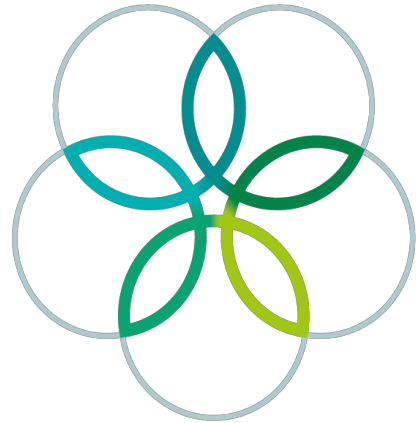
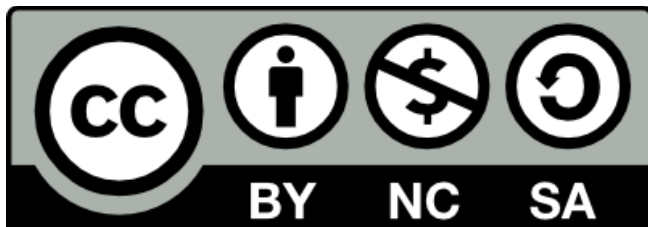


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Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-1

English (Official)

Theory 2

34th International Biology Olympiad

3-10 July 2023, United Arab Emirates University

Duration: 3 hours

General Instructions:

No answers on the exam paper will be graded.

You will use a dedicated browser application to enter your responses. This application includes two different types of screens, namely question screen and "Translation" screen.

You do not need to submit the exam: it will be submitted automatically, once the exam is over. There will be a timer showing the time remaining until the end of the exam.

YOU MUST PRESS "Save" after completing EACH question or else your answers will not be registered.

You MUST NOT quit the Safe Exam Browser.

Questions which are fully or at least partially answered and saved are highlighted in green in the side panel. You can flag questions, and these will be highlighted in orange in the side panel. The current question is highlighted in blue.

To see an electronic copy of the questions, press "Translation". You can select any language version by using the dropdown menu.

You can search specific text using Ctrl-F, but you must first click on the window.

If you minimise the electronic copy of the questions, you can quickly return to it by clicking the icon on the bottom left of the screen.

If you face any technical issues with your computer, raise your card.

Use the following cards to ask for water/washroom/help.

Drinking water	Washroom	Other queries
		



TTT Phe (F)	TCT Ser (S)	TAT Tyr (Y)	TGT Cys (C)
TTC Phe (F)	TCC Ser (S)	TAC Tyr (Y)	TGC Cys (C)
TTA Leu (L)	TCA Ser (S)	TAA STOP	TGA STOP
TTG Leu (L)	TCG Ser (S)	TAG STOP	TGG Trp (W)
CTT Leu (L)	CCT Pro (P)	CAT His (H)	CGT Arg (R)
CTC Leu (L)	CCC Pro (P)	CAC His (H)	CGC Arg (R)
CTA Leu (L)	CCA Pro (P)	CAA Gln (Q)	CGA Arg (R)
CTG Leu (L)	CCG Pro (P)	CAG Gln (Q)	CGG Arg (R)
ATT Ile (I)	ACT Thr (T)	AAT Asn (N)	AGT Ser (S)
ATC Ile (I)	ACC Thr (T)	AAC Asn (N)	AGC Ser (S)
ATA Ile (I)	ACA Thr (T)	AAA Lys (K)	AGA Arg (R)
ATG Met (M)	ACG Thr (T)	AAG Lys (K)	AGG Arg (R)
GTT Val (V)	GCT Ala (A)	GAT Asp (D)	GGT Gly (G)
GTC Val (V)	GCC Ala (A)	GAC Asp (D)	GGC Gly (G)
GTA Val (V)	GCA Ala (A)	GAA Glu (E)	GGA Gly (G)
GTG Val (V)	GCG Ala (A)	GAG Glu (E)	GGG Gly (G)

This is a standard codon table which may be useful for some questions.



Q.1

Some bat species are well adapted to the Arabian desert. The pictures show adaptations of a bat of the genus *Rhinopoma* (Mouse-tailed Bat).



True or false?

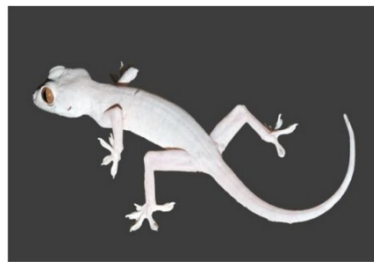
- | | | |
|-------|---|-------|
| Q.1.1 | The closable nostrils, and the fringe of hairs around the mouth, limit the penetration of dust and sand into the bat's nose and mouth. | 1.0pt |
| Q.1.2 | The long tail is an adaptation for crawling, gripping and balancing in areas with dense stands of trees and shrubs. | 1.0pt |
| Q.1.3 | Having relatively sparse hair and large areas of loose skin facilitates thermoregulation in hot desert conditions. | 1.0pt |
| Q.1.4 | Active flight, as a low-energy mode of locomotion, helps bats conserve energy in desert conditions with poor food sources. | 1.0pt |
| Q.1.5 | The ability to fly allows bats to efficiently cover considerable distances between suitable roosts and unevenly distributed food sources in the desert. | 1.0pt |



Q.2

The Arabian Peninsula is one of the world's hotspots of lizard diversity.

Lizards occupy a wide variety of habitats and are therefore very diverse in appearance.



1



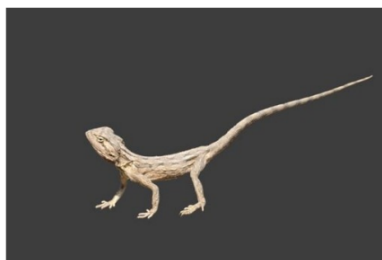
2



3



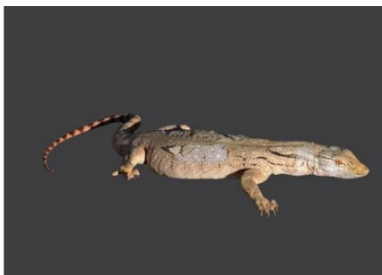
4



5



6



7



8

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-5

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True or False?

Q.2.1 Assuming the pictures were taken in daylight, lizards 3 and 6 are nocturnal lizards.	1.0pt
---	-------

Q.2.2 Lizard 1 could be adapted to live in limestone caves.	1.0pt
--	-------

Q.2.3 Lizards 7 and 8 are both grounds-dwelling predators.	1.0pt
---	-------

Q.2.4 Compared to other lizards in the pictures, lizards 2 and 5 display a morphological characteristic typical of animals adapted to living in colder areas.	1.0pt
--	-------

Q.2.5 Lizards 3 and 8 are fully homeothermic.	1.0pt
--	-------

Q.2.6 Lizards 5 and 6 have the necessary adaptations for burrowing.	1.0pt
--	-------

**Q.3 Shell drilling**

A fictional marine bivalve mollusk 'sea carpet bag' is a prey of carnivorous sea snails.

The sea snails drill through bivalve shells to inject poison which relaxes the bivalve muscle-adductor. Muscle-adductor relaxation allows bivalve shells to be opened and the hunting snail eats the sea carpet bag.

Scientists divided the surface of sea carpet bag shells into four areas with equal size:

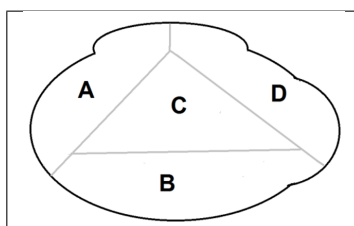
A – anterior area.

B – basal area.

C – central area.

D – distal area

Representative set comprises 100 dead sea carpet bags was analyzed. The number of holes drilled by hunting snails in different areas, and their combinations, are shown in the Table.



Drilling Position	Single hole				Pairwise combination of holes					
	A	B	C	D	AB	AC	AD	BC	BD	CD
Number of shells	23	5	6	25	4	4	16	1	3	5

Drilling position	Triple combination of holes	No holes
Number of shells	2 (1 ABD and 1 ACD)	6

True or False ?

Q.3.1 Hunting snails prefer to drill the anterior end of sea carpet bags and avoid the distal end of shells. 1.0pt

Q.3.2 The sea carpet bag probably has two muscle-adductors, the first in area A and the second in area D. 1.0pt

Q.3.3 Hunting snails are one of the major predators of sea carpet bags. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-7

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Q.3.4 From the data, we could conclude that if the first drilling does **not** result in bivalve opening, hunting snails prefer to repeat their attack on the same sea carpet bag. 1.0pt

Q.3.5 A possible explanation to the data is that some hunting snails could be drilling sea carpet bags which are already dead. 1.0pt



Q.4

The majority of plants serve as food for insects, despite their toxic secondary metabolites.

Several plant pathogenic viruses are spread by whitefly (*Bemisia tabaci*), an agricultural pest with a world-wide distribution.

Whiteflies have acquired the gene *BtPMT1*, which encodes a phenolic glucoside malonyl transferase, which may help them neutralize phenolic glucosides.

According to bioinformatics studies, *BtPMT1* has closest homologs in plants, but no homologs in other arthropods.

To test whether the *BtPMT1* gene is involved in the metabolism of phenolic glucoside in host plants, the effect of several phenolic glycosides on adult whitefly mortality was tested. Many invertebrates can uptake long double stranded RNA (dsRNA) and process them into small interfering RNAs (siRNAs). Dietary RNA interference (RNAi) was performed by feeding whiteflies a diet containing dsRNA. This was followed by feeding of solutions containing five different phenolic glycosides.

In RNAi-fed *B. tabaci*, *BtPMT1* expression was reduced by almost 50% at 48 h post-RNAi compared with the control. Furthermore, the whiteflies showed very high mortality rate when they were fed transgenic tomato plants expressing the dsRNA against the *BtPMT1* gene.

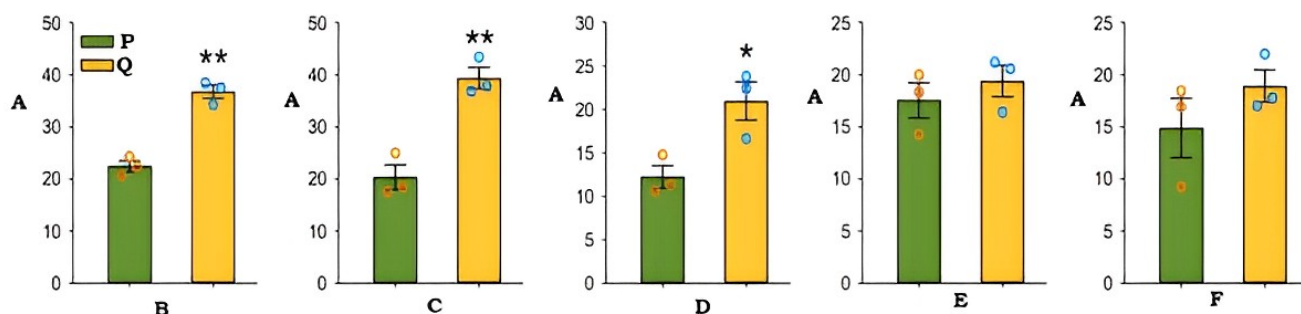


Fig.1. Effects of different phenolic glycosides on the mortality of *B. tabaci* adults either treated with siRNA against *BtPMT1* (yellow) or control (green) group (no siRNA treatment).



A (For all graphs)	Adult mortality (%)
B	Kaempferol 3-O-glucoside
C	Kaempferol 7-O-glucoside
D	Rhaponticin
E	Phenyl β -D-glucoside
F	Phlorizin
P (in the image)	dsEGFP (control)
Q (in the image)	dsBtPMaT1

Additionally, gene expression analyses revealed that *BtPMaT1* was expressed in five developmental stages, and various organs of the adult *B. tabaci*, as shown in Fig. 2. A and B.

