Bio Factsheet

www.curriculumpress.co.uk Number 111

Plant Growth Substances

The plant growth substances listed on specifications are auxins, gibberellins, cytokins, abscisic acid and ethene.
You are expected to know:
- **The main actions of these substances in regulating growth and development.**
- **How the substances interact together to regulate plant growth and development.**
- **The main commercial applications of the substances (their use in cloning will be covered in a Factsheet on 'cloning').**

Definitions

Plant growth substances. Chemicals that occur naturally in plants at very low concentrations. They regulate plant growth and development, from seed production and germination to ageing and death. They also regulate plant responses to environmental stimuli, for example, the phototropic and geotropic responses. The five main groups of plant growth substance are auxins, gibberellins, cytokinins, abscisic acid and ethene.

Synergism. When two or more plant growth substances interact to give a greater effect than the sum of their individual actions. For example, auxins and gibberellins act synergistically in promoting plant growth and apical growth.

Antagonism. When two or more plant growth substances interact to reduce each other's effects. For example, gibberellins and abscisic acid act antagonistically when controlling bud dormancy. Gibberellins break dormancy but abscisic acid causes dormancy.

Similarities and differences between plant growth substances and animal hormones

Plant growth substances do not necessarily move away from their sites of synthesis, and so cannot be defined as hormones because hormones do move to and act at places in the body distant from their site of synthesis. Plant growth substances only act in controlling various aspects of growth whereas hormones control a very wide range of physiological events in animals.

***Remember** – a plant contains a 'cocktail' of plant growth substances. It is not just one compound that produces a set response but a balance of concentrations of two or more growth substances.*

The actions of plant growth substances

Some of the most important of these are listed in Table 2 (overleaf). Remember that although specific functions can be ascribed to particular growth substances, their actual effects in the plant are modified by, for example:
- having different effects at different concentrations.
- having different effects at different developmental stages of the plant.
- having different effects on different tissues.
- having antagonistic or synergistic interactions with other growth substances.

***Remember** – a plant contains a 'cocktail' of plant growth substances. It is not just one compound that produces a set response but a balance of concentrations of two or more growth substances.*

Table 1. Comparison of plant growth substances with animal hormones

Feature	Plant growth substance	Animal hormone
Chemical nature	Fairly simple organic molecules, for example, ethene and indole-3-acetic acid (auxin).	Mainly complex proteins, for example, insulin, or complex steroids, for example, oestrogen.
Stimulus causing secretion	Usually environmental, for example, light direction, cold temperatures, gravity.	Usually a homeostatic change inside the body, for example, a fall in blood glucose concentration.
Site of secretion	Usually from tissues near or where they exert an effect, for example, stem and root tips.	From specialised endocrine glands, for example, the pituitary gland.
Transport to site of action	May exert its effect where produced, or diffuse for short distances, or be carried in the phloem or xylem for long distances.	In the blood and lymph. Animal hormones act on 'target organs' that are distant from the gland which secretes them.
Effects	Control various aspects of growth and development.	Wide range of functions in controlling, for example, blood pressure, metabolism, reproduction.
Speed of action	Slow and sustained.	Mostly slow but some act quickly, for example, adrenaline.

Table 2. Roles of growth substances in plants

Process affected	Auxins	Gibberellins	Cytokinins	Abscisic acid	Ethene
Stem growth	Promote cell extension in region behind tip and mitosis in cambium. Promotes positive phototropism (growth of the stem tips towards light).	Promote cell extension synergistically with auxin. Promotes cell division in apical meristem and cambium. Causes 'bolting' in some rosette plants.	Promotes cell division in apical meristem and cambium in the presence of auxins. Sometimes inhibits cell extension. Promotes rapid cell division in embryos.	Inhibitory, particularly during drought or waterlogging.	Inhibitory, particularly during drought or waterlogging.
Root growth	Promotes at low concentrations. Inhibits at higher concentrations.	Inactive.	Inhibit primary root growth.	Inhibitory.	Inhibitory.
Leaf growth	Inactive.	Promotes.	Promotes.	Inactive.	Inactive.
Fruit growth	Promotes. May induce parthenocarpy.	Promotes. May induce parthenocarpy.	Promotes. Rarely induces parthenocarpy.	Inactive.	Inactive.
Fruit ripening	Inactive.	Inactive.	Inactive.	Inactive.	Promotes.
Abscission (leaf fall)	Inhibits, but can promote once abscission starts.	Inactive.	Inactive.	Promotes.	Inactive.
Apical dominance	Promotes apical bud/ inhibits lateral bud growth.	Promotes synergistically with auxin.	Inhibits/antagonistic to auxins. Promote lateral bud growth.	Inactive.	Inactive.
Root initiation	Promotes growth of roots from cuttings/ calluses.	Inhibits root formation.	Inactive or can promote lateral root growth in some plants.	Inactive.	Inactive.
Seed dormancy	Inactive.	Breaks dormancy in, for example, cereals.	Breaks dormancy.	Promotes dormancy.	Inactive.
Bud dormancy	Inactive.	Breaks dormancy.	Breaks dormancy.	Promotes, for example, in sycamore and birch.	Breaks dormancy.
Stomatal mechanism	Inactive.	Inactive.	Promotes stomatal opening.	Promotes closing of stomata under conditions of 'water stress' (wilting).	Inactive.

