RIVER VALLEY HIGH SCHOOL
JC 2 PRELIMINARY EXAMINATION

CANDIDATE NAME	

CENTRE NUMBER	S					CLASS	22J	INDEX NUMBER				

BIOLOGY **9744/03**

Paper 3 Long Structured and Free-response Questions **15 September 2023**

2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE ON ANY BARCODES.

Section A
Answer **all** questions in the spaces provided on the Question Paper.

Section B
Answer any **one** question in the spaces provided on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.
You may lose marks if you do not show your working or if you do not use appropriate units.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	
2	
3	
Section B	
Total	

Section A

Answer **all** the questions in this section.

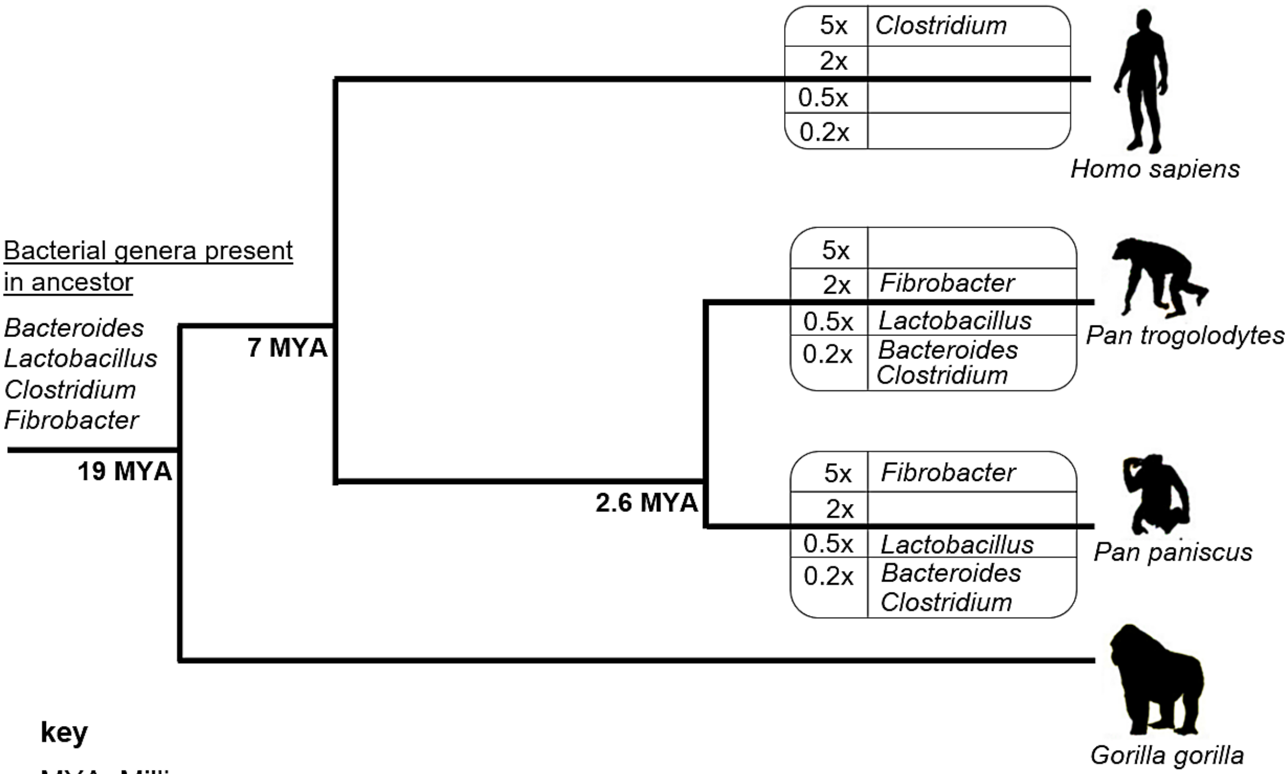
1 The gut microbiota is the community of all micro-organisms (bacteria, archaea, protozoa, fungi, and viruses) present in the digestive tract. Bacteria are the largest component of the microbiota.

(a) Describe the structure of bacterial genome. [3]

Question 1 continues on page 4

Gut bacteria are present in a range of species in Kingdom Animalia including insects, fish, and apes. Gut bacteria are passed vertically from mother to offspring. Its composition and abundance have changed in the generations with evolutionary time.