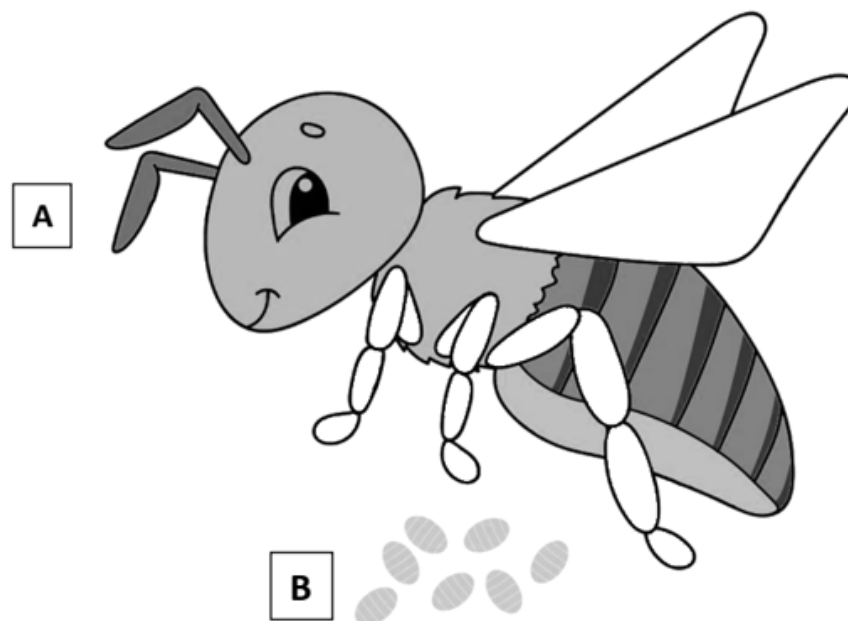


Fig. 2. **(A)** The schematic representation of expression of *BtPMaT1* in the different parts of the adult and **(B)** eggs of *B. tabaci*. The gene expression is indicated by the intensity of the color. Dark grey indicates higher expression and light grey indicates less expression. No color indicates no or insignificant level of gene expression.

True or false?

Q.4.1 White flies have acquired *BtPMaT1* by horizontal gene transfer.

1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-10

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Q.4.2 *BtPMT1* plays a pivotal role in the detoxification of all the phenolic glycosides produced by the tomato leaves. 1.0pt

Q.4.3 Expression of *BtPMT1* in all the developmental stages of *B. tabaci* indicates that it is a plant gene contaminant, rather than part of the fly genome. 1.0pt

Q.4.4 *BtPMT1* must be present in all the whiteflies belonging to genus *Bemisia*. 1.0pt

Q.4.5 Whiteflies feeding on dsRNA expressing tomato plants, had reduced ability to neutralize the phenolic glycosides because siRNA expressing plants started overproducing the phenolics. 1.0pt



Q.5 Angler fish immunity

Genome sequencing has shown that many fish species appear to be partly or completely immunodeficient.

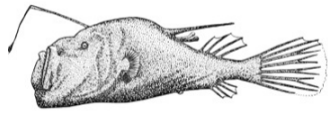
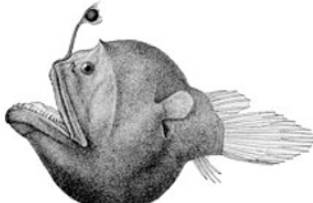
Consider the drawings of four Angler fish.

Analyze the evidence that they have lost some of the genes that are important for the immune system.

- *Aicda* is the gene for cytidine deaminase. In B cells, it is required for hypermutation during antibody maturation and class switching.
- *Cd3z* is the gene for a key T cell receptor signal transduction protein.
- *Cd4* is the gene for an MHC II co-receptor of T helper cells.
- *Cd8a* and *Cd8b* are the genes of MHC I co-receptors of T killer cells.
- *Rag1* is the gene for the enzyme conducting V(D)J recombination (recombination in the genes for antibodies and T cell receptors in B- and T- cells).

Interestingly, the differences in angler fish immunity could be associated with differences in the mating strategy; there are three general types of angler fish mating strategy:

- 1) Mating between an independent male and a female of similar size.
- 2) Mating of a miniature male which is temporarily attached to a large female.
- 3) Mating of a large female with several miniature males which are permanently fused, and sharing a circulatory system, with the female body.

Angler fish	Genes present in genome
 A	Cd3z, Cd4, Rag1
 B	Aicda, Cd3z, Cd4, Cd8a, Cd8b, Rag1
 C	Cd3z, Cd4, Cd8a, Cd8b, Rag1

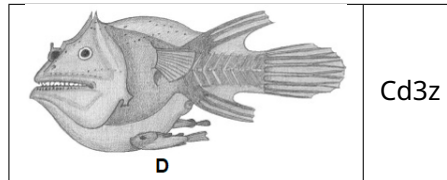
Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-12

English (Official)



Cd3z

A	<i>Ceratias tentaculatus</i>
B	<i>Chaunax abei</i>
C	<i>Diceratias pileatus</i>
D	<i>Haplophryne mollis</i>

True or False?

Q.5.1 All angler fishes have an adaptive immune system which works in a similar way to humans. 1.0pt

Q.5.2 Lack of some immune system components could help angler fish male and female bodies to sustainably fuse. 1.0pt

Q.5.3 Females of the angler fish *Haplophryne mollis* (D) use mating strategy 3. 1.0pt

Q.5.4 The angler fish *Diceratias pileatus* (C) has modified B cell immunity. 1.0pt

Q.5.5 The angler fish *Ceratias tentaculatus* (A) has modified T-cell immunity. 1.0pt



Q.6

Adult humans lack some cell types possessed by children/embryos.

True or False?

Q.6.1	Brown adipocytes (necessary for non shivering thermogenesis) are fully missing in mature adult humans.	1.0pt
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Q.6.2	Ameloblasts (responsible for the formation of the enamel) are fully missing in mature adult humans.	1.0pt
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Q.6.3	Neuronal stem cells in the central nervous system are fully missing in mature adult humans.	1.0pt
--------------	---	-------

Q.6.4	Totipotent stem cells are fully missing in mature adult humans.	1.0pt
--------------	---	-------



Q.7

Elysia marginata is a marine gastropod. Its digestive tract is found in the usual place for gastropods.

E. marginata performs kleptoplasty – the ability to hold chloroplasts derived from food and keep them in its body.

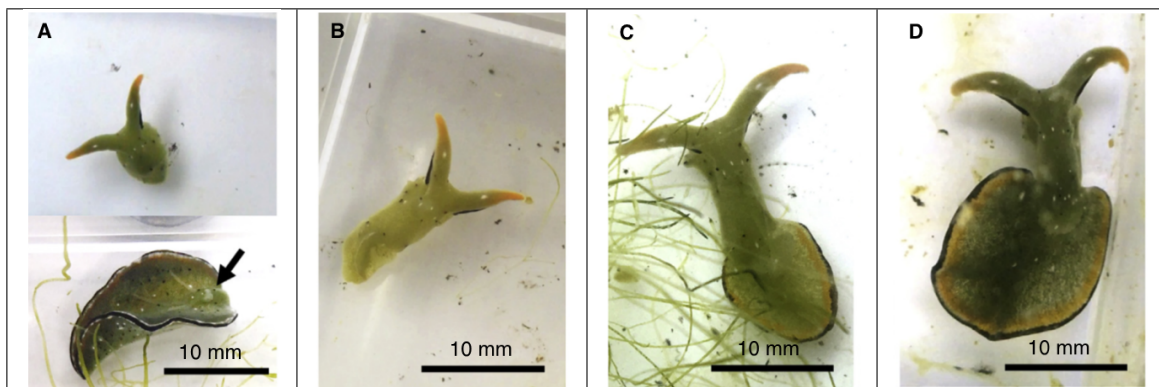
Recently, scientists found another unusual feature of this species; after autotomy (self-removal of a part of the body) one of the pieces may regenerate a body.

Image A shows a dissected animal. The arrow indicates the location of the heart.

B and C show a regenerating body from one of the sections in A.

D shows the whole body regenerated after 22 days.

Scientists noticed body regeneration only in individuals with kleptoplasty.



True or False?

Q.7.1 The observation suggests that most of the body of *Elysia marginata* may die except for the head after autotomy. 1.0pt

Q.7.2 In the initial phase of body regeneration, energy is obtained from the digestion of food in the digestive tract. 1.0pt

Q.7.3 Kleptoplasty – the relationship between chloroplasts and *Elysia marginata* – is a form of symbiosis. 1.0pt

Q.7.4 Kleptoplasty is indispensable for the survival of an individual after autotomy. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-15

English (Official)

Q.8

When eukaryotic nuclear genes are being actively transcribed, their chromatin is usually more relaxed. This leaves the underlying DNA more sensitive to the enzymatic activity of DNase I.

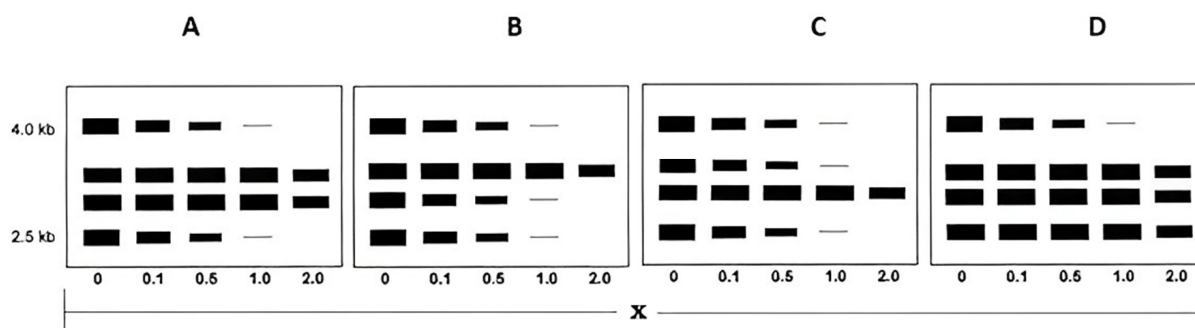
Chromatin was purified from each of pancreatic islet of Langerhans cells, hepatocytes, spermatids and skeletal muscle cells. The chromatin was then exposed to progressively increasing concentrations of DNase I, followed by DNA purification and digestion with restriction endonucleases.

The resulting DNA fragments were subjected to electrophoresis, denaturation and Southern hybridization (with radiolabeled ssDNA probes complementary to the histone, insulin, acetylcholine receptor or actin gene).

Restriction fragments of a particular length correspond to particular genes:

- 2.5 kb = histone H2A.
- 3 kb = insulin.
- 3.3 kb = acetylcholine receptor.
- 4 kb = actin

The autoradiograms (A-D) show the results for each cell type.



In the figure, **X** denotes DNase I concentration in $\mu\text{g/ml}$

Match the autoradiograms A-D with the corresponding cell types.

1. Pancreatic β cells.
2. Hepatocytes
3. Spermatids
4. Skeletal muscle cells

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-16

English (Official)

Q.8

4.0pt

Cell type	Autoradiogram
a)	
b)	
c)	
d)	



Q.9

Brain microglia (a type of macrophage) perform many roles in the central nervous system.

The role of microglia in synaptic reorganisation and circuit rewiring, which modulates memory, was tested in mice. Mice were trained to freeze when receiving a stimulus (A). The % of mice remembering to freeze 5 days, and 35 days, after training is shown in B.

The % of mice remembering to freeze 35 days after training were compared with Pexidartinib (PLX) and without (PLX) treatment at the start of the study (shown in D). Pexidartinib (PLX), selectively removes only microglial cells. A single Pexidartinib treatment permanently removes microglial cells.

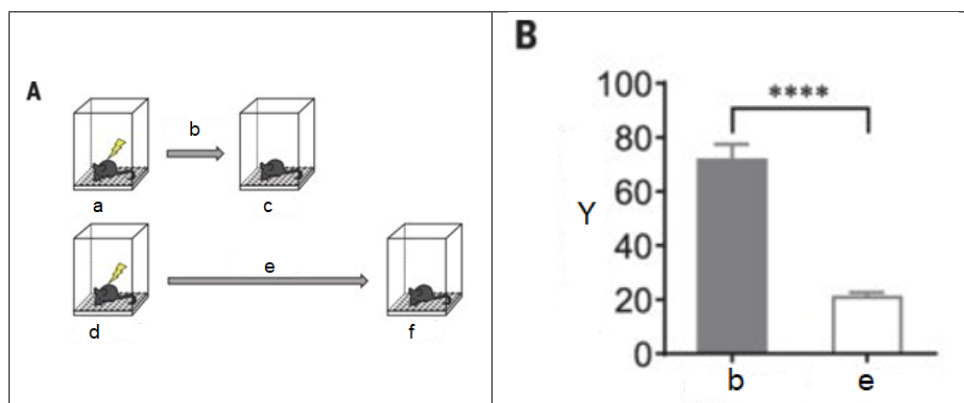
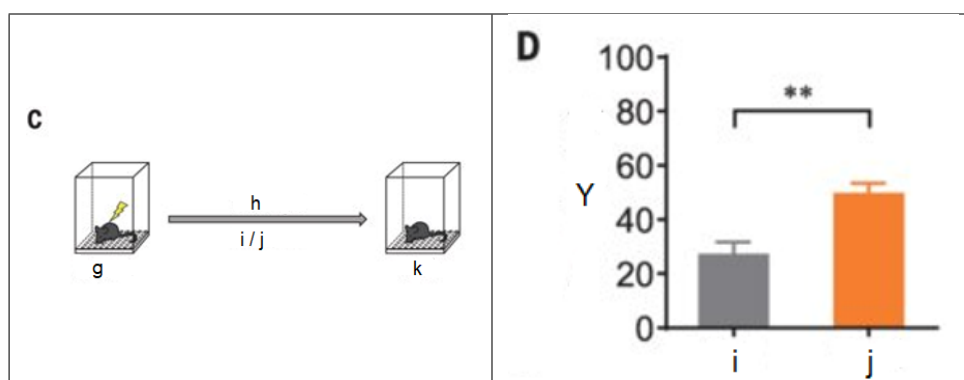


Figure A and B	
a	Training
b	5 days
c	Test
d	Training
e	35 days
f	Test
Y	Freezing (%)



Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-18

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Figure C and D	
g	Training
h	35 days
i	Control
j	PLX
k	Test
Y	Freezing (%)

True or False?