Remember* – *parthenocarpy *is when plants develop fruits without having been pollinated. It is an example of* ***parthenogenesis*** *which is the production of offspring when fertilisation has not occurred.*

Exam Hint *: – Examiners frequently ask questions about the interactions of plant growth substances. When learning their functions, take particular notice of examples showing antagonistic or synergistic relationships.*

Auxins are made continuously in the shoot apex and in young leaves. They move mainly by diffusion from cell to cell and are eventually destroyed by enzymes. Long distance transport occurs from stem to roots via the phloem, although a small amount of auxin is made by root tips. Movement of auxin is **basipetal** (from apex to base of the organ) and **polar** (in one direction only).

Gibberellins are made in young leaves (in chloroplasts), buds, seeds and root tips. They move up and down the plant (non-polar movement) in phloem and xylem vessels.

Cytokinins occur most abundantly where rapid mitosis is occurring, particularly in fruits and seeds where embryos are developing. In mature plants they are made in the roots and move to the stem and leaves in the xylem (transpiration stream).

Abscisic acid is made in chloroplasts in leaves, stems, fruits and seeds. It mainly moves in the phloem, but also diffuses from cell to cell.

Ethene is produced by all plant organs. It is a gas and is quickly lost through the plant surface.

Mode of action of plant growth substances

- **Auxins** promote cell enlargement by causing loosening of the rigid cellulose microfibrils in the cell wall. This allows:
  1. more osmotic entry of water into the cell, thus swelling the cell by increasing turgor;
  2. synthesis of new cell wall material thus permanently extending the cell wall.

  The orientation of the cellulose microfibrils in the original cell wall determines the direction of extension of the cell. In the zone of elongation behind the apical meristem, auxins act to lengthen developing cells. 'Wall loosening' is caused by acid conditions, which are caused by auxins which activate proton pumps in the cytoplasm, thus stimulating the secretion of protons (hydrogen ions) which lower the pH around the cell wall.

  Auxins are though to be destroyed in the presence of light. This would explain why plants become etiolated (grow very tall and straggly) in continual darkness. In the light there is less auxin and thus less cell elongation; in the dark there is more auxin, because it is not destroyed, and so more elongation. It also explains the positive phototropic response shown by shoots growing towards one-sided light. On the illuminated side of the shoot there will be less auxin, because it is destroyed, whereas on the darker side of the shoot there will be more auxin present. Thus there is more cell elongation on the dark side of the shoot than on the light side resulting in the shoot turning towards the light source.

  Auxins also regulate growth responses to other unilateral stimuli, for example, gravity (geotropism) and water (hydrotropism).

- **Gibberellins** stimulate synthesis of the enzyme α– amylase in cereal grains. This enzyme can then mobilise the starch reserves in the seeds thus enabling germination. The gibberellins are thought to act by 'switching' genes on (induction) or off (repression).

- **Cytokinins** have a structure similar to the base adenine, found in DNA and RNA. Cytokinins are thought to be involved in the synthesis of transfer RNA molecules, which are used in polypeptide synthesis during cell division and early cell development.

- **Abscisic acid** possibly acts as a gene repressor 'switching off' genes thus acting antagonistically to the growth promotors, (auxins, gibberellins and cytokinins).

- **Ethene**: Its mode of action is not known, but it is a gas released from ripening fruits, stem nodes, ageing leaves and flowers. It does not travel widely through the air spaces of the plant but tends to be lost through the plant surface and stimulates ripening in nearby fruits.

Commercial applications of plant growth substances

Auxins: Many types of synthetic auxin have been developed and are more powerful and persistent than natural auxin (IAA or indole-3-acetic acid) because plants do not possess enzymes to destroy them.

- Fruit trees can be sprayed with auxins to help natural fruit setting, sometimes in the absence of pollination (parthenocarpy). Other auxins can be sprayed onto fruit trees to prevent premature fruit drop (abscission).
- The ends of cuttings, for example, geranium cuttings, can be dipped in auxin powder or auxin solution to stimulate root production.
- Auxins can be sprayed on harvested potatoes to prevent sprouting thus enabling longer storage.
- Auxins can be used as selective weedkillers. Broad-leaved dicotyledonous plants are more sensitive to auxins than narrow-leaved monocotyledonous plants. Dicotyledonous weeds, for example, plantains and dandelions, tend to grow rapidly (bolt) and die when sprayed with particular concentrations of auxin, leaving the monocotyledons, for example, grass or cereal crops, unaffected. The concentrations of auxin used also tend to inhibit root growth in dicotyledons.

