482.94	682.20	657.92	595.42	827.63	1225.87	1069.50	1144.22
	Disinfectants	104.25	111.02	115.22	145.20	79.04	103.27	119.89	137.15
China	Insecticides	102.44	104.37	116.97	123.47	294.26	481.71	533.54	377.60
	Fungicides	90.09	99.84	104.42	117.96	149.86	228.14	275.27	147.99
	Herbicides	77.48	78.71	104.15	120.98	361.74	553.63	668.26	597.05
	Disinfectants	32.55	27.07	36.27	38.30	14.63	13.68	14.38	13.55
Japan	Insecticides	54.98	59.25	86.15	95.66	107.27	116.78	118.85	136.72
	Fungicides	95.37	99.19	90.83	91.85	74.21	78.39	78.06	72.61
	Herbicides	82.30	98.12	109.46	117.62	74.29	86.32	96.91	91.91
	Disinfectants	10.39	9.64	9.64	9.46	13.27	16.24	15.53	13.69
Thailand	Insecticides	57.79	61.98	70.77	100.54	23.23	17.59	18.33	28.56
	Fungicides	39.24	40.43	38.99	48.20	3.19	2.32	2.74	7.61
	Herbicides	126.17	132.59	128.11	169.73	7.53	3.25	2.56	7.00
	Disinfectants	18.98	22.89	25.03	25.86	13.17	14.16	17.74	23.16

(continued)

Table 1 (continued)

Country	Category	Import (US$Million)				Export (US$Million)			
		2003	2004	2005	2006	2003	2004	2005	2006
Vietnam	Insecticides	62.96	76.70	87.33	123.19	6.32	9.51	10.51	17.49
	Fungicides	53.10	66.06	81.01	96.24	0.76	0.22	0.49	1.30
	Herbicides	47.39	64.98	65.87	70.71	2.53	4.64	8.00	8.67
	Disinfectants	23.71	19.77	20.29	29.08	0.42	0.65	0.43	1.15
Australia	Insecticides	29.91	54.47	66.40	66.46	33.29	23.36	25.67	18.74
	Fungicides	39.75	41.73	54.38	53.76	7.04	9.65	10.88	13.80
	Herbicides	92.65	129.82	132.37	133.88	22.91	32.35	29.36	25.25
	Disinfectants	34.09	39.10	30.89	30.17	9.26	8.51	6.25	8.53
South Africa	Insecticides	51.72	68.80	65.32	67.86	35.53	36.58	42.08	48.43
	Fungicides	24.83	31.24	31.82	37.95	13.68	16.02	22.31	21.86
	Herbicides	43.25	46.54	45.03	55.70	77.31	94.81	70.73	51.13
	Disinfectants	6.52	7.08	8.23	8.82	7.10	6.13	8.02	10.18

Germany, France and China was greatly higher than its import from 2003 to 2006. In 2006 the import (export) of herbicides of the United States made up 45.4% (51.6%) of its total import (export) [8]. Germany is the largest producer of pesticide in Europe. France is the largest pesticide consumer in Europe followed by Germany. Other major pesticides consumer in Europe includes Italy, Spain and UK. In 2008, France announced it would voluntarily cut pesticide use by 50% by 2018, and emerged as the European leader in reducing pesticide dependency [10]. According to data from Ministry of Agriculture of China, from 1991 to 2005, consumption of pesticides has been increased around 50% [8]. To increase food production and to reduce agricultural workload, the use of pesticides has rapidly increased in Japan since the end of World War II. Japan's pesticide export to China and Southeast Asian countries is continuously increasing [8]. From the table it can be seen that pesticide import of Thailand and Vietnam was greatly higher than its export from 2003 to 2006. Australia's pesticide import is greatly larger than pesticide export. Of the pesticides imported, the products from China are quickly increasing, including glyphosate, paraquat and glufosinate-ammonium. About 10% of glyphosate are from China [8]. Endosulfan from China is the major cotton insecticide and acaricide in Australia [8]. Pesticide consumption of Africa accounts for about 3% of the world, of which South Africa makes up 2% of pesticide consumption of the world [8]. As the development of Africa's agriculture, pesticide production of South Africa is expected to grow rapidly in the future. South Africa's pesticide import is larger than export. Herbicides accounted for 40% of the total import in 2006.

2.2 Pesticide Hazard: Global Aspect

Pesticides are associated with adverse impacts on human health and the environment that have arisen as a result of inappropriate use and handling of pesticides by inadequately trained farmworkers. Agricultural workers are reported to be in a greater risk of acute pesticide poisoning in comparison to non-agricultural workers. Farmworkers can become exposed to pesticides through different routes, such as inhalation, ingestion and skin contact. Exposure to pesticides can result in acute and chronic health problems, which include eye irritation, immune system disturbances, chromosomal damage, respiratory distress, hormone disruption, male genital abnormalities, diminished intelligence and cancer [11, 12]. Pesticides also contaminate waterways, impact non-target and beneficial organisms, and persist in the environment for years. These chemicals have also been shown to reduce ecosystem biodiversity. It is reported that the major contributor to the decline in farmland and grassland birds is due to pesticide use. In 2012, a study showed that widely used herbicides adversely impact non-target invertebrate organisms including endangered species [13]. Overall, the pesticide consumption in Europe has declined over the past decades [8].