Q.9.1 Forgetting is an active process involving microglial cells. 1.0pt

Q.9.2 The microglial population is usually self-renewing, rather than replaced by bone-marrow cells. 1.0pt

Q.9.3 Depletion of the microglia in the brain leads to an enhanced ability to forget the behavioural response. 1.0pt

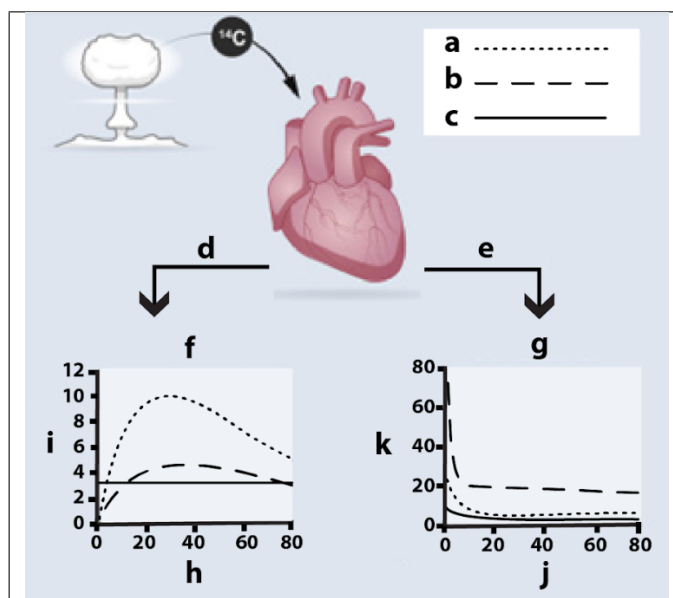
Q.9.4 Given that the result in (D) could be mimicked by the application of an inhibitor of phagocytosis; the potential mechanism explaining the results is physical removal of the synapse by microglial phagocytosis. 1.0pt



Q.10

The contribution of cell propagation to physiological heart growth and maintenance in humans has been difficult to study.

70-60 years ago, atomic bomb testing introduced a large amount of ^{14}C into the biosphere, followed by a rapid drop back to background amounts when the UK, USA and USSR agreed to end testing. The ratio between ^{12}C and ^{14}C isotopes can be quantified in the fractions of individual cardiac cells (mesenchymal cells, endothelial cells and cardiomyocytes). Dating the correct biomolecule allows individual cells to be aged (^{14}C dating).



a	Mesenchymal cells
b	Endothelial cells
c	Cardiomyocytes
d	Stereology
e	^{14}C dating
f	Cell numbers
g	Cell turnover
h	Age (y)
i	Cardiac cells (10^9)
j	Age (Y)
k	Annual cell turnover rates (%)

True or False?

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-20

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Q.10.1 Myosin is the molecule within a cell most likely to maintain the original ratio of the C12 and C14 from when the cell was formed. 1.0pt

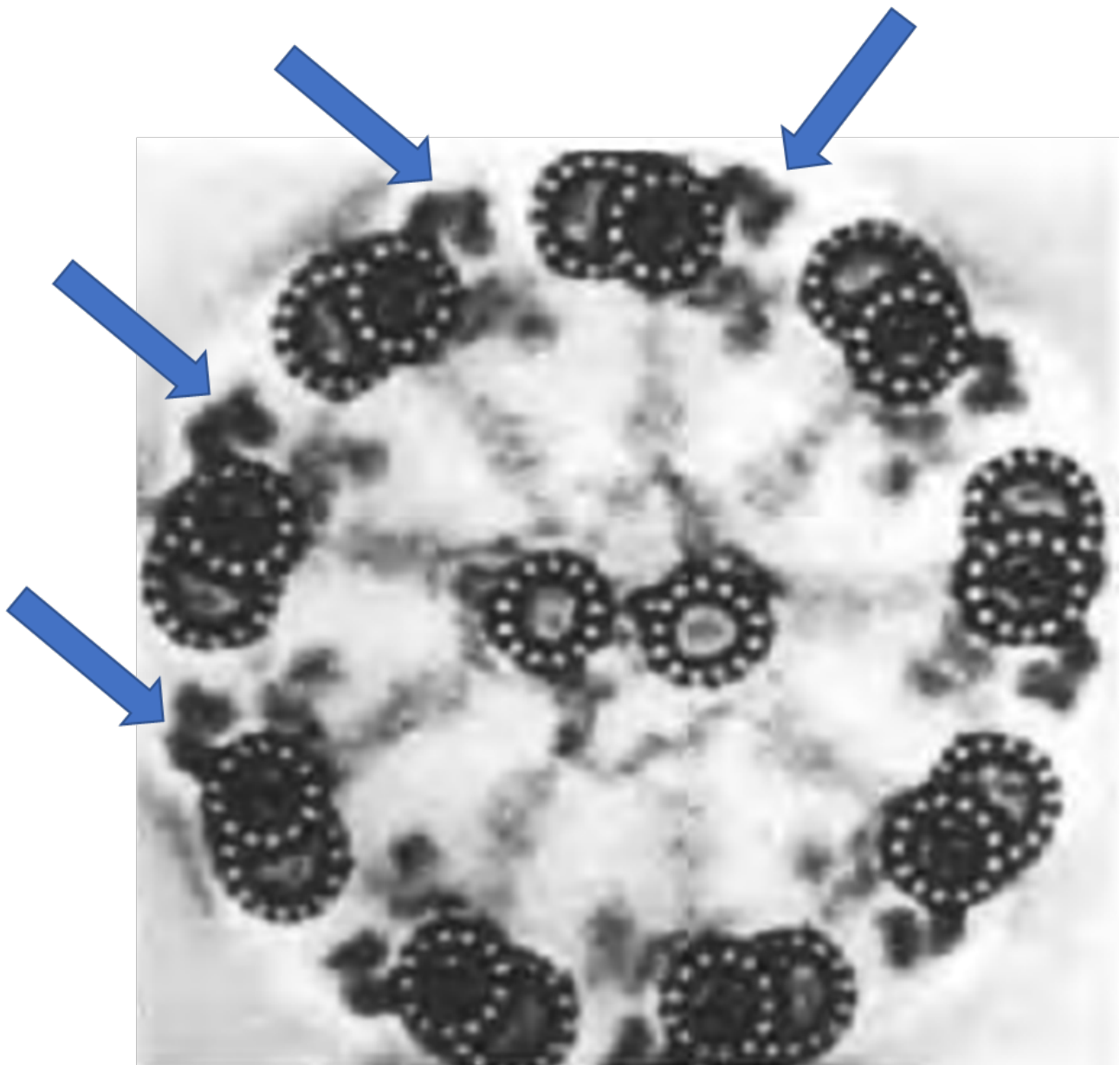
Q.10.2 These data show cardiomyocytes are able to increase their volume over time. 1.0pt

Q.10.3 These data show adults possess only small amounts, if any, cardiomyocyte stem cells. 1.0pt

Q.10.4 The half-life of ^{14}C must be taken into account when interpreting the results. 1.0pt

**Q.11**

Kartagener syndrome, a rare disease, is caused by loss-of-function mutations in the molecular complex shown in the image indicated by the blue arrows. (Note: the figure shows wild type). The syndrome has multiple symptoms, all with one molecular mechanism in common.

**True or false?**

Q.11.1 Due to the impairment of fluid currents in the embryonal development, affected individuals can exhibit disturbance in the determination of the right-left symmetry of internal organs.

1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-22

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Q.11.2 Symptoms include disturbance of the movement of digestive material in the gastrointestinal tract.	1.0pt
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Q.11.3 Symptoms include reduced mucus clearance from the lungs leading to chronic recurrent respiratory infections.	1.0pt
--	-------

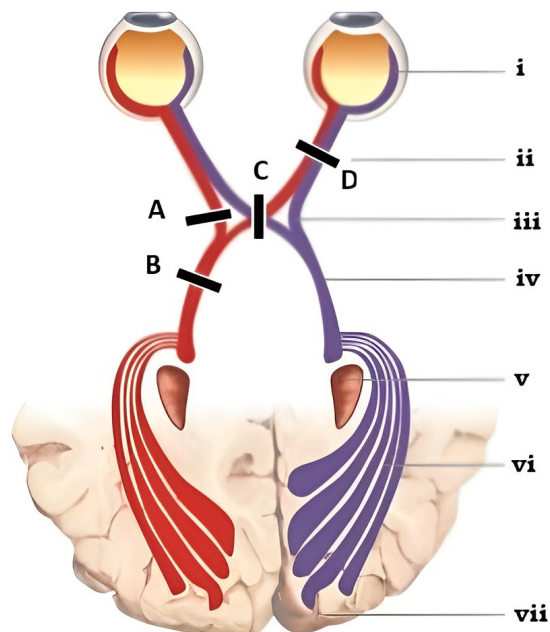
Q.11.4 Symptoms include reduction in fertility in females due to immobility of the oocyte/early embryo in the fallopian tube.	1.0pt
--	-------

Q.11.5 Couples, where the males have this condition, often need In-vitro fertilization (IVF) assistance to conceive.	1.0pt
---	-------



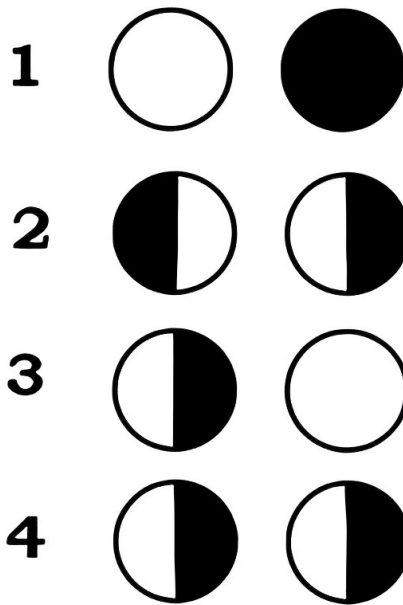
Q.12

The visual field is the entire area that the viewer can see when the viewer's eye is fixed straight on a central point. What does the visual fields look like (black shading indicates vision loss) for a person whose visual paths are interrupted (black line) at the locations **A – D** ?



Visual path interruption

i	Retina
ii	Optic nerve
iii	Optic chiasma
iv	Optic tract
v	Lateral geniculate body
vi	Optic radiation
vii	Visual cortex



Visual defect

Match the visual path interruption **A - D** with the visual defect **1 - 4**.

Q.12

4.0pt

Visual path interruption	Visual defect
A	
B	
C	
D	

**Q.13**

Cold-blooded (poikilothermic) animals are able to tolerate significant fluctuations in body temperature (by several tens of degrees) without negative consequences.

In contrast, some warm-blooded (homoiothermic) animals cannot survive a small change in body temperature (see Table).

Group of animals	Normal core body temperature, °C	Lethal core body temperature, °C
Monotremata (Echidna)	30-31	37
Marsupials	35-36	40-41
Insectivores (Hedgehog)	34-36	41
Human	37	43
Most of placental mammals	36-38	42-44
Birds (Kiwi)	38	44
Birds (except Passerines)	39-40	46

True or False ?