Fig. 1.1 shows the relative change in abundance of selected bacterial taxa in the evolution of humans (*Homo sapiens*). Relative change is shown by the "_x" in the box beside the descendant species, for example "5x" refers to a five times increase in abundance from the ancestor.



key

MYA: Million years ago

Adapted from Moeller et al, PNAS, 111(46), 2014

Fig. 1.1

(b) With reference to the **animals** in Fig. 1.1, explain how phylogeny is related to classification. [2]

Diet has a significant influence on gut bacteria composition. Different diets contribute different nutrients to the digestive tract which affects the presence and proportion of various bacterial genera. Chimpanzees' (genus: *Pan*) diet mainly comprise of plants and plants' produce, with meat contributing only 2% of their diet.

Table 1.1 shows how different nutrients affect selected bacterial genera.

Table 1.1

nutrient		bacterial genus		
		Bacteroides	*Clostridium*	*Fibrobacter*
carbohydrates	digestible (e.g. fruit)	–	–	+
	non-digestible (e.g. plant fibers)		–	++
protein	animal-derived	+	++	–
	plant-derived	–		+
fats	animal-derived	+	+	–
	plant-derived	–	–	

Adapted from Tomova et al, Frontiers in Nutrition, 6(47), 2019

key

\+ nutrient causes an increase in abundance of bacteria
– nutrient causes a decrease in abundance of bacteria
▒ shaded boxes mean that information is unknown

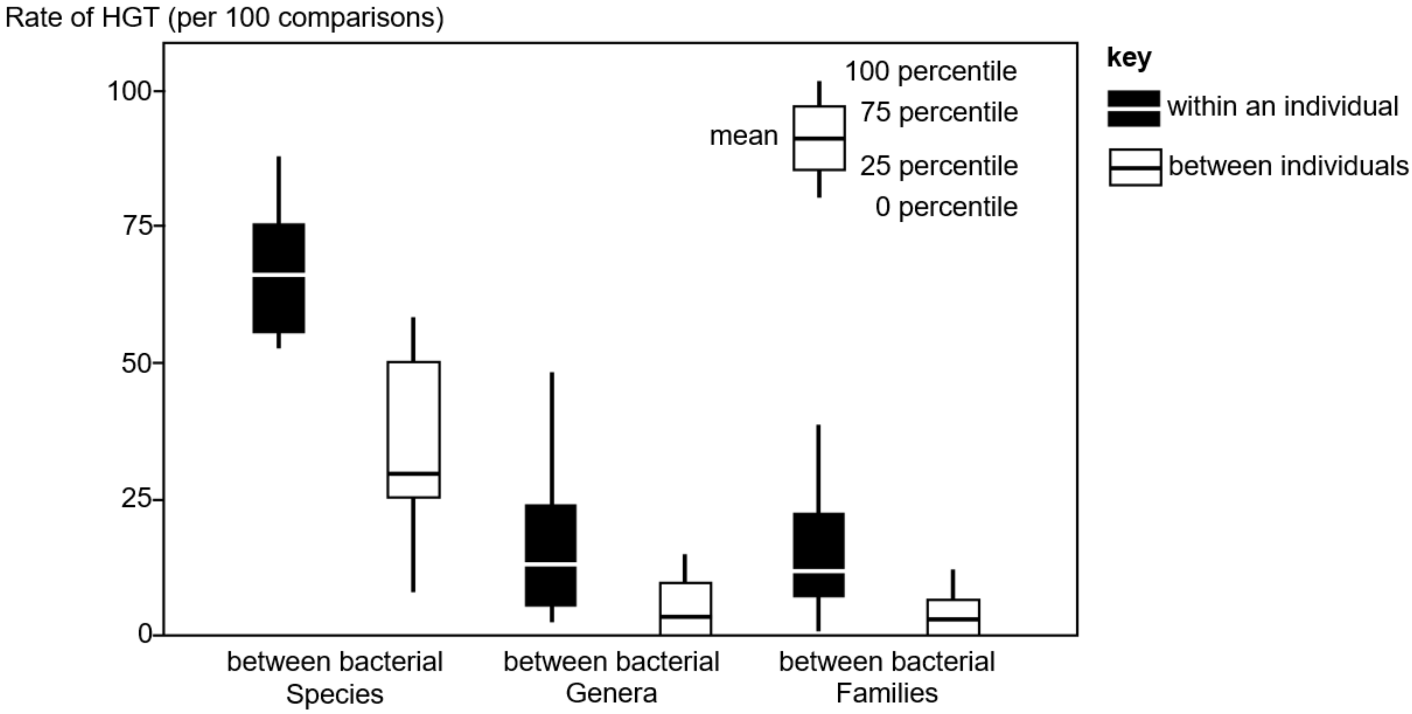
(c) Using your knowledge and information from Fig. 1.1 and Table 1.1,