About 75% of pesticide usage in the United States occurs in agriculture [1]. Poisoning due to pesticides is a notifiable condition in South Africa [14]. In Australia, increased exposure to glyphosate may give rise to numerous chronic diseases. In China, 53,300 to 123,000 people are poisoned by pesticides each year. Deaths from improper use of pesticides in crop production is about 300–500 per year [15]. A survey indicated that many farmers suffer liver, kidney, nerve and blood problems, eye problems, headaches, skin effects and respiratory irritations due to pesticide poisoning [15].

3 Alternative Tactics of Pest Management

3.1 Cultural Control

Cultural control is the deliberate alteration of the production system by targeting the pest itself through agronomic practices to avoid or reduce pest injuries to crops. These methods are utilized most frequently to control pest related issues. Crop rotation, intercropping, sanitation, trap crops and pest resistant crop plants are few examples of cultural control. These individual tactics of cultural control tend to be pest and crop specific [16].

3.1.1 Tactics to Prevent, Reduce or Delay Pest Colonization of the Crop

Site selection Site selection involves locating the crop field in such a manner that pests, from the site of the previous year's crop or from natural overwintering sites, cannot easily find their way there [4]. The selected sites may also have abiotic and biotic characteristics, which affect pests adversely (e.g. suppressive soils). Pest-free plant material, equipment, and soil play a crucial role to prevent infestation with pests.

Intercropping Intercropping is a practice that involves growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Intercropping may concentrate the pest in a smaller, more manageable area so that it can be controlled by appropriate tactic. Strips of *alfalfa*, for example, are sometimes inter-planted with cotton as a trap crop for Lygus bugs (Miridae). The alfalfa, which attracts Lygus bug more strongly than cotton, is usually treated with an insecticide to kill the bugs before they move into adjacent cotton fields. Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would, otherwise, not be present in a single-crop environment. This in turn can help limit outbreaks of crop pests by increasing predator biodiversity [17]. Additionally, reducing the homogeneity of the crop increases the barriers against biological dispersal of pest organisms through the crop.

Based on spatial arrangement, intercropping can be divided into the following four categories [18]:

(i) Row intercropping: Growing two or more crops at the same time with at least one crop planted in rows.
(ii) Strip intercropping: In this method two or more crops grow together in strips wide enough to allow separate production of crops using mechanical implements but close enough for the crops to interact [19].
(iii) Mixed intercropping: Growing two or more crops at the same time with no distinct row arrangement [19].
(iv) Relay intercropping: Growing of two or more crops simultaneously during part of the life cycle of each crop. In this method, a second crop is planted after the first crop has reached its reproductive stage of growth, but before it is ready for harvest [18].

Based on growth pattern and compatibility, inter-cropping may also be divided into the following groups [20, 21].

(i) Parallel cropping: Under this cropping two crops are selected which have different growth habits and have no competition between each other. This technique allows the crops to exhibit their full yield potential.
(ii) Companion cropping: In companion cropping the yield of one crop is not affected by the other, In other words, the yield of both crops is equal to their pure crops. This technique reduces the risk of total crop failure.
(iii) Multistoried cropping: Growing plants of different heights in the same field at the same time is termed as multistoried cropping. It is mostly practiced in orchards and plantation crops for maximum use of solar energy even under high planting density.

Trap Crops Trap crops are grown as a control measure to lure pests away from the cash crop. Pests are either prevented from reaching the crop or concentrated in certain parts of the field away from the main crop. The principle of trap cropping relies on pest preference for certain plant species, cultivars or a certain stage of crop development [22]. A trap crop can be an early or a late crop of the same cultivar as the main crop, or a different plant species. Pests concentrated in the trap crop should be destroyed with pesticides, natural enemies or cultural methods to prevent them from migrating to the main crop at a later stage [23, 24].

Altering the Time of Planting Plantation and harvest dates of some crops can be rearranged to reduce or to avoid potential pest damage [24]. Early planting ensures that seedlings have reached a non-susceptible or tolerant stage when the pest appears. Planting needs to be done only after the emergence or immigration of the pests leaves the pests without hosts. Early harvest date may prevent pests from reaching damaging population densities or overwintering stage by harvest [16].

3.1.2 Tactics to Reduce Survival of Pests By Creating Adverse Biotic and Abiotic Conditions

Sanitation Sanitation or source reduction involves eliminating food, water, shelter, or other necessities that are important for pest survival [25]. In crop production, sanitation includes practices to remove weeds that harbor pest insects or rodents, to eliminate weed plants before they produce seed, to destroy diseased plant material or crop residues, and to keep field borders or surrounding areas free of pests and pest breeding sites. Animal manure management is an effective sanitation practice used to prevent or to reduce fly related issues in poultry and livestock operation.