A.13.1 For Passerines birds (body temperature is 40-41 °C) lethal core body temperature will be about 47 °C ? 1.0pt

What is/are the main reason(s) warm-blooded animals are intolerant to changes in body temperature?

State whether the following statements are **true or false**?

Q.13.2 Thermal denaturation of the majority of enzymes and other proteins with increasing temperature. 1.0pt

Q.13.3 Thermal denaturation (melting) of DNA with increasing temperature. 1.0pt

Q.13.4 Changes in the microviscosity of lipids of cellular and intracellular membranes with increasing temperature. 1.0pt

Q.13.5 Different temperature sensitivity (Q10-coefficient) of biochemical reactions in cells. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-26

English (Official)

Q.14

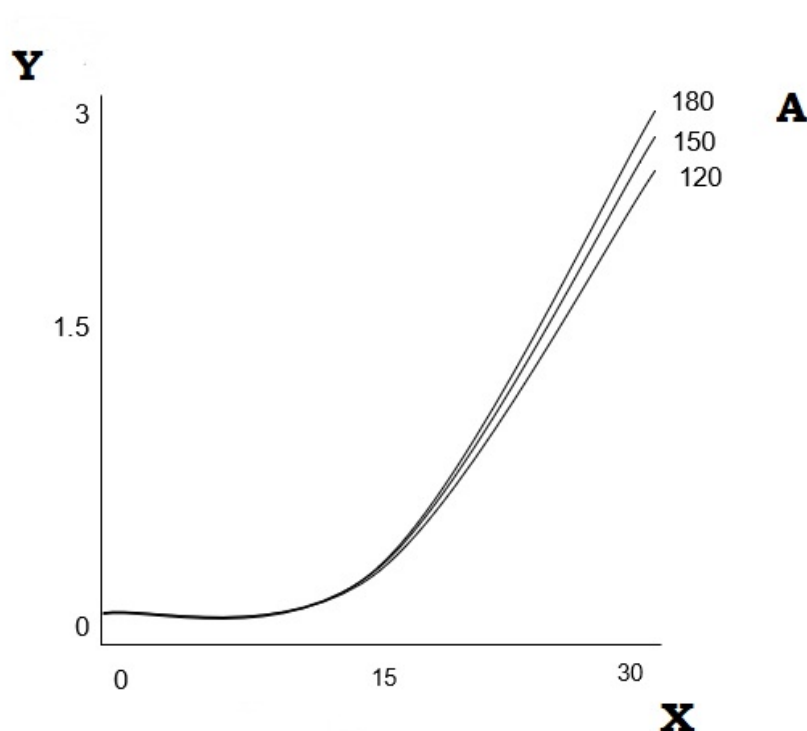
Lung surface area and the speed of oxygen delivery to blood are very rarely the limiting factors for oxygen delivery in a healthy person. Blood usually flows slowly enough that alveolar air is in equilibrium with blood.

Instead, the oxygen affinity of hemoglobin is the main determinant of oxygen loading.

Binding affinity describes the change in binding with concentration. For gases, the molarity of solutions is directly proportional to their partial pressure in air. Partial pressure is the pressure exerted by a particular gas in a mixture of gases.

However, the rate of fire burning is limited by crowding by non-flammable molecules and the strength of convection currents.

The curves below plot the height of a candle flame against the % oxygen in the air (the proportion of total molecules which are oxygen) when the partial pressure of oxygen is fixed.



Y	Flame height (cm)
X	Percentage oxygen
A	Partial pressure of oxygen (mmHg)

Modern military submarine air processing units produce an atmosphere of 16% oxygen at 130% normal sea-level pressure.

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-27

English (Official)

True or False?

Q.14.1 Sailors need time to adapt to this atmosphere and regain normal fitness.	1.0pt
--	-------

Q.14.2 Sailors breathe faster in this atmosphere compared to normal sea-level air.	1.0pt
---	-------

Q.14.3 Submarines could operate at a lower than sea-level atmospheric pressure, and higher than normal % oxygen to optimize fire safety.	1.0pt
---	-------

Q.14.4 When moving along the curves in the graph from 15% oxygen to 30% oxygen, atmospheric pressure is increasing.	1.0pt
--	-------



Q.15

Breathing rate is usually controlled by pH (proportional to carbon dioxide) sensors in the brain.

Oxygen sensors, in the major arteries, only influence breathing when the partial pressure of oxygen falls below ~ 30 mmHg. These sensors stimulate ventilation as oxygen falls below this level.

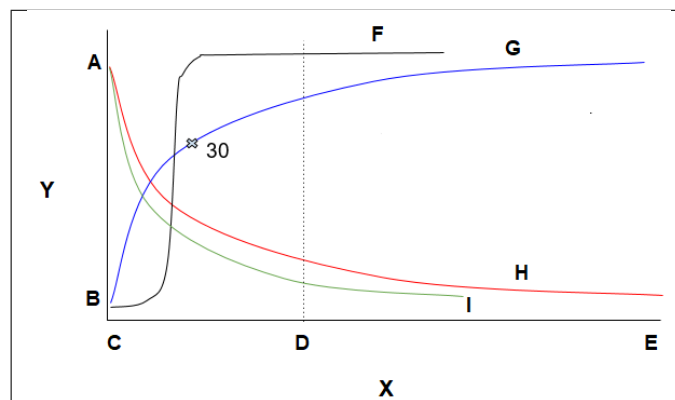


Figure 1. This figure shows how the partial pressure / amount of respiratory gases change in alveolar air and blood as a function of ventilation rate in normal sea level atmosphere.

X	Ventilation (breathing) rate
Y	Gas composition
A	High
B	Low
C	Minimum
D	Normal rest
E	Maximum
F	Total amount of oxygen in blood
G	Partial pressure of oxygen in Alveoli (mmHg)
H	Partial pressure of Carbon dioxide in alveoli (mmHg)
I	Total amount of carbon dioxide in blood

True or False?

Q.15.1 These curves show evidence that haemoglobin can bind carbon dioxide to form carboxyhaemoglobin. 1.0pt

Q.15.2 If the nerves to the oxygen sensors are cut, a person at a very high altitude will breathe more quicker. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P1-29

English (Official)

Q.15.3 These curves show that controlling breathing primarily via CO_2 levels, rather than via O_2 levels, is an arbitrary accident of evolution, rather than clearly advantageous. 1.0pt

Q.15.4 Someone ascending to a very high altitude quickly will suffer decreasing pH in their brain. 1.0pt

Q.15.5 The submariners in the previous question (130% sea-level pressure, 16% oxygen), will experience a fall in pH when exposed to their atmosphere. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-1

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Theory 2

Q.16

The size of a single cell can range from a mycoplasma, which is considered the smallest cell, to a giant skeletal muscle fiber or ostrich egg.

Assume that *Escherichia coli* cells, human hepatic cells, and epidermal cells of an onion scale are cylinders with approximate lengths of 1 micro-meter, 20 micro-meter, and 100 micro-meter, respectively, and the length to diameter ratio is equal 5 to 1. Plant cells are usually much larger.

Also assume that the transport activity of the plasma membrane is proportional to its surface area, and the metabolic capacity of the cell is proportional to its volume.

True or false?

Q.16.1 <i>Escherichia coli</i> has the lowest surface area (S) to volume (V) ratio (S/V) amongst the mentioned cells.	1.0pt
--	-------

Q.16.2 The S/V ratio of human hepatic cells, compared to onion epidermal cells, differs by 5 fold.	1.0pt
---	-------

Q.16.3 A relatively low S/V ratio demands a relatively high plasma membrane density of active transport proteins for the maintenance of constant metabolism level inside the cytoplasm.	1.0pt
--	-------

Q.16.4 To maintain relatively high cytoplasmic metabolic activity, plant cells usually have large metabolically passive vacuoles and active cytoplasmic streaming.	1.0pt
---	-------

Q.16.5 More spherical cells usually sustain a higher metabolic activity than long or flat cells with the same volume	1.0pt
---	-------

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-2

English (Official)

Q.17

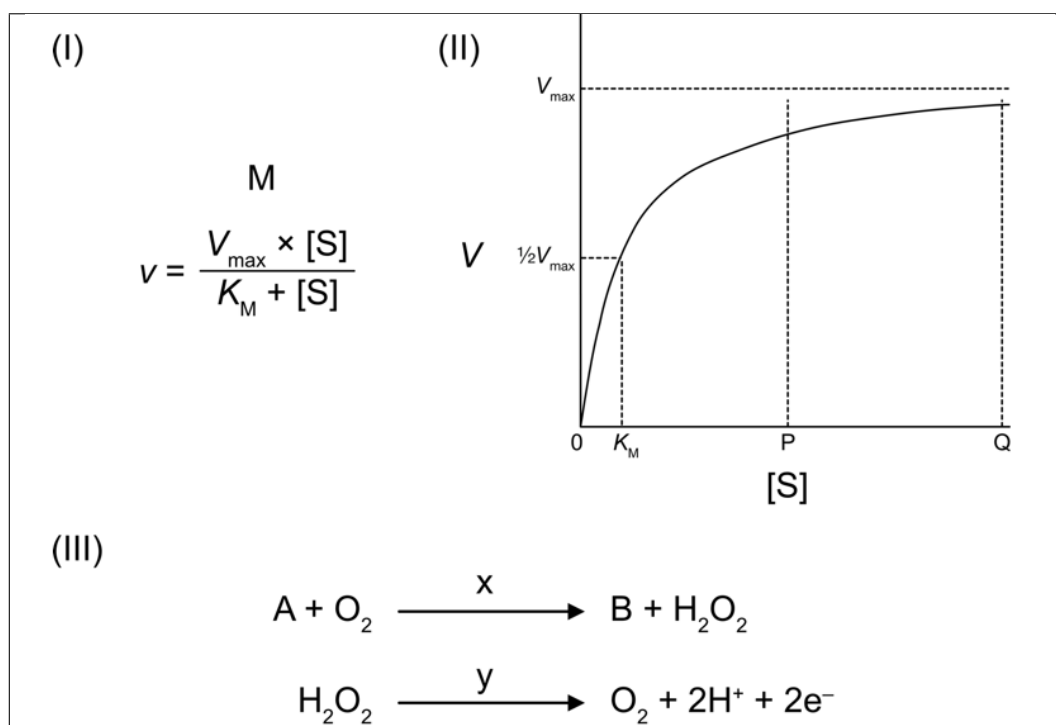
The Michaelis-Menten equation (Fig. I) describes the relationship between substrate concentration ($[S]$) and enzymatic reaction rate (v).

K_M = the Michaelis constant, which is the substrate concentration at which $v = \frac{1}{2}V_{\max}$ and represents the affinity of enzymes to particular substrates.

$V_{\max}$ = the maximum rate in a given reaction mixture.

The Michaelis-Menten plot is a graphic representation of this relationship (Fig. II).

Glucose oxidase catalyses the oxidation of glucose (MW 180 g/mol) to glucono-1,5-lactone, while O_2 is reduced to H_2O_2 (Fig. III). For glucose oxidase K_M is estimated as 25 mmol/l.



A	Glucose
B	glucono-1,5-lactone
M	Michaelis-Menten equation
[S]	Substrate concentration
V	reaction velocity
x	glucose oxydase
y	catalyser

A reaction catalysed by glucose oxidase is used to measure blood glucose concentration.

A glucose meter is actually an electric current meter. The blood sample is applied to a strip containing

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-3

English (Official)

immobilized glucose oxidase, and the meter records the flow of electrons accompanying the oxidation of H_2O_2 catalysed by a non-enzymatic catalyst contained in the meter strip (Fig. III).

True or False?

Q.17.1 Among isoenzymes with the same $V_{\max}$ value but different K_M values, the enzyme with the lowest K_M value has the highest affinity for the substrate.	1.0pt
--	-------

Q.17.2 For the meter to accurately measure blood glucose concentration, the glucose oxidase used should have a broad substrate specificity	1.0pt
---	-------

Q.17.3 For the meter to accurately measure blood glucose concentration, the reaction on the strip should be in the P-Q range of the substrate concentration in figure II.	1.0pt
--	-------

Q.17.4 The two-step reaction presented in Fig. III. is essentially irreversible in these conditions.	1.0pt
---	-------

Q.17.5 An acidic buffer facilitates oxidation of H_2O_2	1.0pt
--	-------

Q.18 Lactic acid fermentation

The process of lactic acid fermentation - the conversion of a glucose molecule into two molecules of lactic acid (lactate) - is schematically presented below.

