Bio Factsheet

www.curriculum-press.co.uk Number 355

Gibberellins and DELLA: The Genetic Control of Plant Growth

This Factsheet:

- Outlines the history of the discovery of gibberellins.
- Describes the role of gibberellins.
- Explains how gibberellins affect transcription.
- Discusses the biochemistry of gibberellin action.
- Describes examples of plant growth mutants.
- Outlines the importance of plant growth mutants.

Introduction

Plants produce several classes of growth substance which are often referred to as plant hormones. It is these chemicals that are responsible for a wide range of functions such as flowering, tropic responses, and fruit ripening (see **Table 1**). In many cases the exact mechanism of these growth substances is unclear but for others the metabolic pathways through which they bring about their effects are well documented.

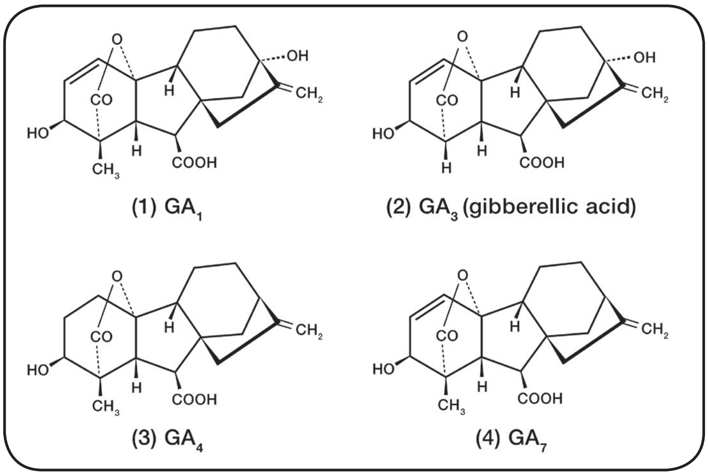
Table 1 The major groups of plant hormones

Class of hormone	Effects
Auxins	Cell elongation, tropic responses
Cytokinins	Stimulate cell division
Ethylene	Fruit ripening
Gibberellins	Stem elongation

Figure 1 'Foolish seedling' disease in a rice plant

As early as 1828, a disease that afflicted some rice plants in Japan was described. It was known as "foolish seedling disease" ("*bakanae*" in Japanese), as infected plants grew unusually tall and spindly (see **Figure 1**). This meant the plants fell over and died very easily. By the end of the 19th century the cause of the disease had been isolated and identified as a fungus called *Gibberella fujikuroi* (now known as *Fusarium fujikuroi)*. This fungus could be found growing in the soil around the roots of the rice plants. When scientists investigated further they found that the fungus produced a chemical that stimulated the spindly growth of the infected plants. The chemical acted in the same way as an overdose of a growth hormone. They named this chemical **gibberellic acid** (**GA**), after the genus of the fungus that produced it.

Figure 2 Selection of gibberellins



The Gibberellins

Now we know that there are many different types of gibberellic acid (collectively referred to as gibberellins) and they are produced by plants during normal growth. The different gibberellins all vary slightly in terms of the specific functional groups they possess. Only some of the gibberellins are **bioactive** which means they are able to stimulate a growth response in a plant. When scientists use the term gibberellic acid, they are actually referring to gibberellic acid 3, GA_3 (see **Figure 2**). From here on, we will use **GA** as an abbreviation for this gibberellic acid.

The Action of GA

GA exerts its effects by changing patterns of **gene expression** in growing plants. The pathway was worked out (in part) by studying the genetic and biochemical differences between dwarf and normal varieties of several species of plants. One protein – known as **DELLA** - was found to be very important in this pathway. DELLA protein acts as a **transcriptional repressor**. This means that it stops **RNA polymerase** from being able to transcribe (make mRNA copies of) certain genes.

Many genes can only be transcribed when proteins called **transcription factors** are present. These proteins help the RNA polymerase bind to a special sequence of DNA called the **promoter**. Once it is bound, the RNA polymerase can begin the process of transcription. DELLA protein binds to these transcription factors. The transcription factors are then unable to help RNA polymerase bind to DNA. This means the genes are not transcribed.