Crop rotation Crop rotation interrupts the normal life cycle of pests by placing them in a non-host habitat. It is highly effective to prevent different weeds, soil-borne plant pathogens and root-living arthropods. To control arthropods, rotation is generally most successful against species with long generation cycles and with limited dispersal capabilities. The limiting factor of this tactic is organization of the required land area to perform area-wise crop rotation [26].

Plant and row spacing Sufficiently sparse plant and row spacing are important in preventing plant pathogens that usually require a certain moisture threshold to germinate and grow. In contrast, by increasing plant density it is possible to 'dilute' the damage caused by pests to individual plants.

Tillage and destruction of breeding or overwintering refugia Tillage (soil-turning and residue-burying practices) and seed bed preparation reduce the number of soil-living pest stages [27]. Some forms of tillage can reduce pest populations indirectly by destroying weeds and volunteer crop plants in and around crop-production habitats. Many pests can breed on alternate host plants and migrate from there to crop plants. The removal of the alternative host thus helps in alleviating pest problems.

3.1.3 Tactic to Reduce Injury Caused By Pests to Crop Plants

Plants, resistant to pest attack, are less preferred by pests as they adversely affect the pests' normal development and survival or the plant may tolerate the damage without an economic loss in yield and/or quality [28]. Constitutive plant resistance is easy to use, cheap and compatible with other pest management tactics. Induced resistance to herbivores and pathogens reduces plant exposure to autotoxic environment of secondary compounds [29].

3.2 Physical and Mechanical Control

Physical and mechanical controls either kill insects and small rodents, or make the environment unsuitable for them by attacking, or setting up barriers. These methods are used for crop growing and household pest management.

3.2.1 Barriers

Row covers, typically used for horticulture crops, are useful to keep insects away from plants. These are knitted tenuously with plastic or polyester fiber so that plants can still absorb sunshine and moisture from the air. Diatomaceous earth, made from fossilized and pulverized silica shells, is used to impair the protective cuticle layer of insects, such as: ants. As a consequence, the insects become vulnerable to becoming dry. As moisture diminishes the effectiveness of diatomaceous earth, it must be attributed at regular intervals.

3.2.2 Traps

Devices like fly paper or sticky boards, covered with sticky and poisonous substance, are used to attract insects. Insects, attracted by those traps, land upon the surface and get glued. These traps are commonly used for capturing flies or leafhoppers [30]. Sometimes, a special type of crop is farmed most frequently beside main crops in the field to attract insects. This additionally farmed crop is called trap strip. Trap strip prevents the infestation of insects on principal crops. Trap strips are very useful in dealing with the wheat stem sawfly. When solid stemmed plants are farmed around the wheat field, sawflies usually lay their eggs on the solid stemmed plant leaves in lieu of wheat leaves [31].

3.2.3 Fire

Farmers consider fire to destroy insect breeding grounds. Fire burns the soil-top and kills insects present there. However, firing may kill beneficiary insects as well. Besides, some larvae can sustain below the surface of the soil.

3.2.4 Temperature

Different thermal conditions can be used to kill insects or to prevent their infestation. Cold storage prolongs the shelf life of agro-products, and retards the development of pests. Heat treatment is also effective in killing insect larvae in certain types of products. Mangoes, for example, are submersed in hot water baths (at 115 °F for 68 min) in order to kill the eggs and larvae of fruit flies (Tephritidae) prior to export [32].

3.2.5 Radiation

Gamma radiation kills all stages of pests in storage conditions. This is a common method, which is employed to kill insects or insect larvae during export or import of large quantities of grains, fruits and vegetables.

3.2.6 Ultrasonic Vibrations

Moths are often sensitive to bats' ultrasonic signals, quickly escaping from the area. Imitation of the bat's echolocation system helps in driving away the lepidopterous insect pests from the area.

3.3 The Biological Alternatives

Biological alternatives can be used as a replacement of chemical pesticides to leave the ecosystem undisturbed. Biological alternative options can be broadly classified as: (a) Biological Control, (b) Biopesticides, (c) Semiochemicals, and (d) Transgenic Organisms [33]. Biological control, also known as biocontrol, is the use of natural enemies (predators, parasitoids, insects or other arthropod species) to reduce the damage caused by pests. Biopesticides, also known as biological control, are based on pathogenic microorganisms or natural products which usually kill pests. The term biopesticide may also be used, more widely, to describe the application of biological agents, pathogens, predators, or parasitoids. In addition, botanicals, semiochemicals and transgenic plants sometimes be described as biopesticides. According to the US Environmental Protection Agency (EPA), biopesticides are certain type of pesticides derived from natural materials such as animals, plants, bacteria and certain minerals.

3.3.1 Biological Control

Biological control involves the suppression of reproductive organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density [34]. There are three different approaches of biological control.

Importation Importation involves the enforcement of the natural enemies of a pest to a new locale where the pest does not inhabit naturally. The process involves determination of pest-origin and consequently collection of appropriate natural enemies associated with the pest. Selected natural enemies are then passed through rigorous assessments, testing and quarantine processes to ensure their appropriate use. Finally, the selected natural enemies are mass-produced and distributed [35]. To control pests most effectively, a biological control agent requires a colonizing ability, which will allow it to keep pace with the spatial and temporal disruption of the habitat. The control of a biological control agent over the pest will also be effective if the agent possesses temporal persistence. This ability enables the agent to maintain its population during the temporary absence of the target species. However, an agent with such attributes is likely to be non-host specific, which may unintentionally affect non-target organisms.