Theory 2

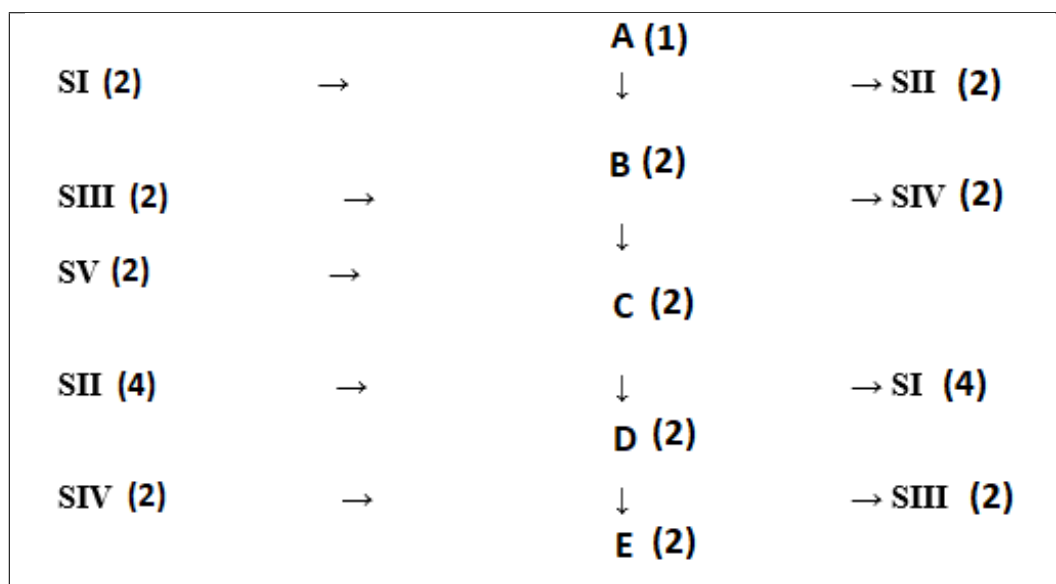


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United Arab Emirates 2023

P2-4

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Numbers SI-SV indicate unidentified substances I-V involved in this process.



A	Glucose
B	3-Phosphoglyceric aldehyde
C	1,3-Bisphosphoglyceric acid
D	Pyruvic acid (Pyruvate)
E	Lactic acid (Lactate)
(1)	1 molecule
(2)	2 molecules
(4)	4 molecules

True or False?

Q.18.1 All substances (SI-SV) on the scheme are organic substances.

1.0pt

Q.18.2 The process shown on the scheme proceeds at a high rate in many types of cancer cells.

1.0pt

Q.18.3 In aerobic eukaryotic cells, the substance SI can be synthesized at a high rate in mitochondria.

1.0pt

Q.18.4 The last reaction in this process (pyruvate → lactate) is needed for the reduction of the substance SIV.

1.0pt

Theory 2



34th International
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United Arab Emirates 2023

P2-5

English (Official)

Q.18.5 Many yeasts, for example, *S. cerevisiae*, use this process in carbohydrate metabolism under anaerobic conditions. 1.0pt



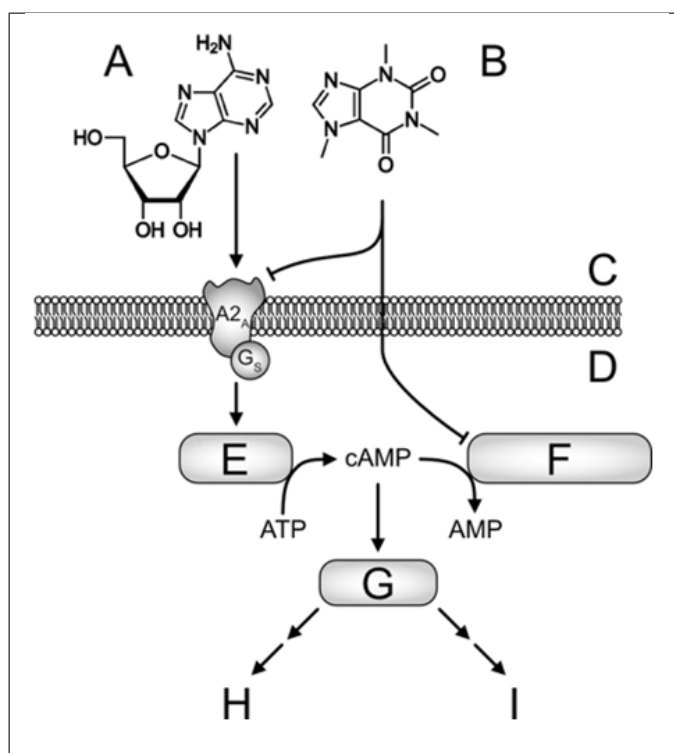
Q.19

Some of the numerous physiological effects of caffeine consumption are based on the similarity of its structure to adenosine.

- Adenosine interacts with the $A2_A$ receptor, which activates adenylyl cyclase via the G_s protein, resulting in the synthesis of cyclic AMP (cAMP) – a signalling molecule in the cell.
- cAMP molecules directly interact with protein kinase A and cause the activation of this enzyme. Protein kinase A phosphorylates substrate proteins and produces certain physiological effects.
- cAMP molecules are broken down by phosphodiesterase to AMP, therefore the signal caused by the interaction of adenosine with the $A2_A$ receptor disappears after some time.

Caffeine can also interact with the $A2_A$ receptor, but it does not cause the exact same effects as adenosine. In addition, caffeine is a phosphodiesterase inhibitor.

The diagram shows the structures of adenosine and caffeine as well as how these substances work in the cell. The lines ending in a crossbar indicate the inhibitory effect of caffeine.



Theory 2



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United Arab Emirates 2023

P2-7

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A	adenosine
B	caffeine
C	extracellular environment
D	cytosol
E	adenylyl cyclase
F	phosphodiesterase
G	protein kinase A
H	decreased dopaminergic activity in the central nervous system
I	expansion of the blood vessels

True or False?

Q.19.1 Enzymatic synthesis of cAMP molecules amplifies the signal. 1.0pt

Q.19.2 Caffeine inhibits the increase in cAMP concentration usually caused by the activated A_{2A} receptor. 1.0pt

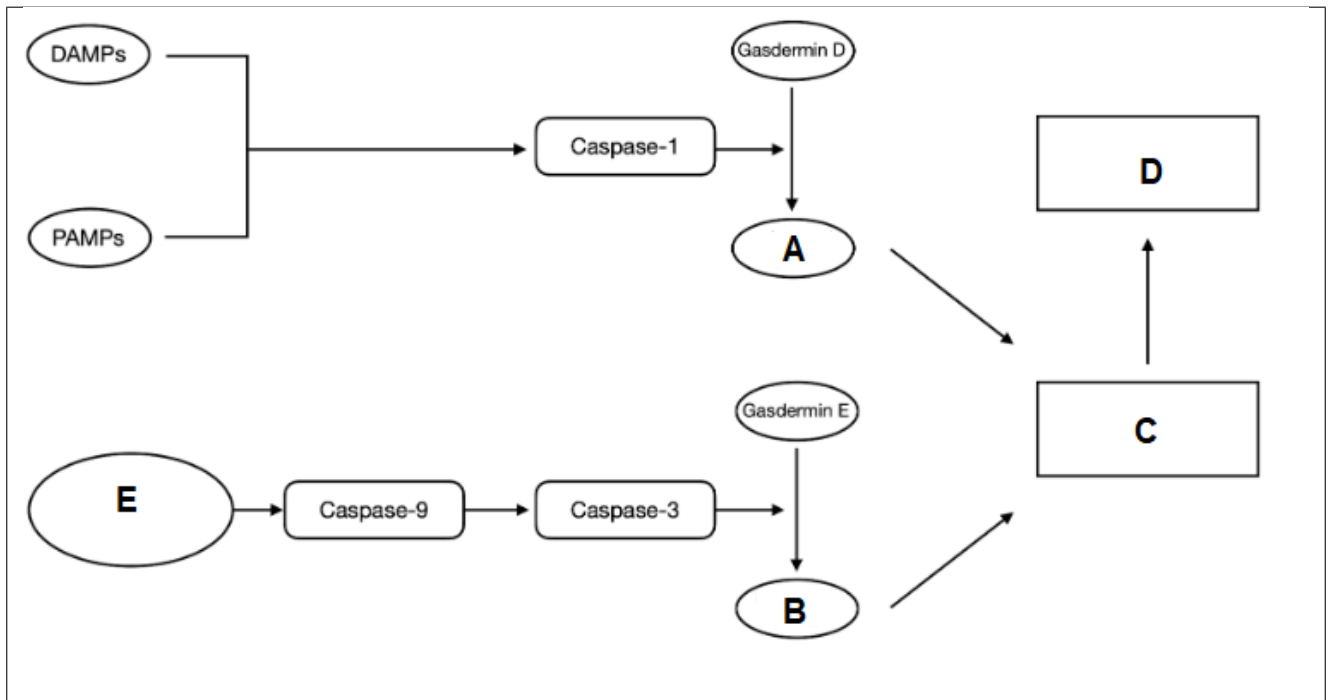
Q.19.3 Caffeine slows down the decline in cAMP level after receptor activation. 1.0pt

Q.19.4 Caffeine is likely to be a competitor of adenosine at the receptor. 1.0pt



Q.20

Pyroptosis is initiated by various damage-associated molecular pattern (DAMP) and pathogen associated molecular pattern (PAMP) and formation of a large supramolecular complex (inflammasome) in the cell. The inflammasome activates a different set of caspases. Caspase activation takes place through cleavage of procaspases which contributes to the maturation and activation of several proinflammatory cytokines and pore-forming protein Gasdermins like Gasdermin D or Gasdermin E. Formation of pores causes cell membrane rupture and release of cytokines, as well as various DAMP molecules out of the cell. These molecules recruit more immune cells and further perpetuate the inflammatory cascade in the tissue lead to the development of neuroinflammation in central nervous system (CNS) diseases.



A	N-terminal fragment
B	N-terminal fragment
C	Pore formation
D	Pyroptosis
E	Mitochondrial disruption

**True or False?**

Indicate, as True or False, whether the following treatment will reduce the progress of CNS inflammatory diseases.

Q.20.1 Inhibition of procaspase 9 cleavage.

1.0pt

Q.20.2 Disruption of expression of Gasdermin E.

1.0pt

Q.20.3 Production of intracellular ROS (reactive oxygen species) by a chemotherapy drug.

1.0pt

Q.20.4 Acetylation of surface cysteine in N-terminal domain of Gasdermin D.

1.0pt

Q.20.5 Inhibition of the cleavage of Gasdermin E.

1.0pt

Theory 2



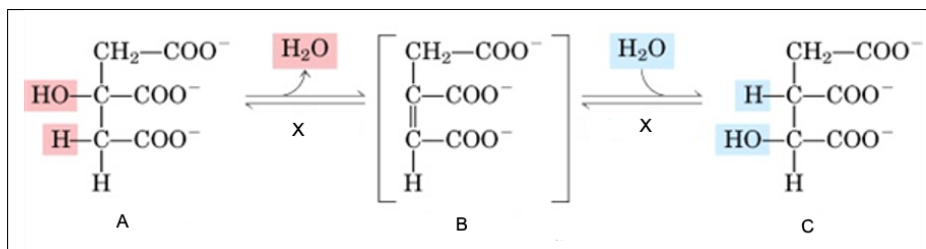
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P2-10

English (Official)

Q.21

Aconitase, one of the enzymes in TCA cycle (Krebs cycle / citric acid cycle) catalyzes the following reaction:



A	Citrate
B	cis-Aconitate
C	Isocitrate
X	Aconitase

In order to explore its mechanism, reactions were carried out in D_2O , instead of H_2O . D represents deuterium (heavy hydrogen).

A reverse enzymatic reaction using isocitrate as the substrate did **NOT** produce any labeled citrate.

When starting from Cis-aconitate, all produced citrate had a D atom. Do not consider hydroxyl transfer with the environment in this reaction.

True or False?