When GA is present, DELLA protein is destroyed by the cell. With no DELLA protein to block them, transcription factors are free to assist RNA polymerase. As a result, the genes that encode the proteins required for growth are expressed (see **Figure 3**).

Figure 3 Transcription of the proteins required for stem elongation

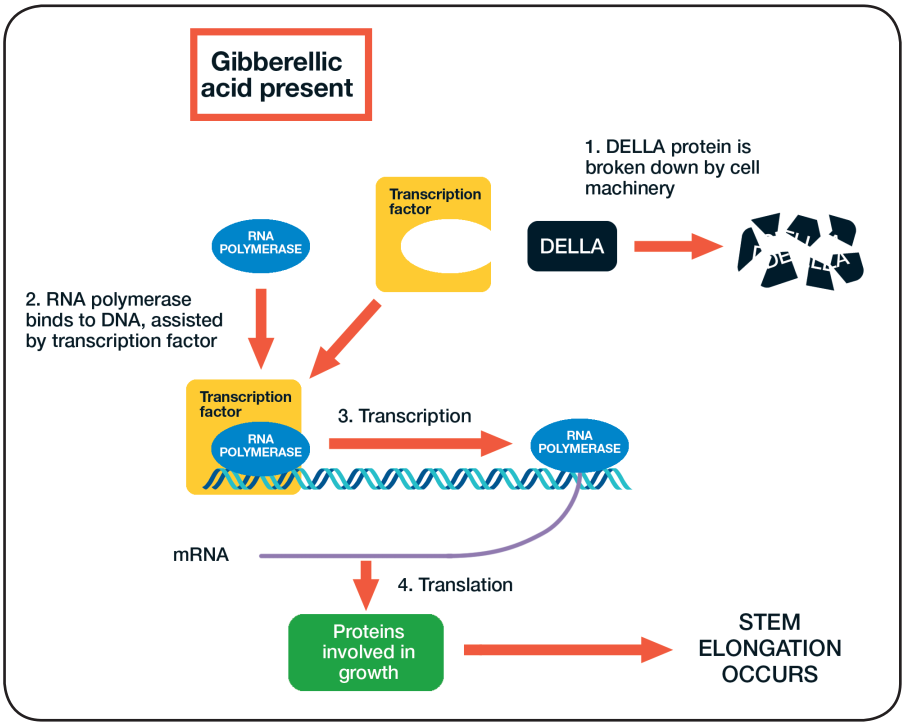
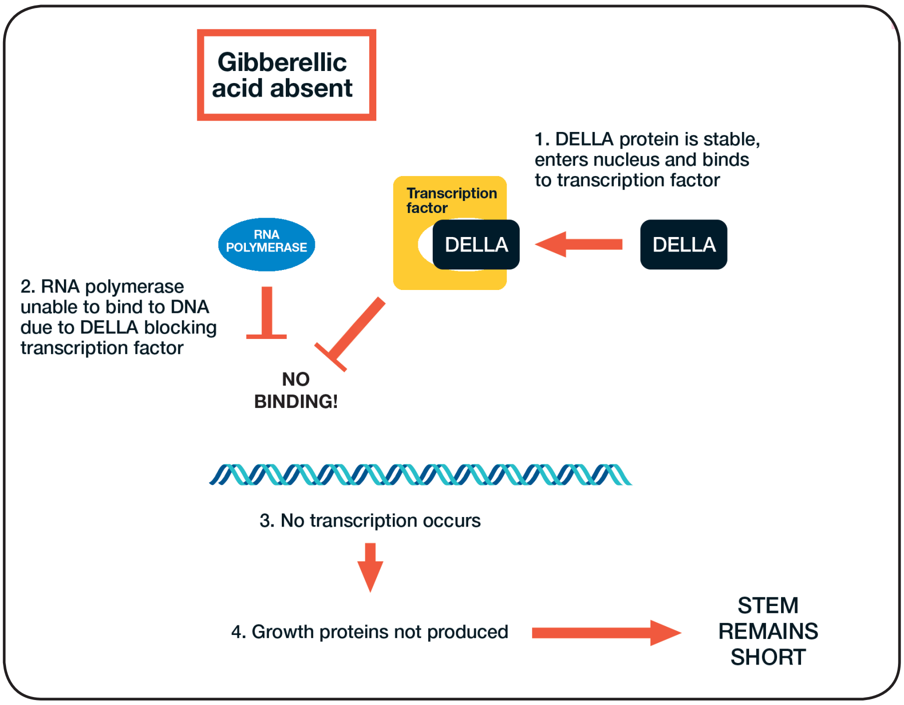