(i) predict the change in proportion for *Bacteroides* and *Fibrobacter* in the gut of *Homo sapiens* and fill in the boxes in Fig. 1.1 with their genus names, and [2]

(ii) comment on the validity of the statement "gut bacteria can act as evidence of evolution". [4]

Horizontal gene transfers (HGT) occur frequently in gut bacteria, particularly in response to selection pressures targeting new functions such as antibiotic resistance.

Fig. 1.2 shows the HGT rate of antibiotic resistance genes across taxonomic levels of bacteria, and two sets of data, the HGT rate **within** an individual's gut and the HGT rate **between** two individuals' gut.



Adapted from Kent et al, Nature Communications, 2020

Fig. 1.2

(d) **(i)** Outline how antibiotic resistance genes are transferred between bacteria. [3]

(ii) Account for **one** similarity and **one** difference in the two data sets in Fig. 1.2. [4]

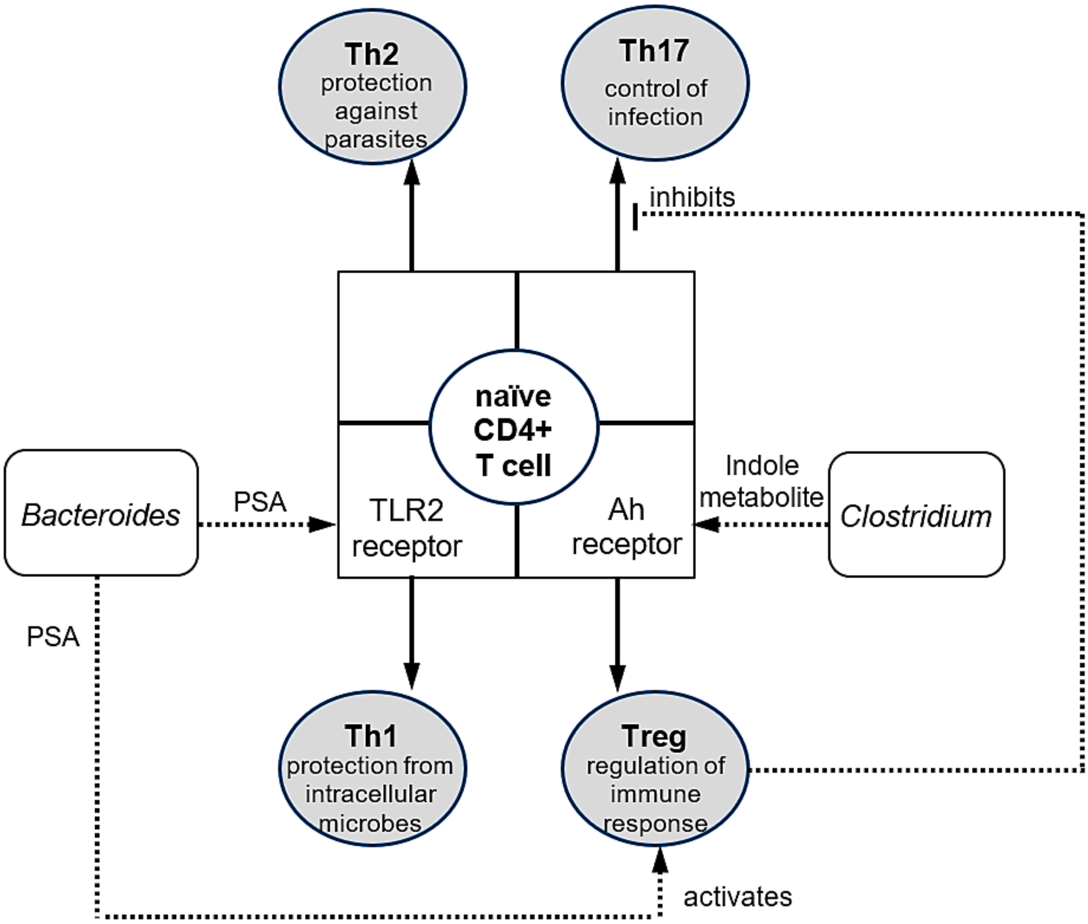
Gut bacteria provide essential health benefits to their hosts. These include nutrient metabolism, drug metabolism and regulating immune homeostasis. Gut bacteria have a role in innate immunity, and more importantly can also induce T lymphocyte differentiation.

