Bio Factsheet

Number 88

The Biology of Pesticides

This Factsheet covers the following topic areas relevant to students of AS/A2 level Biology:
- **the need for pesticide use.**
- **the chemical nature of some pesticides and their actions.**
- **disadvantages of using pesticides.**
- **the advantages of biological control rather than chemical control.**

The need for pesticide use

A 'pest' is an animal or plant living where humans do not want it to live.
A pesticide is a chemical used to kill pests. Some examples are shown in Table 1.

Table 1. Examples of pesticides

Pesticide	Target organism	Examples of use
Herbicide	Herbaceous weeds	To kill weeds amongst crops and in lawns, to clear roadside verges
Fungicide	Fungi	To reduce fungal infection of crops or greenhouse plants, to remove dry rot of wood in buildings
Insecticide	Insects	To kill any insect pests, such as houseflies, mosquitoes, aphids and cockroaches
Molluscicide	Snails and slugs	To kill snails and slugs in gardens
Muscicide	Mosses	To kill mosses in lawns and sports pitches
Rodenticide	Rats or mice	To reduce rat and mouse populations in granaries and food store warehouses.
Nematicide	Nematode worms	To 'worm' dogs and cats.

Pesticides are used for two main reasons:

1. **To kill pests which pose health threats to humans or to domestic animals or plants.**

For example:
- the use of insecticides to kill insect vectors of disease, such as various species of mosquito which transmit malaria or yellow fever, tsetse flies which transmit sleeping sickness to humans or cattle, aphids which damage crops but also transmit plant viral diseases.
- the use of rodenticides, such as warfarin, to kill rats whch can transmit plague bacilli and Leptospirosis.
- the use of insecticides to kill houseflies which can transfer disease-causing organisms on their bodies and in their saliva onto food.
- the use of molluscicides to kill snail species which transmit liver flukes to sheep, cattle, and fish.
- the use of nematicides to kill roundworms which parasitise dogs and cats. Without regular 'worming' the parasite populations may build up to levels which can seriously debilitate the dog or cat and which may also infect humans. For example, the worm Toxocara canis carried by pet dogs can cause blindness in humans.

2. **To kill pests which cause economic loss to humans.**
   For example:
- the use of fungicides to kill or prevent the growth of moulds on stored seeds and fruits.
- to spray crops with fungicides to prevent the growth of, for example, fungal rusts on wheat crops, blight on potato plants, mildews on greenhouse seedlings.
- to use fungicide on the wood of buildings to prevent or remove wet rot or dry rot fungus.
- to use insecticides to kill insects such as weevils which damage stored food products.
- to use insecticides on crops to reduce damage due to insects, such as aphids.
- to use insecticides on dogs and cats to kill fleas.
- to use insecticides to kill cockroaches in bakeries and other situations
- to use rodenticides to kill rats and mice in farmyards, granaries and food stores.
- to use herbicides to kill weeds among crop plants, in flower beds or on paths.

The nature of pesticides and their actions

Some herbicides are **auxin simulators** which mimic the action of natural plant growth substances (for example, indole acetic acid, commonly referred to as auxin). They lead to rapid, exagerated, distorted growth which eventually kills the plant. Monocotyledons are much less susceptible to auxin simulators than dicotyledons so that these herbicides can be used selectively when sprayed on cereal crops and lawns to suppress dicotyledonous weeds.

Other herbicides act on chloroplasts, for example, **simazine** which inhibits the Hill reaction of photosynthesis, thus preventing the reduction of NADP and the associated release of oxygen. Another example is **paraquat** which picks up an electron from ferredoxin in photosystem 1 and transfers it to O_2 producing a highly toxic superoxide ion O_2^-. This probably destroys (by peroxidation) the lipid component of cell membranes.

Some herbicides, **uncouplers**, act by uncoupling phosphorylation from the transport of electrons down the respiratory chain and so inhibit about 80% of ATP formation, resulting in death.. An example is **dinitro-orthocresol (DNOC).** However, uncouplers are also fatal to animals and so must only be used with great care.