Q.21.1 The reaction mechanism involves proton (H^+) transfer. 1.0pt

Q.21.2 Cis-aconitate remains bound, in the same orientation, to the enzyme active site throughout the whole reaction. 1.0pt

Q.21.3 The labeled H atoms in the figure are the same individual atoms in citrate and isocitrate. 1.0pt

Q.21.4 The enzyme has only one catalytic base (e.g. serine) in its active site. 1.0pt

Q.21.5 The enzyme needs a coenzyme as redox center e.g. FAD 1.0pt

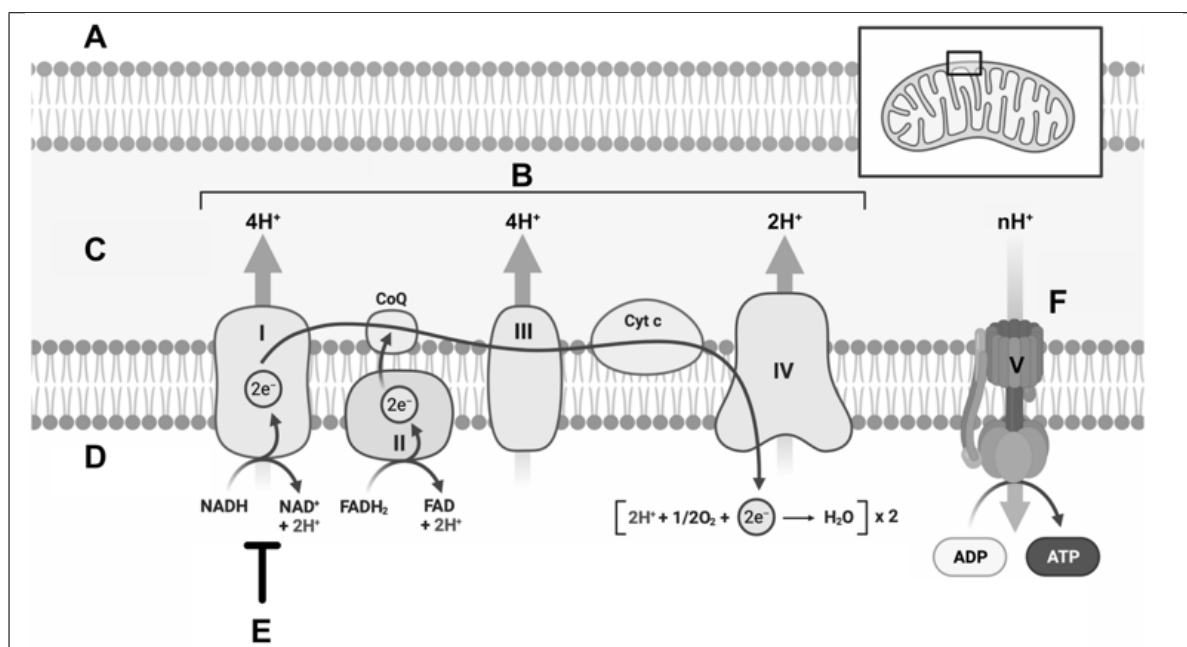


Q.22

In mitochondria, ATP is synthesized using an electron transport chain containing four complexes (I–IV) and ATP synthase (complex V). Three NADH and one FADH₂ molecules are produced by one turn of the Krebs cycle (citric acid cycle / TCA cycle).

The efficiency of ATP synthase varies between different cell types, but assume that the flow of about 3.3 protons allows the synthesis of one ATP molecule.

Metformin, which inhibits complex I, is used to treat type 2 diabetes. Metformin is believed to alter the usual cellular AMP:ADP:ATP ratio of 1:10:100, which produces a beneficial effect from AMP-activated protein kinase (AMPK).



A	cytosol
B	electron transport chain
C	intermembrane space
D	mitochondrial matrix
E	metformin (inhibitor)
F	ATP synthase



True or False?

Q.22.1 The oxidation of one glucose molecule leads to the synthesis of approximately 11 ATP molecules. 1.0pt

Q.22.2 The number of ATP molecules synthesized by ATP synthase is reduced by metformin. 1.0pt

Q.22.3 Metformin directly increases the concentration of FADH_2 in the mitochondrial matrix. 1.0pt

Q.22.4 Metformin indirectly activates AMPK by raising the amount of AMP relative to ATP. 1.0pt



Q.23

When a battery is placed in an aqueous solution containing salts similar to those found in human body fluids, charged particles flow from the anode to the cathode. The location of the anode from which the electrical current flows is called the “source” (starting point), and the location of the cathode into which it flows is called the “sink” (end point, or absorber) (Figure 1 A).

The same principle can be used to measure the extracellular current generated when cells are electrically excited. When excitation is initiated locally in a resting cell, it generates a movement of ions at the site of the excited membrane. This is true of nerve fibres.

Note: the locations of the source and sink change rapidly, *i.e.* a phenomenon occurring in milliseconds during the conduction of action potentials. When electrodes are placed along a nerve fibre (positive closer to the cell body than negative Figure 1 B), the excitation generated in the cell body will be observed as a signal. This signal can be recorded as a graph.

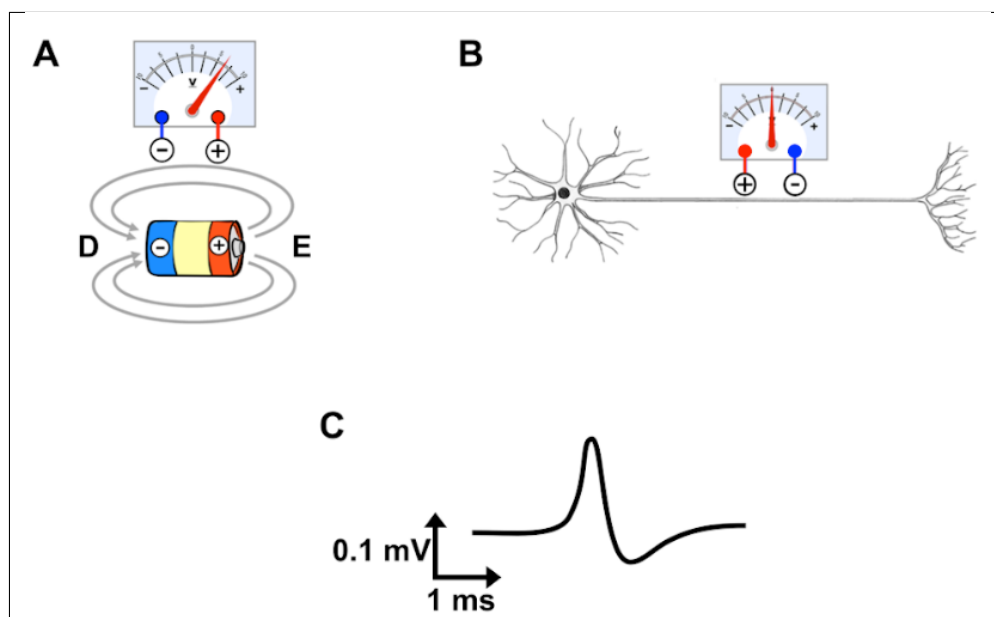


Figure 1

D	Sink
E	Source

True or False?

Q.23.1 In a resting cell, an excitation initiated locally causes an influx of Na^+ to the cell. 1.0pt

Q.23.2 In the repolarization phase of an action potential, an efflux of Na^+ is observed. 1.0pt



Q.23.3 When the resting region of the cell acts as the source, the excited region acts as the sink. 1.0pt

Q.23.4 Figure 1 C presents a signal registered by the experimental setup shown in Figure 1 B. 1.0pt



Q.24

C-STAR (caffeine-stimulated advanced regulators) is a system constructed in the cells that contain a gene encoding a synthetic human glucagon-like peptide (shGLP-1). These cells were encased in microscopic capsules.

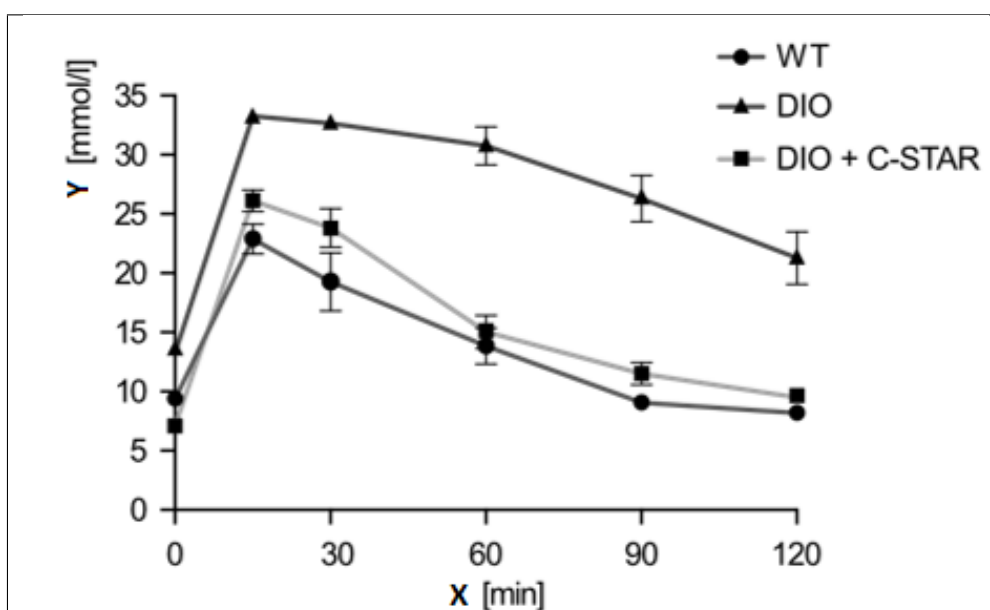
The shGLP-1 peptide is used to treat type 2 diabetes because it stimulates pancreatic B cells to secrete insulin as in a blood glucose-dependent response.

In the cells that contain C-STAR, there are proteins which form dimers in the presence of caffeine molecules. The active dimer causes phosphorylation of the STAT3 transcription factor, which turns on the transcription of the shGLP-1 gene.

The performance of the C-STAR system was tested on three groups of laboratory mice: (i) wild type (WT), (ii) diet-induced obesity (DIO) and

(iii) DIO with administration of C-STAR microcapsules.

All mice received caffeine orally daily. An oral glucose tolerance test was performed. 2 g of glucose, per 1 kg of body weight, was administered and blood glucose concentration was measured for 120 minutes. Error bars in the figure show the standard error.



X	time
Y	blood glucose concentration

True or False?

Q.24.1 In WT mice, glucose levels returned to basal level after 90 minutes.

1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-16

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Q.24.2 STAT3 is indispensable for the synthesis of shGLP-1 in the C-STAR system.	1.0pt
---	-------

Q.24.3 C-STAR caused blood glucose levels of DIO mice to be similar to WT mice 60 minutes after glucose administration.	1.0pt
--	-------

Q.24.4 Both WT mice and DIO mice are needed as controls to assess the effectiveness of C-STAR in this experiment.	1.0pt
--	-------

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

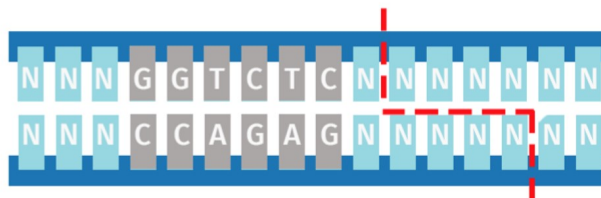
P2-17

English (Official)

Q.25

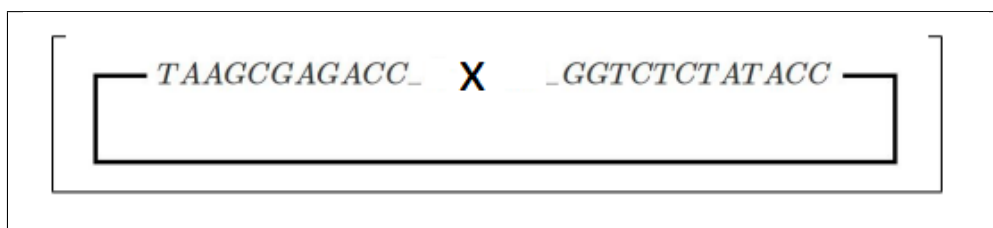
Golden gate assembly is a one-step cloning method for joining multiple DNA inserts into a plasmid backbone.

This method uses BsaI (a type II_S restriction enzyme). In contrast to traditional restriction enzymes, it recognizes a non-palindromic sequence and cuts the adjacent sequence, which is shifted by a number of base pairs, as shown in the figure below.



Notice the restriction enzymes are only specific for the recognition site (shaded in gray), while the cutting site can have any nucleotide sequence.