Details of how gut bacteria induces T lymphocyte differentiation are provided below:

- Naïve CD4+ T cells can differentiate into four major T cell subtypes: Th1, Th2, Th17 and regulatory T cell (Treg).
- Differentiation into subtypes Th1 and Treg can be triggered by gut bacteria.
- *Bacteroides* and *Clostridium* secrete Polysaccharide A (PSA) and indole metabolite respectively, which bind different receptors on the naïve CD4+ T cell.
- This induces different transcription factors resulting in differentiation into the 4 lineages.

Uncontrolled Th1 and Treg responses result in gastrointestinal-associated autoimmune diseases while uncontrolled Th2 responses result in allergic reactions.

Fig. 1.3 shows the interactions of gut bacteria, *Bacteroides* and *Clostridium*, on naïve CD4+ T cells and its differentiated T cell subtypes.



Adapted from Wu et al, Gut Microbes, 4(14), 2012

Fig. 1.3

(e) Using information provided in this entire question, deduce the outcomes on an individual with a gain-in-function mutation of the promoter of the TLR2 receptor gene, and living in a country of high affluence. [5]

(f) State the advantage of cell signalling shown in Fig. 1.3. [1]

(g) Scientists identified Mg^{2+} ion as a possible second messenger involved in T lymphocyte activation.

Describe the nature of second messengers such as Mg^{2+}. [1]

[Total: 25]

2 Apoptosis is an important part of tissue homeostasis. It ensures that cells die quickly and are safely removed when necessary.

(a) Protein kinases play an important role in the cell signalling pathway leading to apoptosis.

Explain the role of protein kinases. [2]

(b) The BCL-2 protein is involved in the regulation of apoptosis. It is a monomeric protein consisting of a single polypeptide chain.

Outline how BCL-2 protein is synthesised from its mRNA. [5]

Question 2 continues on page 12

The *BCL-2* gene is a proto-oncogene found on chromosome 18. In B-cell lymphoma, a cancer involving B-cells, a mutation shifts the *BCL-2* gene to a different chromosome where the gene coding for antibodies (*IgH*) is found.

Fig. 2.1 shows the mutation and how it results in the disruption of the apoptotic pathway.