Augmentation Augmentation involves the supplemental release of natural enemies to boost up the natural inhabitant population. In addition, the cropping system may also be modified to favor or augment these natural enemies called as habitat manipulation. During the critical time of the season, a small number of natural enemies to pest is released, which is called inoculative release. *Encarsia formosa*, a parasitoid, is released periodically to control greenhouse whitefly which is an example of inoculative release. The predaceous mite, *Phytoseiulus persimilis*, is also used periodically to control two-spotted spider mite. On the contrary, inundative release means the release of millions of natural enemies. Lady beetles, lacewings, or parasitoids such as *Trichogramma* are frequently released in large numbers. Entomopathogenic nematodes are released at rates of millions and even billions per acre for controlling certain soil-dwelling insect pests [36].

Conservation In conservation method, biological control action is taken to enhance the effectiveness of existing natural enemies to pests in the ecosystem. As natural enemies are already adapted to the habitat and target pest, their conservation becomes simple and cost-effective. An example of such cost-effectiveness is growing nectar-producing crop plants in the borders of rice fields. These provide nectar to support parasitoids and predators of planthopper pests and thus effectively reduce pest densities by 10–100 folds. This also diminishes the necessity to spray insecticides by 70%, and consequently boosts overall crop yield by 5% [37].

Habitat manipulation is the modification of cropping system to favor natural enemies by providing a suitable habitat such as shelterbelt, hedgegrow, or beetle bank, where beneficial insects can live and reproduce. This can be done in several ways, such as [38]:

(a) Leaving a layer of fallen leaves or mulch provides a suitable food source for worms, and provides a shelter for small insects.
(b) Compost pile and containers for making leaf compost also provide shelter as long as they are accessible by animals.
(c) Artificial shelters in the form of wooden caskets, boxes or flowerpots can be undertaken, particularly in gardens to make a cropped area more attractive to natural enemies.
(d) Some types of birds in birdhouses eat certain pests. Attracting the most useful birds can be done by using a correct diameter opening in the birdhouse (just large enough for the specific species of bird that needs to be attracted to fit through, but not other species of bird). Besides facilitating natural or artificial housing, growing nectar-rich plants is also beneficial. Many natural predators are nectivorous during their adult stages, but are parasitic or predatory during larvae stage. Seeding of certain plants (*Helianthus spp*., *Rudbeckia spp*., *Dipsacus spp*., *Echinacea spp*.) is also advised to supply food for birds. Trees and shrubs, producing berries, also serve as food sources for the birds [35]. To avoide food competition, generally, human inedible berry trees are planted.

3.3.2 Biopesticides

Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered as biopesticides.

Classification of Biopesticides Biopesticides fall into three major classes: (1) Microbial pesticides, (2) Plant-Incorporated-Protectants and (3) Biochemical pesticides or herbal pesticides [39].

1. *Microbial pesticides*, which consist of a microorganism (e.g. bacterium, fungus, virus or protozoan) as active ingredient, are used to control different types of pests. Each active ingredient is specific to its target pest. For instance, some fungi are capable of controlling certain weeds, while certain fungi are specific to kill insects. The most widely used microbial pesticides are subspecies and strains of *Bacillus thuringiensis* (Bt) [40].
2. *Plant-Incorporated-Protectants* (PIPs) are pesticidal substances, which are produced from the genetic materials of plants. These materials are produced by applying genetic engineering. For example, gene from the Bt pesticidal protein can be introduced into the genetic material of plant. The plant then produces substances that destroy the pests. The protein and its genetic material excluding the plant itself are regulated by regulatory bodies, such as the US EPA [41].
3. *Biochemical pesticides* or herbal pesticides are naturally occurring substances that control (or monitor) pests and microbial diseases. Conventional pesticides are generally synthetic materials that directly kill or inactivate the pest. Biochemical pesticides are often called botanical pesticides when they are derived from plant extracts. Biochemical pesticides include substances like insect sex pheromones and various scented plant extracts. Neem is one of the best known and most effective botanical pesticides. The active ingredient of Neem, azadirachtin, has the same activity as an insect hormone and disrupt moulting in a range of insect pests. Neem cake has multiple effects on the soil in controlling soil borne fungi and nematodes; the effects also last for the subsequent years [42]. Pyrethrin, extracted from chrysanthemum plants, is another highly effective botanical insecticide. Pyrethrin acts rapidly on insects causing immediate knock down [43].

Global market of Biopesticides About 1400 biopesticide products are being sold worldwide. At present, there are 68 biopesticide active substances registered in the EU and 202 in the USA. The EU biopesticides consist of 34 microbials, 11 biochemicals and 23 semiochemicals, while the USA portfolio comprises of 102 microbials, 52 biochemicals and 48 semiochemicals [44]. However, these biopesticide products represent only 2.5% of the total pesticide market. It is estimated that the biopesticides sector has been maintaining a compound annual growth rate of 16% in the recent years (compared with 3% for synthetic pesticides), and it is expected to become a market of $10 billion by 2017 [44, 45]. Table 2 enlists different types of botanical pesticides approved for use in different countries [2].