Figure 4 Repression of transcription by DELLA protein



When GA is not present, DELLA protein is stable and it binds to transcription factors and prevents transcription from occurring. There is no expression of the proteins needed for stem elongation so no growth occurs (see **Figure 4**).

In a healthy plant, the level of GA (and therefore DELLA protein) is carefully regulated to control how much stem growth occurs. This ensures that the plant does not stay too short (like a dwarf variety) or grow too spindly and tall (like a plant suffering from bakanae).

Biochemistry of GA Action

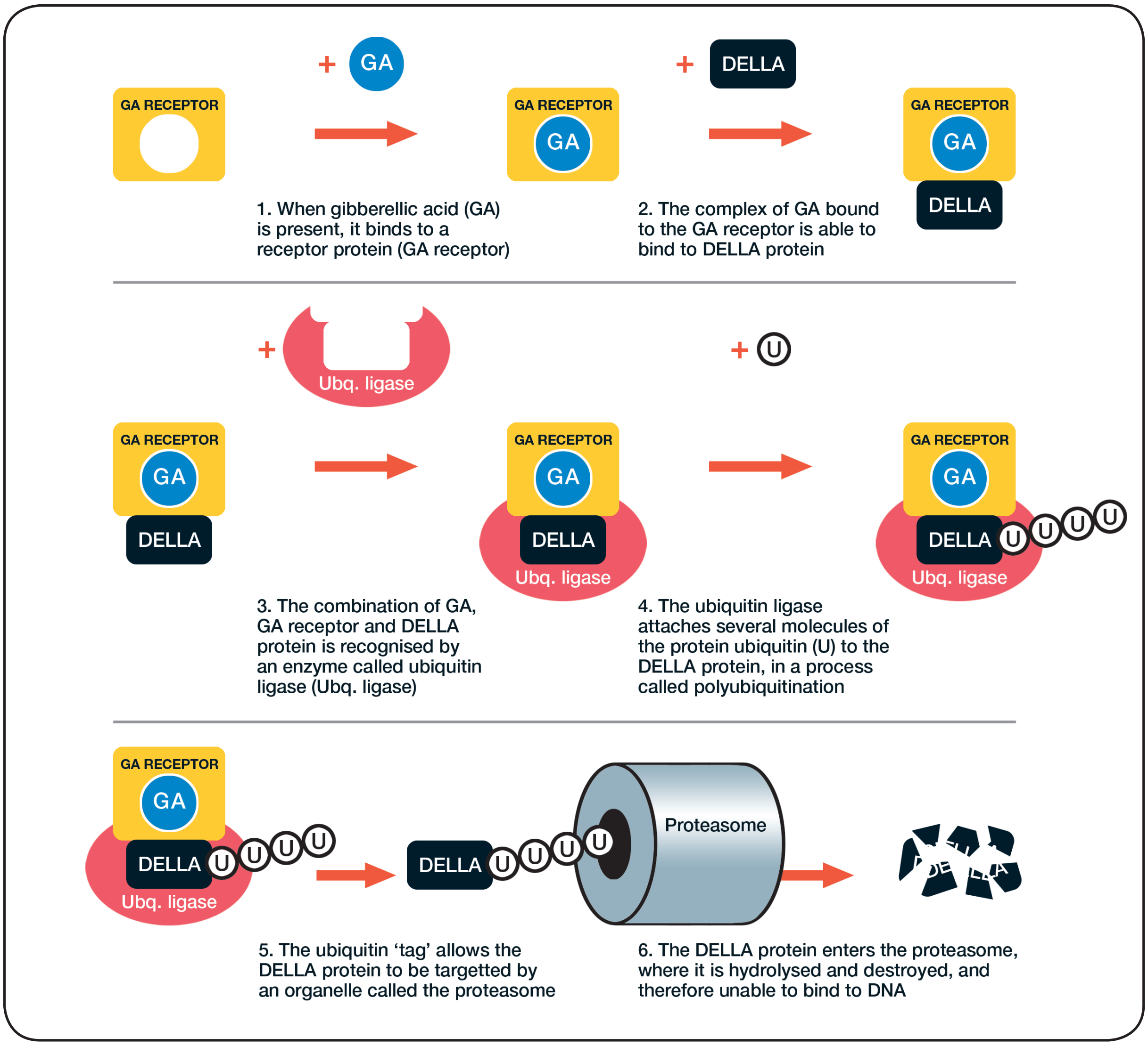
The next question is, how does the presence of GA actually lead to the destruction of DELLA protein? GA is a plant hormone and, like all hormones, it must bind to a **receptor** in order to have an effect. Plants produce a GA receptor. When the receptor binds to GA, it triggers a complex sequence of events (see **Figure 5** on **Page 3**) that ultimately lead to the destruction of DELLA protein. This prevents DELLA protein from turning the growth genes off. The steps are as follows:

- When GA is present in a plant cell, it binds to a receptor protein. This forms a **GA-receptor complex** that enters the nucleus.
- The GA-receptor complex binds to DELLA protein.
- The combination of GA, GA-receptor and DELLA protein is recognised by an enzyme called **ubiquitin ligase**. This enzyme binds to the complex.
- The ubiquitin ligase catalyses the addition of a **polyubiquitin** tag to the DELLA protein. **Ubiquitin** is a small protein found in all eukaryotic cells. It is named because it is ubiquitous (found everywhere).
- Ubiquitin tags are a type of molecular 'flag' that are recognised by a structure in the cell called the **proteasome**. Proteasomes are small protein-recycling organelles. They destroy any protein that has been marked with a ubiquitin tag.
- The proteasome breaks down the tagged DELLA protein by hydrolysing it into its constituent amino acids. With the DELLA protein destroyed, transcription of genes involved in cell growth takes place. The plant is able to grow.

Explaining plant growth mutants

With an understanding of the GA/DELLA pathway, it is now possible to explain the genetic basis of various plant growth mutants. Any mutation that affects the genes coding for proteins involved in the GA/DELLA pathway could potentially affect plant growth. We will look at three examples of such mutants.

Figure 5 The steps leading to destruction of DELLA protein



Plant Growth Mutants 1: Dwarf Wheat

There are many different causes of dwarfism in wheat plants. One cause is due to mutations in the gene for the DELLA protein itself. In these mutants, the altered DELLA protein is able to repress transcription in the normal way. However, it is not able to bind to the GA-receptor complex formed when GA is present. This means that the presence of GA does not lead to DELLA breakdown so growth is permanently repressed. These mutants are usually dominant. A heterozygous individual would produce mutant DELLA protein that repressed growth even though some 'normal' DELLA would also be being synthesised.

Plant Growth Mutants 2: Mendel's Dwarf Peas

Gregor Mendel worked with pea plants. One characteristic he investigated was the inheritance of height. He found that dwarfism in pea plants was a recessive characteristic. We now know that the inherited allele for dwarfism codes for an enzyme involved in gibberellin biosynthesis, even though some 'normal' DELLA would also be being synthesised.

The gene involved affects the length of the pea plant stems. Geneticists decided to abbreviate it to 'Le'. The gene exists in two alleles:

- The dominant Le allele, which encodes a functional enzyme.
- The recessive le allele, which encodes a mutant enzyme that cannot complete gibberellin synthesis.