Rotenone is an insecticide which blocks the transfer of hydrogen ions by $NADH_2$ along the respiratory chain. **Apholate** is an insecticide which renders insects sterile, thus preventing reproduction. Many insecticides are **organochlorine** compounds, e.g **DDT (dichlordiphenyltrichloethane), aldrin** and **dieldrin**, or **organophosphorus** compounds, for example **parathion** and **malathion**. Both organochlorine and organophosphorus insecticides act on the central nervous system as acetylcholine esterase inhibitors.

> ***Remember*** *– acetylcholine is the main excitatory synaptic transmitter substance in animals. Once the impulse has passed the synapse, acetylcholine must be rapidly broken down by acetylcholine esterase. If this enzyme is inhibited then the synapse and nerve will be kept in a state of continuous excitation, resulting in the paralysis and death of the insect.*

Disadvantages of using pesticides

- **toxicity to other organisms.** Ideally pesticides should be selective and only kill the 'target' organism. Many herbicides, including auxin simulators which tend to be absorbed via the leaves, are generally much less toxic to the narrow leaved monocotyledons than to the broad leaved dicotyledons. Thus they do not affect grasses but kill broad leaved plantains in lawns. Muscicides kill mosses in lawns but do not harm the grass species.

  Insecticides tend to be non-specific and may kill any insect that they come into contact with. Thus insecticides sprayed on crops may, for example, kill bees, butterflies and moths. In extreme cases this may result in a failure of plants to get insect pollinated, or may result in harmless or useful insect populations being eradicated. For instance, spraying of aphids (greenfly, blackfly, whitefly) may result in the death of ladybirds which predate on the aphids.

  Insecticides may also be toxic to organisms other than insects, such as vertebrates, including humans. For example, the insecticide parathion is very toxic to humans (but still in use) whereas malathion is much less toxic. The toxicity of a pesticide can be quantitatively measured by its LD50. LD stands for 'lethal dose'.

  The LD50 is the dosage of poison that kills 50% of the 'target' or test organisms with a single application of the pure pesticide for a given weight of animal.

> ***Exam hint*** *– exam papers have often contained data interpretation questions concerning pesticide LD50 values and their significance.*

  Oral LD50 is the measure of toxicity of the pure pesticide when administered internally to the animal. Dermal LD50 is the measure of toxicity of pure pesticide when applied to the surface of the animal. Rats or rabbits are usually used as test mammals to assess the possible toxicity and danger of pesticides to humans. Table 2 shows LD50 values for some common insecticides. The lower the LD50 dose the greater the effectiveness of the insecticide. An ideal insecticide would have a very low LD50 for insects but a very high LD50 for mammals.

Table 2. LD50 values for some insecticides tested on adult houseflies and rats.

Insecticide	*LD50/mg insecticide kg^{-1} body mass*		
	Houseflies (dermal)	**Rats (dermal)**	**Rats (oral)**
Malathion	51	49	2750
Parathion	2.9	3.1	7.9
DDT	19	19	115 - 175
Gamma HCH	1.6	1.6	90

- **persistence in the environment.** Once pesticides have eradicated or controlled their 'target' organism they should degrade quickly to harmless substances so that other organisms are not overexposed to them. This is especially so if a pesticide is toxic to a wide range of organisms. Rapid degradation of pesticides reduces the risks of passage through food chains with associated bioaccumulation, and reduces the risks of developing resistant strains of the 'target' organism. On the other hand, a pesticide which persists at its application site may prevent later recurrent infestations of the pest.

  Most herbicides are not persistent and are destroyed within a few days. An exception is the herbicide 2,4,5-T (Agent Orange) which was used as a defoliant to reduce forest cover during the Vietnam war. This herbicide produces a byproduct called **dioxin** which is extremely toxic to many organisms and which is very persistent. Thus 2,4,5-T is no longer used.

  Insecticides such as the **pyrethrins** are quickly destroyed on exposure to air, but DDT remains active for up to seven years. Organochlorine insecticides such as aldrin and dieldrin can persist in an active form for up to 12 years, and since farmers applied them at regular intervals, their concentrations in the soil rose very high. The use of these insecticides is now banned.