Market Trend of Biopesticides The global market for biopesticides was valued about US $1 billion in 2010, and it is expected to reach US $ 3.2 billion by 2017. On the other hand, the global market for synthetic pesticides was US $ 24 billion in 2010. From 2003 to 2010, global market for biopesticides has been increased by 56% (Fig. 1) [39, 46]. Increasing demand of residue-free crop production is one of the key drivers of the biopesticide market. High demand of organic food market and easier registration system than that of chemical pesticides are other important driving factors of enlarging biopesticide market.

Table 2 Botanical pesticides approved for use in specific countries [2]

	Pyrethrum	Rotenone	Nicotine	Neem	Others
Australia	✓	✓			Citrus oils
New Zealand	✓	✓		✓	
India	✓	✓	✓	✓	Ryania
Germany	✓			✓	
Brazil	✓	✓	✓	✓	
United States	✓	✓	✓	✓	
Canada	✓	✓	✓		
Mexico	✓	✓		✓	
South Africa	✓				

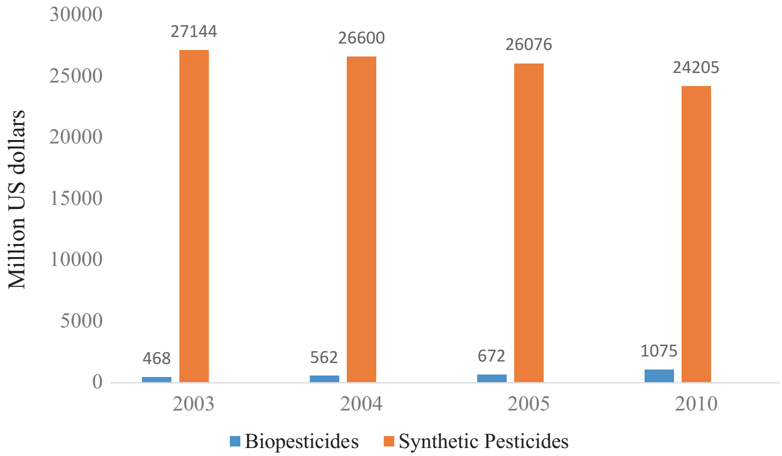

Fig. 1 Global biopesticides and synthetic pesticides market [46]

3.3.3 Semiochemicals

Semiochemicals (Greek word "semeon" means "signal") are chemical substances that mediate interactions between organisms. Semiochemicals are attributed to interspecific and intraspecific interactions, which are categorized as allelochemicals and pheromones, respectively [47]. The allelochemicals are classified as allomones, kairomones and synomones. Allomones are often found in nature as part of a chemical defense, such as toxic insect secretions. Predators also use allomones to lure prey. Kairomones are a class of compounds that are advantageous for the receiver. The term "kairomone" is derived from the Greek word "kairos," which means "opportunistic". Kairomones benefit many predators and bugs by guiding them to prey or potential host insects. Synomones (from the Greek "syn" for "with" or "together") are compounds that are beneficial to both the receiver and the sender [48]. Pheromones (Greek word "phereum" means "to carry") are released by one member of a species to cause a specific interaction with another member of the same species. Pheromones may be further classified on the basis of the interaction mediated, such as alarm, aggregation or sex pheromone. It is the sex pheromones of insects that are of particular interest to agricultural integrated pest management (IPM) practitioners [49, 50].

The existence of pheromones has been known for centuries, apparently originated in observations of mass bee stinging in response to a chemical released by the sting of a single bee. The first isolation and identification of an insect pheromone (silkworm moth) occurred in 1959 by German scientists [50]. Since then, hundreds, perhaps thousands of insect pheromones have been identified by increasingly sophisticated equipment. Their main uses are to disrupt mating to restrict pest population growth, and to entrap pest species. Pheromone traps are often used with a fungal biopesticide, in which the lured individual gets infected and then released to spread the fungus to other healthy individuals.

3.3.4 Transgenic Organisms

Genes of one species can be modified or can be transplanted to another species. Organisms that have altered genomes are known as transgenic. Genetic modification with recombinant DNA techniques is the newest way of generating pest-resistant plants. The most successful commercial transgenic crops resistant to insects include cotton, maize and potato. These crops possess transgenes from the insecticidal bacterium *Bacillus thuringiensis* (Bt) and herbicide-resistant soybean [51–53]. Resistance against plant pathogens has been achieved by transferring genes from viruses into plants, bacteria, fungi, and other plants and insects [54, 55]. Herbicide-resistant transgenic crops, allow chemical weed control without harming the crop plant [56].