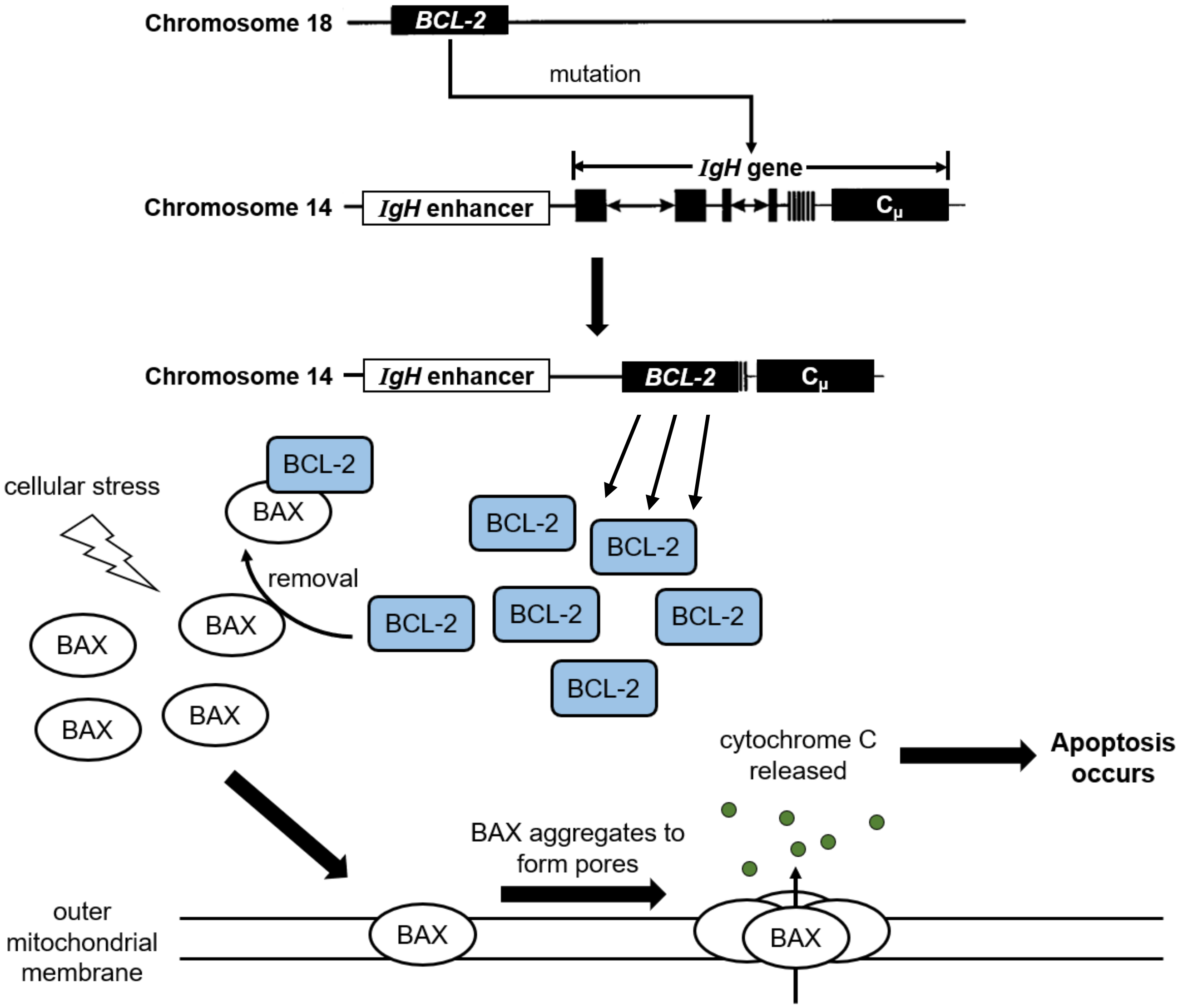


Fig. 2.1

Adapted from Konstantinidis and Tiedje, PNAS, 2004

(c) With reference to Fig. 2.1, explain how the mutation of *BCL-2* proto-oncogene results in B-cell lymphoma. [4]

In chemotherapy, a prescribed drug is used to kill dividing cancer cells.

Fig. 2.2 shows the number of healthy cells and cancer cells per unit volume of blood in a patient receiving chemotherapy. The arrows labelled **F** to **I** show when the prescribed drug was given to the patient.