This explains why this particular form of dwarfism is inherited in a recessive fashion. Only one copy of the non-mutant allele needs to be present for the plant to be able to synthesise bioactive gibberellin, and hence remove the repression of growth caused by DELLA protein. To be a dwarf pea plant requires the inheritance of two le alleles. This means that there is no functional enzyme and therefore no gibberellin synthesis. In this case, it is not possible to trigger the destruction of DELLA in order to lift its repression.

Plant Growth Mutants 3: Tall Wheat Mutants

In the first example, we described a mutant DELLA protein that could repress transcription but could not bind to the GA-receptor complex needed to destroy the DELLA protein. In some tall wheat mutants, the opposite happens. The mutation affects part of the DELLA protein which means it is unable to bind to transcription factors. The result is the same as if DELLA had been destroyed and the plant responds as though GA is always present. It grows tall and spindly due to the permanent lack of transcriptional repression.

The Importance of Plant Growth Mutants

During the middle of the 20th century, great changes occurred in worldwide agricultural practices resulting in tremendous increases in production. Many of these changes were technological, but one of the most significant was the discovery of dwarf varieties of important cereals such as wheat and rice. These dwarf varieties provided a greater yield of grain for two reasons:

1) They had more energy available to put into producing grain as they did not waste energy on growing tall.
2) Shorter, sturdier crops were less likely to fall over and spoil than their taller cousins.

Extensive breeding programs resulted in the worldwide adoption of such high-yielding dwarf varieties. This 'green revolution' has been credited with preventing the starvation of huge numbers of people across the world.

Questions

1) It acts as a transcription blocking factor in dwarf rice. It is not removed by the ubiquitin / proteasome mechanism because of a mutation that results in a lack of gibberellin.

Name the molecule.

[1]

2) Read the following statements:

- Gibberellins belong to a group of chemicals known as terpenoids. They are made up of the elements carbon, hydrogen and oxygen only.
- In the pea plants that Mendel studied, the stem length gene, Le /le, controls the length between nodes.
- Pure-breeding, tall pea plants were crossed with pure-breeding, dwarf pea plants. The F1 generation plants were all of the same height. When these were crossed, the numbers of tall and dwarf plants in the F2 generation were counted. There were 787 tall and 277 dwarf plants.
- The dwarf variety of the pea plant lacks gibberellin.
- Addition of gibberellin to the dwarf plants results in conversion of the dwarf to the tall phenotype.

Which of the following can be concluded from these statements?

a) Heterozygous genotypes for the stem length gene are of an intermediate height, as only 50% of the product of gene expression is synthesised.

b) The lack of a ratio of 3 tall pea plants to 1 dwarf pea plant in the F2 generation means that there is an environmental effect contributing to height in pea plants.

c) The Le /le gene codes for the protein gibberellin, with only the LeLe or Lele genotypes expressing gibberellin and with the lele genotype unable to express gibberellin.

d) There is at least one altered triplet code in the dwarf allele of the Le /le gene, producing a polypeptide with an altered tertiary structure and resulting in a non-functioning protein.

[1]

3) Gibberellins are a group of signalling molecules. Describe how gibberellins stimulate stem elongation in flowering plants.

[3]

Answers

1) DELLA (protein)

2) D

3) Gibberellins promote stem elongation by stimulating cell elongation.

Cell elongation in plant cells is (normally) suppressed by, DELLA / a repressor protein.

Gibberellic acid (binds to a receptor and) causes the degradation of;

DELLA / repressor / protein (allowing cell elongation).

Gibberellin synthesis may be triggered off by (external / environmental) factors.

Gibberellin activity may be affected / modified by auxin / IAA / concentration.

[Max 3]

Acknowledgements: *This* ***Biology Factsheet*** *was researched and written by* ***Aaron Bridges*** *and published in* ***September 2018*** *by* ***Curriculum Press****.* ***ISSN 1351-5136***