4 Integrated Pest Management (IPM)

Integrated Pest Management (IPM) aims to eliminate or drastically reduce the use of pesticides, and to minimize the toxicity of and exposure to any products which are used [57]. IPM utilizes a variety of methods and techniques, including chemical, cultural, biological, physical and mechanical strategies to control a multitude of pest problems. Non-integrated pest control programs tend to focus on killing pests, without taking into account the reason behind the pests' existence in the first place. On the other hand, IPM practitioners can better cure existing infestations and prevent future ones by removing or altering conducive conditions for pest infestations.

4.1 Working Principles of IPM Program

IPM is not a single pest control method; it is a series of pest management evaluations, decisions and controls. Growers practicing IMP are reported to follow a four-tiered approach [58]. The four steps include:

1. *Setting Action Thresholds* – Before taking any pest control action, IPM programs set an action threshold point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not always mean that control is needed. The level at which pests will either become an economic threat is critical to guide future pest control decisions [58].
2. *Monitoring and Identifying Pests* – All insects, weeds, and other living organisms may not require control. Many organisms are innocuous, and some are even beneficial. IPM programs work to monitor for pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification process eliminates the possibilities of unnecessary and inappropriate pesticide usage [58].
3. *Prevention* – As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat. In an agricultural crop, this may mean using cultural methods, such as rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock. These control methods can be very efficient, cost effective, and present little to no risk to people or to the environment [58].
4. *Control* – Once monitoring, identification, and action thresholds identify the necessity or improvement of pest control method, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective techniques with minimum risk are preferred, which include targeted chemicals (pheromones to disrupt pest mating), or mechanical control (trapping or weeding). Additional pest control methods, such as targeted spraying of pesticides, are only employed only if monitoring, identifications and action thresholds indicate that lower risk controls are not working [58].

4.2 Advantages and Disadvantages of IPM Program

IPM program is a cost effective method, and easy to implement [59]. In IPM programs, chemical pesticides are used only when needed and in combination with other approaches for more effective and long-term control. In addition, pesticides are selected and applied in a way that minimizes their possible harm to people and the environment, thus reducing pesticide residue hazards. IPM makes full use of environmentally sound control methods, which diminishes chances of contamination and worker health problems. An increase in yield due to integrated pest management also facilitates the economic benefits. Figure 2 shows different benefits of IPM programs [60].

There are also certain drawbacks of IPM programs. An IPM program requires a higher degree of management, which includes attention to field histories to anticipate pest problems. Besides, selecting crop varieties and choosing tillage system that will suppress anticipated pest damage while generating the highest yield potential are other commercial factors. Thus, IPM approach is much labor intensive; success of the approach is also weather dependent.

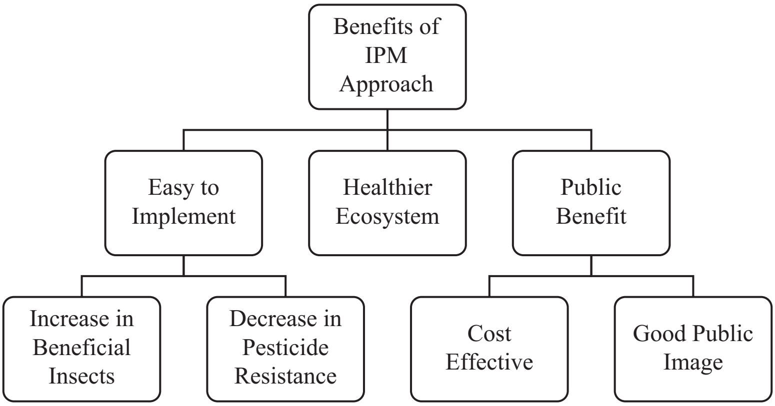

Fig. 2 Benefits of IPM Program [60]

5 Conclusion

Extensive use of pesticides has caused food and groundwater contaminations, and destruction of beneficial insects. Pesticides have been linked to a number of health problems, including neurologic and endocrine (hormone) system disorders, birth defects, and cancer. Increased understanding and awareness of the adverse effects of pesticides on health and environment is driving the demand for alternatives of pesticides. There are proven alternatives to pesticide use. These approaches consider pest problems within a broad context, which include the presence of natural enemies, the distribution of pest population, active season to grow, and expected weather patterns. Many sustainable farms use Integrated Pest Management (IPM) as an alternative to pesticides. IPM is a growing movement among farms of all sizes that incorporates a variety of techniques to eliminate pests, while minimizing environment damage. An IPM farm may grow pest-resistant crop varieties, use predatory insects to kill plant-eating pests, employ mechanical pest traps, crop rotation and vegetational biodiversity. IPM program also call for determining if pests are actually causing or are likely to cause damage to health or crops, and, if they are, whether the extent of damage warrants action. Because of versatility and cost effectiveness, IPM can be a suitable choice for most of the developing countries as an alternative of pesticides.