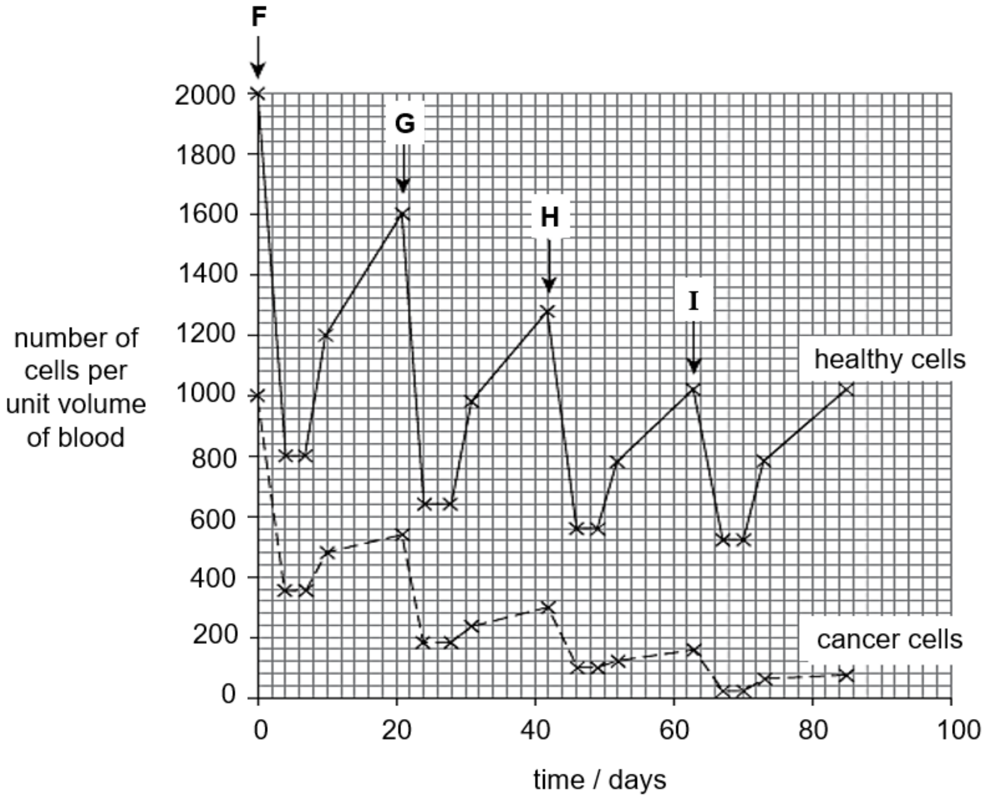


Fig. 2.2

(d) With reference to Fig. 2.2, describe the limitations of using chemotherapy in treating cancer patients. [4]

[Total: 15]

Question 3 starts on page 16

3 Maize (*Zea mays*) is a staple food that originated in the Americas. Due to its importance in global food security, much research has been undertaken in particular to understand how maize may be affected by changes in the climate.

In one experiment carried out in 1998 and 2022, scientists investigated the relative effects of genotype and environment on the yield of maize.

Maize seeds with different 'inbreeding coefficients' were used. The greater the inbreeding coefficient, the greater the degree of homozygosity in the maize plants.

Maize seeds with different inbreeding coefficients were planted in two different areas in 1998, and in the same two areas in 2022.

Fig. 3.1 shows the results.

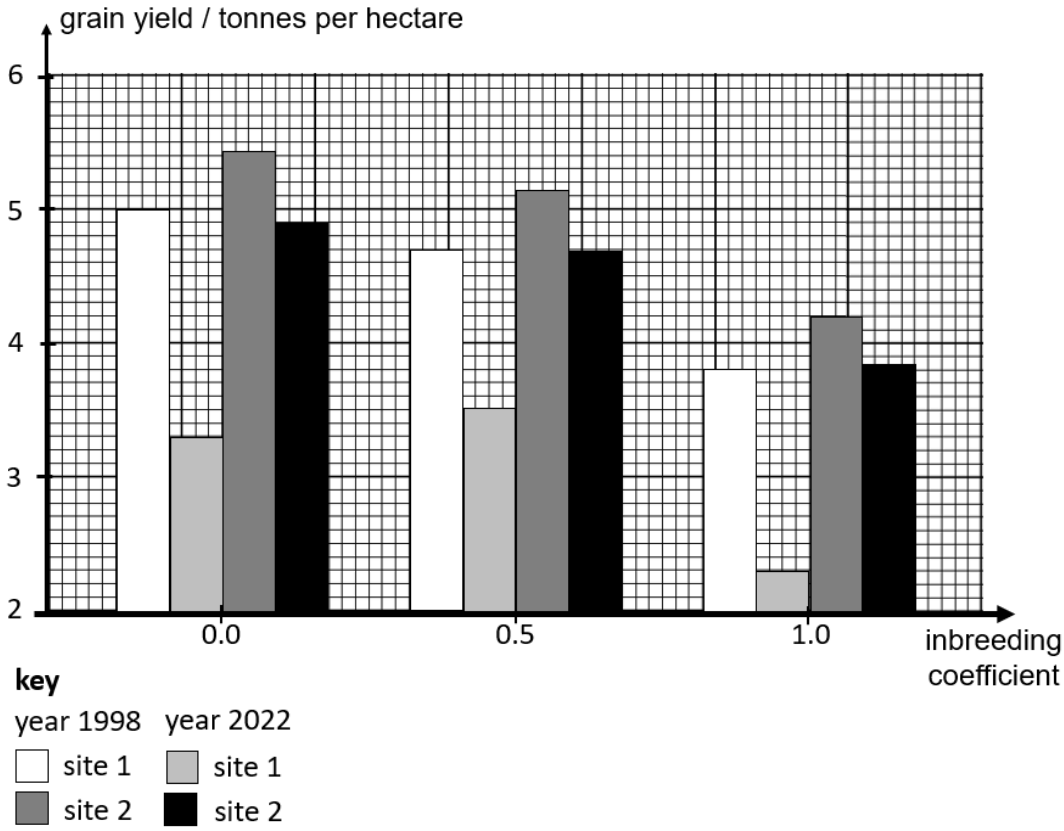


Fig. 3.1

Table. 3.1 shows the average annual environmental conditions at the two areas, where all other variables are kept constant.