  Most insecticides contact the surface of the insect and are absorbed, or are on the food of the insect and are eaten. In contrast, **systemic insecticides**, for example **dimethoate**, are sprayed on plants and absorbed through leaves or roots. They persist in the plant sap for up to several weeks and are taken in by sucking or biting insect pests. It is important that the active insecticide does not persist in the plant until harvesting or eating, so that consumers are not put at risk.

- **bioaccumulation.** Many pesticides are lipid soluble and so can be absorbed and accumulate in body fat if ingested over a period of time. Accumulation also occurs through food chains. For example, aldrin was used for many years to treat seeds and to rid soil of nematodes. Thus earthworms and insects in the soil accumulated aldrin and in turn the aldrin was passed to predatory birds, often resulting in the death of the birds. DDT has accumulated in birds. At the top of the food chain, the birds of prey are particularly vulnerable. DDT accumulation in their tissues has resulted in a decrease in the fertility and hatchability of eggs, probably because derivatives of DDT formed in the birds have oestrogenic activity. The rodenticide endrin is thought to have caused human deaths in Nicaragua, possibly by the leaching of endrin into rivers and its uptake into fish species which are eaten by humans.

- **development of resistance.** This is a major problem involved in the use of insecticides, although rat populations have also become resistant to the effects of warfarin. In the 1960s, DDT, gamma HCH and dieldrin were used worldwide in an effort to eradicate insect vectors of disease, for example, Anopheline mosquitos which are the vectors of malaria. Within a few years the incidence of malaria and other insect-borne diseases fell to low levels, but this was followed by an upsurge in the incidence of the diseases as insecticide-resistant strains of the insects appeared. For example, gene mutations in the insects occured which gave them resistance to DDT. The mutation enabled insects to produce a dechlorinating enzyme which removed the chlorine atoms from DDT, rendering it harmless. Overexposure of the insect populations to DDT then allowed the resistant strains to be selected so that eventually whole insect populations were resistant. DDT is no longer used as an insecticide. Insects have also become resistant to dieldrin and to lindane (benzene hexachloride)

***Exam hint** – a common error made by candidates is to use the word 'immune' rather than 'resistant'. Bacteria can be resistant to antibiotics, insects can be resistant to certain insecticides, but immunity involves antigen-antibody reactions. An insect cannot be immune to an insecticide.*

The advantages of biological control rather than chemical control.
Biological control is the use of one species of organism to reduce the numbers of another harmful species of organism. The classic example is the use of ladybirds to kill aphids. Although biological control is not 100% effective, and some crop damage may still occur, it is more environmentally or ecologically friendly and has many advantages over the use of chemical pesticides:

- biological control is more focussed and does not harm other organisms – the pest is preyed upon by a specific predator as in the case of aphids being eaten by ladybirds, or rabbits have been controlled by the use of myxomatosis virus which infects rabbits only.

- biological control does not involve the use of toxic chemicals which can kill many other organisms and which are not specific to the pest.

- there is no problem of accumulation of pesticides in body fat or accumulation through food chains, and so organisms higher up food chains are not put at risk from accumulating toxic chemicals.

- there is no problem of pesticides persisting in the environment for long periods. When the population of prey organisms falls the population of predator organisms also falls. However, a residual population of the predators should survive, so that if the prey population increases again, the predator population also increases and control will occur.

- there is no risk of toxic pesticides leaching into waterways, or being windblown onto neighbouring areas of vegetation.

- there is no risk of the pest organisms developing resistance to their predators, although if viruses are used as pesticides the pests may develop resistance. Resistance has developed in some rabbit populations against myxomatosis virus.