References

1. G.M. Calvert, J. Karnik, L. Mehler, J. Beckman, B. Morrissey, J. Sievert, R. Barrett, M. Lackovic, L. Mabee, A. Schwartz, Y. Mitchell, S. Moraga-McHaley, *Acute pesticide poisoining among agricultural workers in the United States, 1998-2005*. Am. J. Ind. Med. **51**(12), 883–898 (2008)
2. E.N. El-Wakeil, Botanical pesticides and their mode of action. Gesunde Pflanzen **65**(4), 125–149 (2013)

3. O. Koul, *Microbial biopesticides: opportunities and challenges* (CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources/CAB International, Wallingford, 2011)
4. I. Vänninen, W. Jongen, in *Imperoving the Safety of Fresh Fruit and Vegetables*. Alternatives to pesticides in fruit and vegetable cultivation (CRC Press, Boca Raton, 2005), pp. 293–330
5. D.S. Hill, *Agricultural insect pests of the tropics and their control* (Cambridge University Press, Cambridge, NY, 1983.) CUP Archive
6. G. Sharma, B. Mangat, R. Baker, Alternatives to pesticides in Southeastern United States. Sci. Total Environ. **2**(1), 21–44 (1973)
7. D.R. Bottrel, in *Integrated Pest Management*. Integrated pest management (Consortium for International Crop Protection, Berkeley, 1979)
8. W. Zhang, F. Jiang, J. Ou, Global pesticide consumption and pollution: with China as a focus. Proc. Int. Acad. Ecology Environ. Sci. **1**(2), 125 (2011)
9. M. Rein, Phenomena of Liquid Drop Impact on Solid and Liquid Surfaces. Fluid Dyn. Res. **12**(1993), 61–93 (1993)
10. Beyond Pesticides, (2015) [cited 2016 22 July], Available from: http://beyondpesticides.org/dailynewsblog/2015/02/france-elevates-effort-to-reduce-pesticide-use-by-50-but-delays-deadline/
11. T.A. Mokhele, Potential health effects of pesticide use on farmworkers in Lesotho. S. Afr. J. Sci. **107**, 29–35 (2011)
12. R.G. Rita Ganava, R.R. Kanhere, H. Pandit, *Toxic impacts of Thiodan 35EC® on protein, glycogen and oxygen consumption in Tilapia Mossambica*. Eur. J. Biomed. Pharma. Sci. **3**(3), 251–255 (2015)
13. S. Oosthoek, *Pesticides Spark Broad Biodiversity Loss*, Nature News 17 June (2013)
14. L. London, *The health hazards of organophosphate use in South Africa.* Pesticides News (United Kingdom) (1995)
15. Y. Yang, in *Pesticides and Environmental Health Trends in China. China Environment Forum*. A China environmental health project factsheet (Wilson Center, Washington, DC, 2007)
16. D.N. Ferr, *Culturael Control*. *Radcliffe's IPM World Textbook* (2003) [cited 2016], Available from: http://ipmworld.umn.edu/ferro
17. Altieri, C. Nicholls, *Biodiversity and pest management in agroecosystems* (CRC Press\Food Product Press R \an imprint of The Haworth Press Inc., New York, 2004)
18. P. Sullivan, Intercropping principles and production practices (November 1998, [cited 2016 June 22]), Available from: http://www.iatp.org/files/Intercropping_Principles_and_Production_Practi.htm#top
19. K.B. Kabir, M.S. Khan, in *The National Symposium on Engineering and Technological Education (NSET)*. Engineering education in Bangladesh: some new approaches (Bangladesh University of Engineering and Technology (BUET), Dhaka, 2007)
20. *Types of Inter-cropping*. Farming System and Sustainable Agriculture (2015, [cited 2016 June 22]), Available from: http://www.agriinfo.in/?page=topic&superid=1&topicid=663
21. B. Horwith, A role for intercropping in modern agriculture. Bioscience **35**(5), 286–291 (1985)
22. S.B. Annette Wszelaki, *Trap Crops, Intercropping and Companion Planting* (University of Tennessee, Tennessee)
23. H.M. Hokkanen, Trap cropping in pest management. Annu. Rev. Entomol. **36**(1), 119–138 (1991)
24. M. Kogan, *Water Quality and Use: Integrated Pest Management*, (University of Arizona, Arizona, 1998), pp. 16–18.
25. P.J. Marer, *The safe and effective use of pesticides*, vol 1 (UCANR Publications, Oakland, 2000)
26. J. Helenius, Spatial scales in ecological pest management (EPM): importance of regional crop rotations. Biol. Agric. Horticulture **15**(1–4), 162–170 (1997)
27. W. Jongen, *Improving the safety of fresh fruit and vegetables* (CRC Press, Boca Raton, 2005)
28. H. Van Emden, Conservation biological control: from theory to practice. in *Proceedings of the International Symposium on Biological Control of Arthropods*, UK (2002)