Consider combining the following plasmid backbone:



X	Dropout
---	---------

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-18

English (Official)

And the two following inserts:

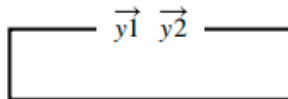
ATCGGTCTCTGTAT_ $\overrightarrow{y1}$ *_ATACCGAGACCGCA*

ATCGGTCTCTTAAG_ $\overrightarrow{y2}$ *_GTATCGAGACCGCA*

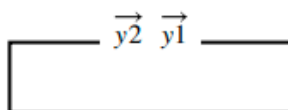
y1	Insert 1
y2	Insert 2

For each of the constructs below, indicate if it can be observed after treatment with BsaI and DNA ligase.

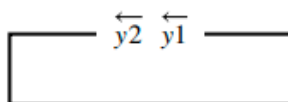
a)



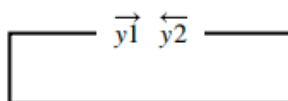
b)



c)



d)





Q.25.1 a

1.0pt

Q.25.2 b

1.0pt

Q.25.3 c

1.0pt

Q.25.4 d

1.0pt

Q.26

During *Agrobacterium*-mediated transformation of plants, one or more copies of T-DNA (Transfer DNA) can integrate randomly into the plant genomic DNA.

The number of T-DNA insertions can be analyzed by Southern hybridization of digested genomic DNA from transformed plants, using probes against sequences within the T-DNA.

The restriction enzyme used for digestion of genomic DNA should preferably have a single cut site within the T-DNA. The restriction enzyme would cut within the integrated T-DNA, and also in the flanking genomic DNA.

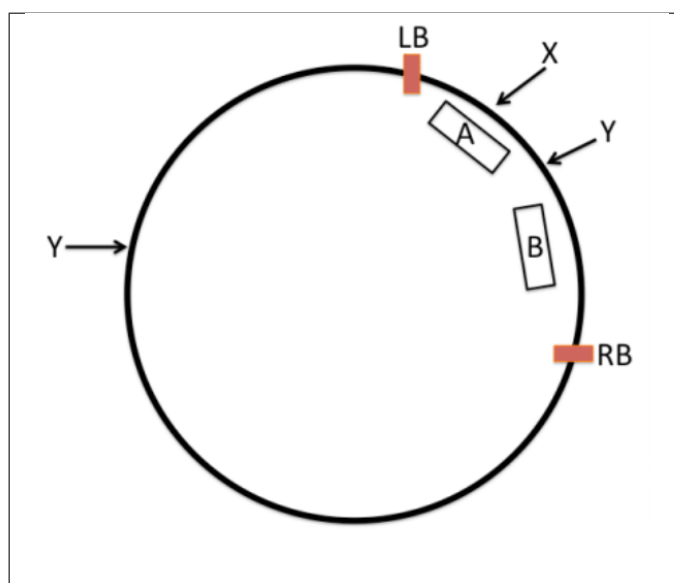
**Figure 1**

Figure 1 represents a vector (15 Kb) used for plant transformation. The T-DNA region (5 Kb) lies between the LB (left border) and RB (right border). The rectangles marked as A and B represent the regions of T-DNA used as probes. X and Y denote the restriction sites for enzymes that could have been used in the experiment.

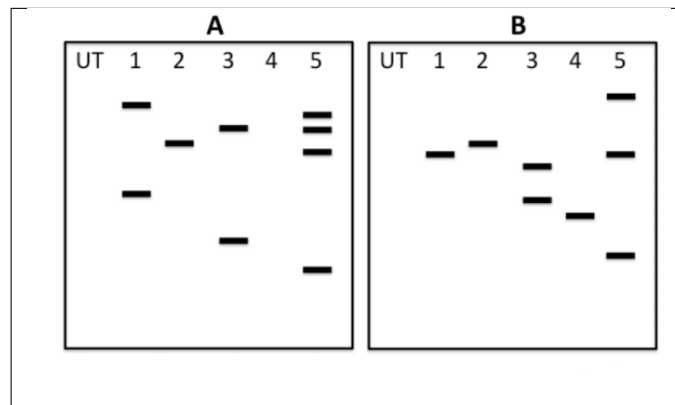


Figure 2

Figure 2 represents the results of Southern hybridization carried out with DNA from independently transformed plants (1 to 5) and DNA from an untransformed plant (UT). Hybridization was carried out with either probe A or B.

True or False?

Q.26.1 The genomic DNA was digested with restriction enzyme Y.

1.0pt

Q.26.2 The digested DNA fragments that hybridized to the probe contain regions of T-DNA only.

1.0pt

Q.26.3 There are two copies of T-DNA in plant number 1.

1.0pt

Q.26.4 One copy of T-DNA is integrated in plant number 2.

1.0pt

Q.26.5 Complete T-DNA region has been transferred in plant 4.

1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-21

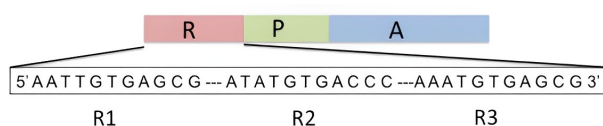
English (Official)

Q.27

The regulatory region of a bacterial gene, called 'A', is shown below.

The promoter (P) and regulatory region (R) regulate the transcription of the gene.

Chemical X regulates the expression of the gene by interacting with a protein Y. There are 3 binding sites (R1, R2, R3) for protein Y in region R. Protein Y has different binding affinities for the 3 sites.



An experiment was carried out to study the role of the 3 binding sites.

The binding sites (R1 to R3) were deleted individually, or in combination, and the expression of gene 'A' was measured in the presence or absence of chemical X.

The table shows the ratio of expression of gene 'A' in the presence: absence of chemical X. A cross (×) denotes that the site is deleted, while a tick (✓) denotes the presence of the binding site.

In each of the strains below, the expression of gene 'A' in the absence of chemical 'X' is 15 arbitrary units.

Strain	R1	R2	R3	Ratio of expression of gene 'A' in the presence: absence of chemical 'X'
WT	✓	✓	✓	120
M1	✓	✓	×	52
M2	✓	×	✓	3
M3	×	✓	✓	107
M4	×	✓	×	30
M5	✓	×	×	1
M6	×	×	✓	1
M7	×	×	×	1

True or false?

Q.27.1 If gene Y is deleted, the ratio of activity will increase.

1.0pt

Q.27.2 The binding affinity of protein Y for R2 site is expected to be the highest.

1.0pt

Q.27.3 The sequence TGTGA is important for the binding of protein Y to the R sites.

1.0pt

Q.27.4 The binding of protein Y to R3 and R2 influences the gene activity in the same way as protein Y binding to R1 and R2.

1.0pt



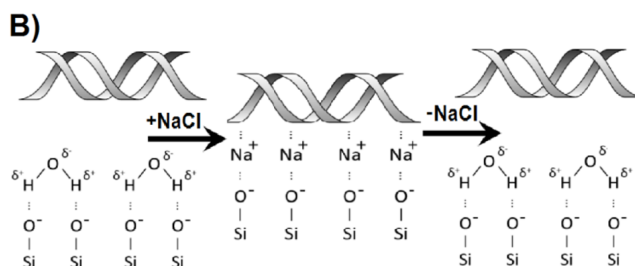
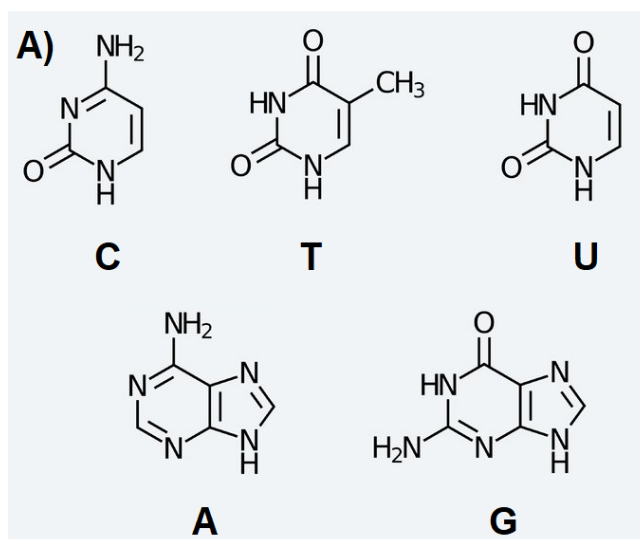
Q.28

Imagine you need to sequence DNA from a 25,000-year-old bone specimen.

For this, DNA can be isolated using the following steps:

1. Grind the bone into powder in liquid nitrogen.
2. Add buffer with high salt concentration (high-salt buffer; HSB) to the powder and incubate.
3. Add silica particles to the powder suspension and incubate.
4. Remove the silica particles from the HSB and wash them with fresh HSB.
5. Elute DNA from the silica particles using a buffer with low salt concentration.

This DNA isolation method is based on the ability of DNA to bind to silica particles in HSB as shown in Figure 1B.



Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P2-23

English (Official)

A)	Nitrogenous bases
B)	Principles of DNA purification on silica sorbent

True or False?

Q.28.1 This DNA isolation method could also be used for modern samples.	1.0pt
--	-------

Q.28.2 This DNA isolation method allows scientists to obtain intact (full-length) chromosomes.	1.0pt
---	-------

Q.28.3 The DNA sample obtained with this method could be contaminated with bacterial DNA.	1.0pt
--	-------

Q.28.4 DNA binds to the silica particles via positively charged nitrogenous bases.	1.0pt
---	-------

Q.28.5 As some DNA bases undergo deamination when exposed to the environment, ancient DNA will contain more uracil compared to modern DNA of the same species.	1.0pt
---	-------



Theory 2**Q.29**

Paulinella is a genus of small aerobic amoeba from *Rhizaria* clade.

This genus includes a monophyletic clade of photosynthetic species. The photosynthetic species of *Paulinella* have oval theca, long filamentous pseudopodia and two curved chloroplasts. The genome of *Paulinella* chloroplasts is extremely large, about one million base pairs, and its sequence is relatively close to the free-living cyanobacteria *Synechococcus* genome. The *Synechococcus* genome contains about three million base pairs. The last common ancestor of *Paulinella* chloroplast and *Synechococcus* lived approximately 500 million years ago. The last common ancestor of all known photosynthetic species in the *Paulinella* genus lived approximately 50 million years ago. The photosynthetic clade of *Paulinella* diverged from its closest non-photosynthetic relative approximately 120 million years ago.



True or false?

Theory 2



34th International
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P3-2

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Q.29.1 During <i>Paulinella</i> chloroplast genome evolution, many genes were lost.	1.0pt
--	-------

Q.29.2 <i>Paulinella</i> probably obtained chloroplasts as a result of secondary endosymbiosis.	1.0pt
--	-------

Q.29.3 The endosymbiosis event which made <i>Paulinella</i> a photosynthetic amoeba is estimated to have occurred 50-120 million years ago.	1.0pt
--	-------

Q.29.4 <i>Paulinella</i> cells contains ribosomal RNA from two different sources.	1.0pt
--	-------



Q.30

Parasite-mediated competition occurs in host species that live sympatrically (in the same place) and are differentially affected by parasite infections. Species that are badly affected by parasites may not be able to compete well with a sympatric species, except in situations where the parasite is absent.

Squirrels in Canada host the intestinal nematode *Strongyloides robustus*. However, nematode effects on the hosts are varied.

Researchers conducted a study to determine if parasite-mediated competition was occurring in squirrels. Four species of squirrel were trapped, and the presence of parasite eggs was determined.

To assess the impact of the nematodes on the squirrels, the researchers measured Scaled Mass Index (SMI) as a measure of body condition—lower values indicate worse health.

The figure below shows the SMI for the four species. The error bars represent the standard error of the means. NOTE that the scales in the figures are different.