Gibberellins: These are produced commercially from fungal cultures, for example, the fungus *Gibberella fujikuroi.*

- They can be sprayed on fruit trees and vines to stimulate fruit setting and parthenocarpy. An example of their use in parthenocarpy is to stimulate the development of seedless grapes.
- Gibberellic acid can be used in the brewing industry. It is sprayed onto barley grains and stimulates α–amylase production. This enzyme then converts the starch in the grains to maltose sugar, a process called 'malting'.
- They can be sprayed onto biennial plants during their first year of growth, stimulating them to flower during the first year of growth. Biennials which are not treated will not flower until the second year of growth.

Cytokinins: Synthetic cytokinins can be made by chemically modifying the nitrogenous base, adenine.

- Cytokinins can be sprayed onto the leaves of fresh leaf crops, for example, lettuce and cabbage to delay ageing (senescence) thus prolonging storage life.
- Cytokinins can also be sprayed onto cut fresh flowers or dissolved in the water they are standing in, so that they last longer before the petals shrivel and drop off.

Abscisic acid:

- Abscisic acid can be sprayed onto fruit trees to regulate fruit drop during the harvesting season. This removes the need for picking over a long time-span because all the fruit on a tree will ripen at the same time and so can all be picked at the same time.

Ethene:

- Ethene gas can be applied to pineapple plants to induce flowering.
- Ethene gas can be applied to many fruits, for example, tomatoes and citrus fruits, to stimulate ripening. Many fruits are prevented from ripening by storing them in an oxygen-deficient atmosphere. When they are needed they can be ripened by adding an atmosphere of ethene and oxygen.
- A commercial compound called 'ethephon', which breaks down to release ethene in plants, can be applied to rubber plants where it stimulates the flow of latex.

Practice Questions

1. Read through the following passage about auxins and then complete it by filling in the spaces with the most appropriate word or words.

Auxins, such as ……………………., are the most abundant plant growth substances. They are concerned with ………………. growth due to cell ………………… and differentiation. They also cause ………………………. to external stimuli, such as …………….. and ………………. . They also promote the growth of ……………… roots from stems, suppress the development of ……………. buds, and initiate ………………..development, even if pollination has not occurred (a process known as …………………..). Auxin is produced in the ……………… of stems and …………………. down to the target region.

Total 12

2. The table below shows the sites of production and main effects of some plant growth substances. Complete the table by writing appropriate information in the empty boxes.

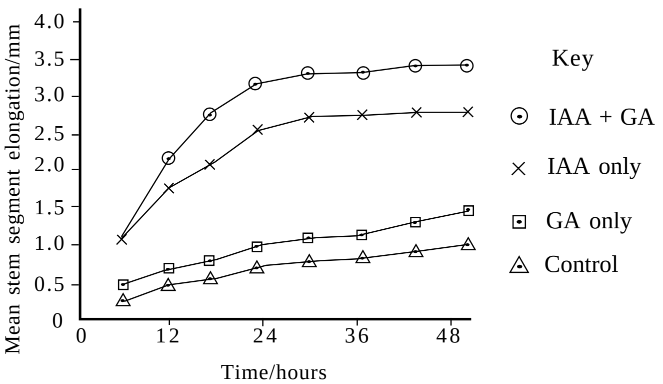
Name of growth substance	Site of production	One main effect
		promotes leaf fall
Ethene		
		Stimulates α– amylase production in germinating seeds.
		Promotes growth of stem tips towards light (positive phototropism)
		Stimulates rapid cell division in plant embryos.
		Promote stomatal opening.

Total 12

3. An experiment was performed to investigate the effects of auxin (IAA) and gibberellic acid (GA) on elongation of bean seedlings. Intemode sections of the plant/stems were used and kept in identical conditions apart from the following treatments.

The control batch received no growth substance
One batch received IAA only
One batch received GA only
One batch received both IAA and GA

The graph below indicates the results that were obtaine.



(a) (i) Compare the effects of the three treatments on the elongation of the bean segments. **4**
(ii) With reference to the results of this investigation explain the meaning of the term 'synergism'. **2**
(iii) Suggest a possible source of error in the experiment. **1**

(b) (i) Distinguish between the effects of auxins and cytokinins in regulating stem growth. **2**
(ii) Give an example of 'antagonism' between plant growth substances. **2**
(c) State two commercial applications of gibberellins. **2**

Total 13

4. The table below shows the effects of auxin at different concentrations on the growth of shoots and roots of oat seedlings. The elongation of the test seedlings was compared to the elongation of a group of control seedlings which did not receive auxin treatment. A positive value indicates that the test seedlings grew more than the controls and a negative value indicates that the test seedlings grew less than the controls.