Practice Questions

1. (a) Define the terms 'pest' and 'pesticides'. 2

   (b) List four properties that an ideal pesticide should possess. 4

   (c) Suggest how resistance to an insecticide may develop in a population of cockroaches. 3

   (d) An insecticide used against aphids in one garden had an LD50 of 5 mg insecticide kg^{-1} body mass but the same insecticide used against aphids in another garden had an LD50 of 100 mg insecticide kg^{-1} body mass.
   (i) Suggest a reason for the difference in LD50 values. 1

   (ii) How could this problem of insecticide use have been avoided? 2

   Total 12

2. The table below shows the LD50 values for three insecticides.

Insecticide	**LD50/mg insecticide kg^{-1} body mass**		
	Houseflies (dermal)	**Rats (dermal)**	**Rats (oral)**
A	3	3	6
B	20	139	1000
C	4	5	100

Insecticides A, B and C could be applied either in powder for or in aerosol form.

   (a) Which insecticide would be safest to use in the kitchen to control houseflies? Explain your answer. 3

   (b) Which insecticide would be most dangerous to use in the kitchen to control houseflies? Explain your answer. 2

   (c) Which insecticide would be best applied as a powder? Explain your answer. 3

   (d) A and B are persistent insecticides. Comment on the importance of this. 3

   Total 11

3. Suggest why:

   (a) Top predators, such as birds of prey, tend to accumulate high concentrations of pesticide residues in their bodies. 3

   (b) Auxin simulators kill plantains but do not kill not grass. 3

   (c) It is important to regularly 'deworm' and 'deflea' pet dogs. 3

   (d) It is best to use a systemic insecticide to kill aphids on roses but not to kill aphids on broad beans. 3

   Total 12

Answers

1. (a) a pest is an animal or plant living where humans do not want it to live;
a pesticide is a chemical used to kill pests; 2

(b) it should only be toxic to the pest/should not kill other organisms;
it should not be required in large doses/have a low LD50;
it should not persist in the environment longer than is necessary to control the pests;
it should not pass up food chains/bioaccumulate;
it should be cheap and readily available; max 4

(c) gene mutation;
enables some cockroaches to resist the insecticide and these pass on the resistance gene to their offspring;
continual exposure to the insecticide means that non-resistant cockroaches are killed but resistant cockroaches survive/are selected; 3

(d) (i) aphids who have an LD50 of 100 mg insecticide kg^{-1} body mass have developed resistance to the insecticide; 1

(ii) employing biological control using ladybirds;
do not apply the insecticide as frequently/use different insecticides on successive occasions; 2

Total 12

2. (a) B;
it has the highest dose before it kills/harms rats (and thus humans) when it lands on the skin;
it can be taken in by rats/humans through the mouth/on food in very large doses before it becomes harmful/lethal; 3

(b) A;
it is dangerous to rats/humans in the lowest doses via both oral and dermal routes; 2

(c) A;
it is most dangerous to rats/humans via both oral and dermal routes;
as an aerosol it may land on skin/food but this can be avoided with powder; 3

(d) persistence will allow insects to be killed over a long period;
persistence is relatively safe with B which is not very toxic to rats/humans;
but A is very toxic to rats/humans and so persistence would be dangerous; 3

Total 11

3. (a) earthworms, insects, freshwater invertebrates accumulate pesticides from their environment;
pesticides tend to dissolve and be stored in body fat;
fishes/birds eat many individual worms/insects/invertebrates thus receiving multiple amounts of pesticide;
top carnivores receive all pesticide passed on at all stages of the food chain; max 3

(b) auxin simulators are absorbed mainly through leaf surfaces;
plantains are broad leaved plants and so absorb large/toxic doses of herbicide;
grasses are narrow leaved plants and so absorb little/non toxic doses of herbicide; 3

(c) worm and flea infestations can cause much discomfort to the dog;
dog fleas will bite humans and cause discomfort, particularly if they cannot land on the dog;
tapeworms and nematode worms may infect humans and can be dangerous/ref Toxocara canis; 3

(d) a systemic insecticide enters the plant and persists for some weeks (in the phloem);
thus aphids are killed for several weeks if they suck sap from the rose/rose is protected from aphid attack for several weeks;
broad bean plants must not contain any traces of a systemic insecticide when the pods/beans are harvested for human/animal consumption; 3

Total 12

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