29. A.A. Agrawal, R. Karban, in *The ecology and evolution of inducible defenses*, ed. by R. Tollrian, C. D. Harvell. *Why Induced Defenses May be Favored Over Constitutive Strategies in Plants* (Princeton University Press, Princeton, 1999), pp. 45–61
30. *Physical Pest Control*, Available from: http://broom02.revolvy.com/main/index.php?s=Physical%20pest%20control&item_type=topic
31. A. Marmur, *Equilibrium contact angles: theory and measurement*. Colloids Surf.A Physicochem. Eng. Aspects **116**, 55–61 (1996)
32. C.W. Hoy, in *Temperature Sensitivity in Insects and Application in Integrated Pest Management*. Insect control in the field using temperature extremes (Westview Press, Boulder, 1998), pp. 269–287
33. Biological alternatives of harmful chemical pesticides, in *IPM Research Brief Number 4* (International Institute of Tropical Agriculture, Benin, 2006) https://www.cbd.int/doc/case-studies/tttc/tttc-00147-en.pdf
34. P. De Bach, Biological control of insect pests and weeds, in *Biological Control of Insect Pests and Weeds* (1964).
35. Z. Polosky, *21st Century Homestead: Biological Pest Control* (2015)
36. *Biological Control Agent*, Available from: http://www.gutenberg.us/articles/biological_control_agent
37. P. Zhu et al., Selection of nectar plants for use in ecological engineering to promote biological control of rice pests by the predatory bug, Cyrtorhinus lividipennis,(Heteroptera: Miridae). PLoS One **9**(9), e108669 (2014)
38. L.G. Napolitano, R. Monti, G. Russo, Marangoni convection in one- and two- liquids floating zones. Naturwissenschaften **73**, 352–355 (1986)
39. S. Dutta, Biopesticides: an ecofriendly approach for pest control. Institutions **124**, 60 (2015)
40. A. Kalra, S. Khanuja, in *Business Potential for Agricultural Biotechnology*. Research and Development priorities for biopesticide and biofertiliser products for sustainable agriculture in India (2007), Asian Productivity Organization (APO), Tokyo, Japan pp. 96–102.
41. Y. Thakore, The biopesticide market for global agricultural use. Ind. Biotechnol. **2**(3), 194–208 (2006)
42. National Research Council, *Neem: a tree for solving global problems* (The Minerva Group, Inc., Calgary, 2002)
43. L.A. Lacey, R. Georgis, Entomopathogenic nematodes for control of insect pests above and below ground with comments on commercial production. J. Nematol. **44**(2), 218 (2012)
44. D. Chandler et al., The development, regulation and use of biopesticides for integrated pest management. Philos. Trans. R. Soc. B Biol. Sci. **366**(1573), 1987–1998 (2011)
45. K. Bailey, S. Boyetchko, T. Längle, Social and economic drivers shaping the future of biological control: a Canadian perspective on the factors affecting the development and use of microbial biopesticides. Biol. Control **52**(3), 221–229 (2010)
46. P. Lehr, *Global Market for Biopesticides* (BCC Research, USA, 2014)
47. H.S. Rathore, L.M. Nollet, *Pesticides: Evaluation of Environmental Pollution* (CRC Press, Boca Raton, 2012)
48. A.W. Martinez et al., Simple telemedicine for developing regions: camera phones and paper-based microfluidic devices for real-time, off-site diagnosis. Anal. Chem. **80**(10), 3699–3707 (2008)
49. C. Joshi, in *Termirepel*. Communication in termites via semiochemical (Wordpress, Gurugaon, 2015)
50. H.M. Flint, C.C. Doane, in *Radcliffe's IPM World textbook*. Understanding semiochemicals with emphasis on insect sex pheromones in integrated pest management programs (University of Minnesota, St. Paul, 1996.) URL: http://ipmworld.umn.edu
51. M.D. Owen, S. Powles, in *Herbicide Resistance and World Grains*. World maize/soybean and herbicide resistance (CRC Press, Boca Raton, 2001), pp. 101–163
52. A.M. Shelton, J.-Z. Zhao, R.T. Roush, Economic, ecological, food safety, and social consequences of the deployment of Bt transgenic plants. Annu. Rev. Entomol. **47**(1), 845–881 (2002)
53. H.C. Sharma et al., Prospects for using transgenic resistance to insects in crop improvement. Electron. J. Biotechnol. **3**(2), 21–22 (2000)

54. D. Gonsalves, et al., Transgenic virus resistant papaya: New hope for controlling papaya ringspot virus in Hawaii. Plant Health Prog. (Plant Health Rev.) **21**, 105–121 (2000)
55. K. Ko, Using antimicrobial proteins to enhance plant resistance. *APSnet Feature* (2000), Online Publication, www.apsnet.org
56. H.A. Kuiper, G.A. Kleter, M.Y. Noordam, Risks of the release of transgenic herbicide-resistant plants with respect to humans, animals, and the environment. Crop. Prot. **19**(8), 773–778 (2000)
57. *What is Integrated Pest Management* (2003, [cited 2016 June 22]), Available from: http://www.beyondpesticides.org/resources/safety-source-on-pesticide-providers/what-is-integrated-pest-management
58. *Integrated Pest Management (IPM) Principles* (2015, [cited 2016 June 19]), Available from: https://www.epa.gov/safepestcontrol/integrated-pest-management-ipm-principles
59. *Advantages of Integrated Pest Management* (2013, [cited 2016 June 20]), Available from: http://sccoastalpesticides.org/knowledgebase/ipm_advantages.php
60. *Environmental Knowledge & Decision Making Toolbox*, Available from: http://www.sccoastalpesticides.org/knowledgebase/ipm_advantages.php