Auxin concentration/parts per million	Elongation relative to control/mm	
	Shoot	Root
10^{-6}	0	+3
10^{-5}	0	+5
10^{-4}	+2	+11
10^{-3}	+6	+10
10^{-2}	+9	-3
10^{-1}	+34	-23
1	+60	-38
10	+33	-40
100	-22	-40

(a) Plot these results in a suitable graphical form. **5**
(b) Compare the response of the shoots to auxin with the reponse of the roots. **4**
(c) Synthetic auxins are used as weedkillers. Suggest how they operate selectively to kill broadleaved weeds such as thistles in a cornfield. **3**

Total 12

Answers

1. indole acetic acid/IAA; apical; elongation; tropic/growth responses; light; gravity/water; adventitious; lateral/axillary; fruit; parthenocarpy; tips; diffuses;

Total 12

2.

Name of growth substance	**Site of production**	**One main effect**
abscisic acid;	leaves/stems/fruits/ seeds;	
	ripening fruits;	promotes fruit ripening;
gibberellins;	embryo/seeds/buds/ young leaves/root tips;	
auxin;	stem/root tips	
cytokinins;	fruits/seeds; (embryo)	
cytokinins;	roots; (adult plants)	

Total 12

3. (a) (i) all caused greater elongation than the control;
GA alone had a small increase in (cell) elongation compared with the control group;
IAA alone had a much larger effect on stimulating (cell) elongation, especially over the first 30 hours;
IAA + GA had the greatest effect, especially over the first 24 hours/increase over three times greater than in control; **4**

(ii) when one substance enhances the effects of another substance;
gibberellic acid enhances the effect of auxin on (cell) elongation/ vica versa; **2**

(iii) seedlings may not be identical/seedlings may receive slightly different quantities of growth substance/cutting (the intemodes) may interfere with their growth; **1**

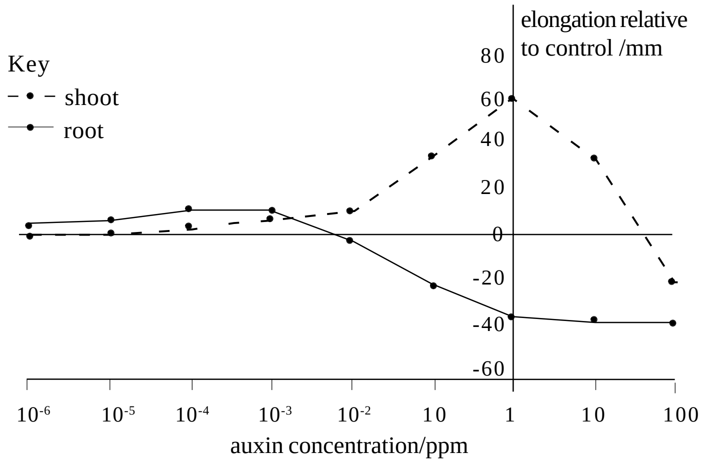
(b) (i) auxins stimulate cell elongation;
cytokinins stimulate cell division/mitosis; **2**

(ii) auxins and cytokinins in control of apical dominance;
auxins promote apical bud growth but inhibit lateral bud growth, cytokinins inhibit apical bud growth but stimulate lateral bud growth; **2**

(c) to encourage fruit setting;
to cause the development of seedless fruits/induce parthenocarpy;
to stimulate amylase production to promote 'malting' in the brewing industry; **max 2**

Total 13

4. (a) axes (auxin on X axis, elongation on Y axis);
suitable scale (at least half of graph paper and easy to use);
accurate plotting;
points joined with ruler (IOB recommendations);
curves labelled/key;
(accept alternative layouts) **5**



(b) root elongation stimulated most at low auxin concentration/around 10^{-4} ppm;
root elongation inhibited above 10^{-2} ppm/at higher auxin concentrations;
shoot elongation stimulated best at high auxin concentration/1 ppm;
not stimulated at low auxin concentrations/below 10^{-5} ppm;
inhibited at concentrations of 100 ppm; **max 4**

(c) (thistles are broad leaved whereas) cereals/corn species are narrow leaved;
thus thistles tend to absorb more auxin than cereals and so thistles affected more;
inhibit root growth whilst causing 'bolting'/overgrowth of shoots which die; **3**

Total 12

Acknowledgements:
This Factsheet was researched and written by Martin Griffin.
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ISSN 1351-5136