Table. 3.1

site	year 1998			year 2022		
	temperature / °C	precipitation / mm	acidity / pH	temperature / °C	precipitation / mm	acidity / pH
site 1	28.3	870	6.8	28.5	420	7.1
site 2	30.7	650	7.2	27.4	880	6.9

The optimal conditions for maize are for annual temperature (28 °C – 32 °C), for annual precipitation (600 mm – 1000 mm) and for soil acidity (pH6 – pH7).

(a) Inbreeding depression is a reduction in vigour that results from inbreeding.

Using the information provided, evaluate if inbreeding depression in maize is affected by the environment. [4]

The fluctuation of external environmental conditions often has limited effect on internal conditions of living organisms. This is particularly important in cells to maintain optimum conditions for metabolic processes to proceed.

(b) The optimum pH for activity of rubisco is pH8.

Explain how the illumination of chloroplasts leads to optimum pH conditions for rubisco. [3]

Due to the more limited migration range as compared to animals, plants often have to adapt to changes in their habitat's environment.

Fig. 3.2 shows the relationship between stress due to high light intensity and temperature, and some of the short-term and long-term adaptations plants may employ.

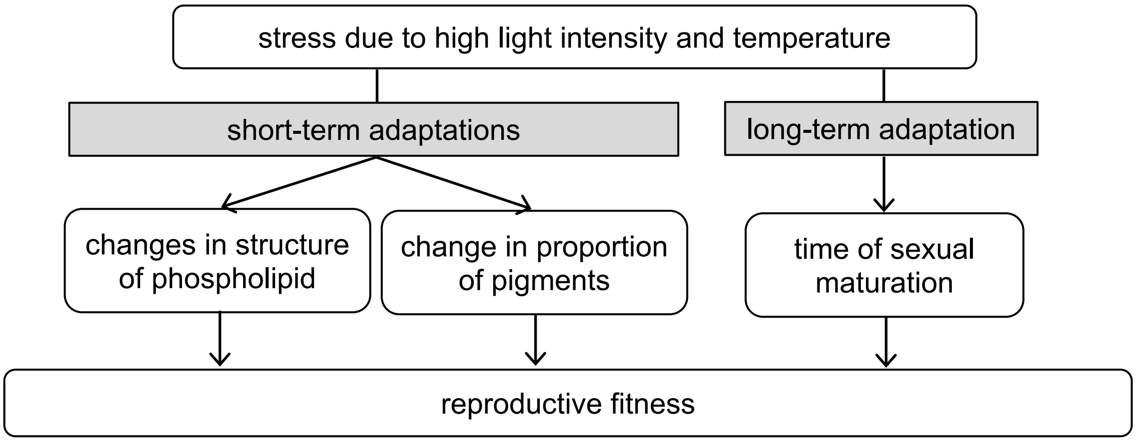


Fig. 3.2

Adapted from Mathur et al., J Photohem Photobiol B., 2014

(c) With reference to Fig. 3.2, explain how plants improve their reproductive fitness in response to stress due to high light intensity and temperature. [3]

[Total: 10]

Section B

Answer **one** question in this section.

Write your answers on the lined paper provided at the end of this Question Paper.

Your answers should be illustrated by large, clearly labelled diagrams, where appropriate.

Your answers must be in continuous prose, where appropriate.

Your answers must be set out in parts **(a)** and **(b)**, as indicated in the question.

4 **(a)** Carbohydrates are involved in various functions in a living organism, including energy storage and structural support.

Describe the structural significance of **two** named carbohydrates to their different functions and explain how a wide variety of carbohydrate structures is achieved. [15]

(b) Outline the reproductive cycles of a temperate phage and describe the differences between the release of bacteriophages and the movement of water across membranes. [10]

[Total: 25]

5 **(a)** Stem cells have different potency levels and can differentiate into all cell lineages in a living organism.

Describe the role of **two** named stem cells of different potency levels and suggest ways to identify different cell types in an organism. [15]

(b) Outline how antibody diversity is achieved and the ways viruses avoid detection from the hosts' immune system. [10]

[Total: 25]

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