S: Southern flying squirrel (*Glaucomys volans*),

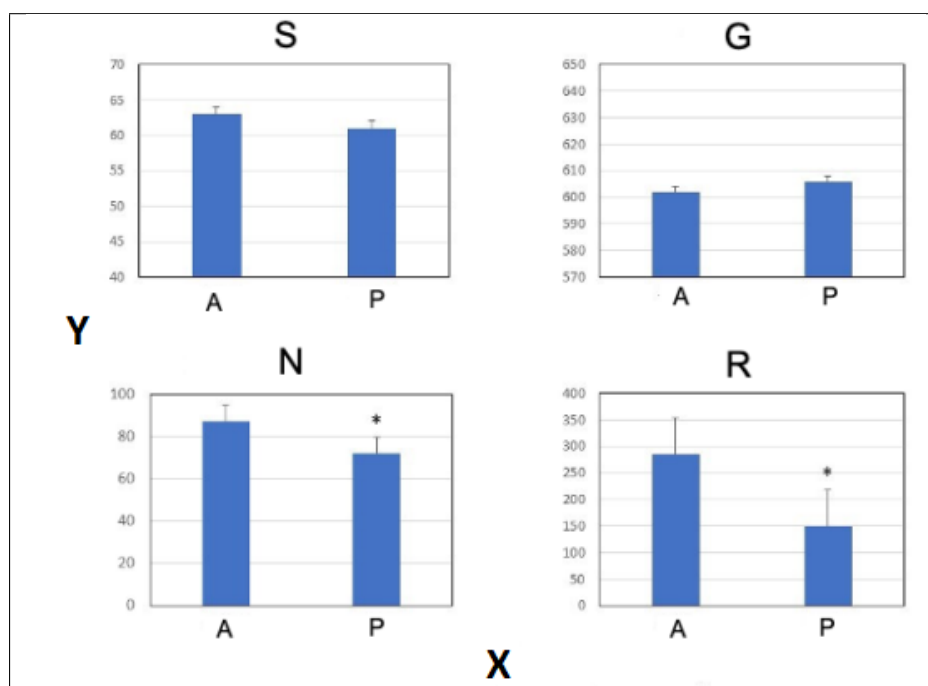
G: Grey squirrel (*Sciurus carolinensis*),

N: Northern flying squirrel (*Glaucomys sabrinus*), and

R: Red squirrel (*Tamiasciurus hudsonicus*).

* Indicates a statistically significant difference.

The two nocturnal species of flying squirrels have different diets and foraging strategies from the diurnal red and grey squirrels.



Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P3-4

English (Official)

X	Parasite infections
Y	Scaled Mass Index (g)
A	Absent
G	Grey squirrel
N	Northern flying squirrel
P	Present
R	Red squirrel
S	Southern flying squirrel

True or False?

Q.30.1 Northern flying squirrels and red squirrels are likely to be vulnerable to parasite-mediated competition. 1.0pt

Q.30.2 Under conditions of high nematode infections, northern flying squirrels are likely to be outcompeted by grey squirrels. 1.0pt

Q.30.3 Under conditions of high nematode infections, southern flying squirrels are likely to be outcompeted by northern flying squirrels. 1.0pt

Q.30.4 If we were to increase the sample size of one of these species for greater credibility of the study results, the best choice would be red squirrels. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

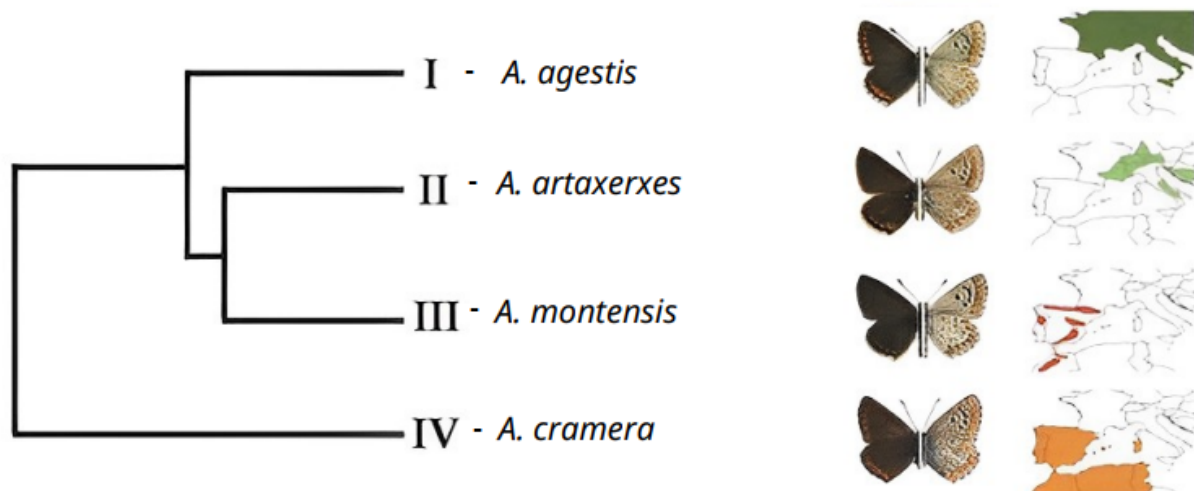
P3-5

English (Official)

Q.31

Cryptic species are organisms that look identical, but which represent distinct evolutionary lineages.

The diversity and geographical distribution of two cryptic species of *Arícia* butterflies, *A. agestis* and *A. cramera*, were studied.



Species	Elevation	Host Plants
<i>A. agestis</i>	0-1700 m	<i>Erodium</i> , <i>Geranium</i> , <i>Helianthemum</i>
<i>A. artaxerxes</i>	0-2200 m	<i>Erodium</i> , <i>Geranium</i> , <i>Helianthemum</i>
<i>A. montensis</i>	1000-2800 m	<i>Erodium</i> , <i>Helianthemum</i>
<i>A. cramera</i>	0-2800 m	<i>Erodium</i> , <i>Geranium</i> , <i>Helianthemum</i>

True or false?

Q.31.1 The pair of studied cryptic species apparently formed because of geographical isolation. 1.0pt

Q.31.2 These cryptic species have a clear ecological confinement to certain habitats. 1.0pt

Q.31.3 *Arícia* species without an exact specialization can coexist with species that are clearly confined to a limited range of habitats. 1.0pt

Q.31.4 Specialist *Arícia* species could be formed from generalist ancestors with wide geographical areas of distribution. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P3-6

English (Official)

Q.32

Seabirds spend much of their lives in the open ocean foraging but, during breeding, they congregate on remote islands or cliffs to nest. Figure A shows the foraging distribution of four species of seabirds. Relative proportions of stable isotopes (^{15}N and ^{13}C) were determined from blood collected from breeding individuals (Figure B). The colour codes in figures A and B also correspond with the information in Table 1. 'n' represents sample size.

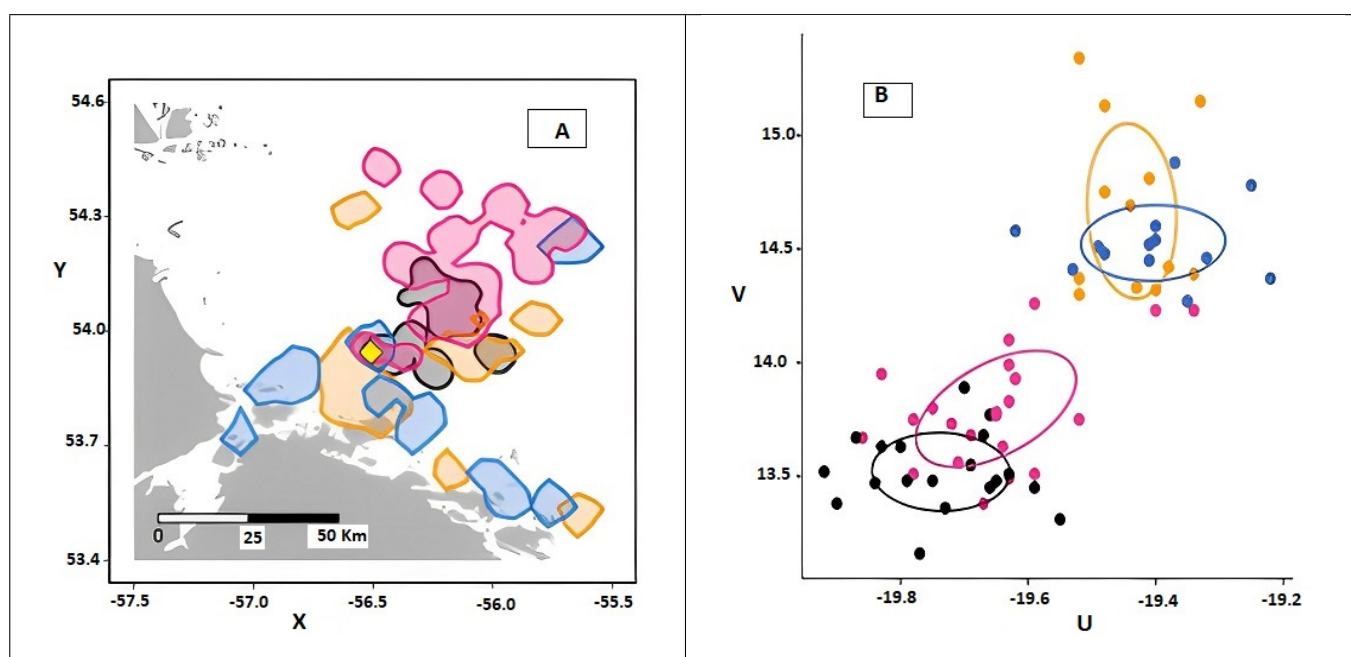


Table 1. Variation in the diving depths of the seabirds.

X	Longitude
Y	Latitude
U	Difference in percentage of ^{13}C parts per thousand
V	Difference in percentage of ^{15}N parts per thousand

	Atlantic Puffin (<i>Fratercula arctica</i>) (n=3)	Razorbill (<i>Alca torda</i>) (n=5)	Common Murre (<i>Uria aalge</i>) (n=5)	Thick-billed Murre (<i>Uria lomvia</i>) (n=7)
Colour code	Black	Blue	Orange	Pink
Maximum diving depth (meters)	60	120	180+	180+

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P3-7

English (Official)

Based on the figures above, state if the following statements are true or false.

Q.32.1 The foraging patterns indicate evidence of niche segregation in Atlantic Puffins and Razorbills.	1.0pt
--	-------

Q.32.2 Common Murres and Thick-billed Murres have similar diets.	1.0pt
---	-------

Q.32.3 Atlantic Puffins mostly forage in near-shore areas (close to the coast).	1.0pt
--	-------

Q.32.4 Razorbills and Common Murres have similar diets.	1.0pt
--	-------

Q.32.5 Thick-billed murres and razorbills have considerable foraging overlap.	1.0pt
--	-------



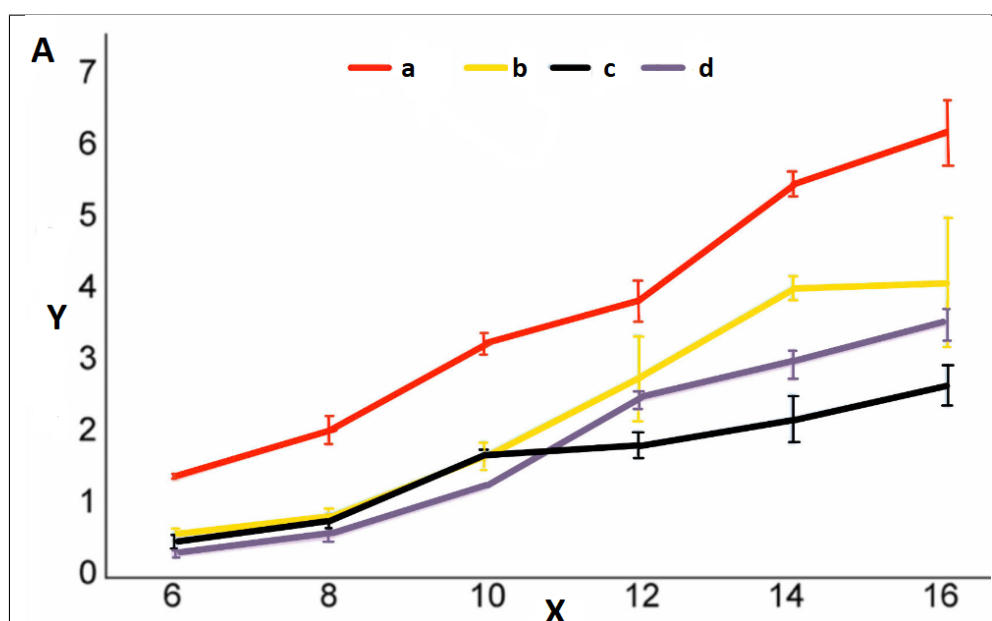
Q.33

Corals form mutualistic associations with a dinoflagellate, *Symbiodinium* of the family Symbiodiniaceae. *Symbiodinium* has two major life stages: a flagellated stage, called mastigote, and an aflagellated stage, called coccoid.

When *Symbiodinium* is grown in culture, each coccoid cell undergoes cell division to produce two mastigote cells. The mastigotes swim for a few days before they shed their flagella and metamorphose into the coccoid stage.

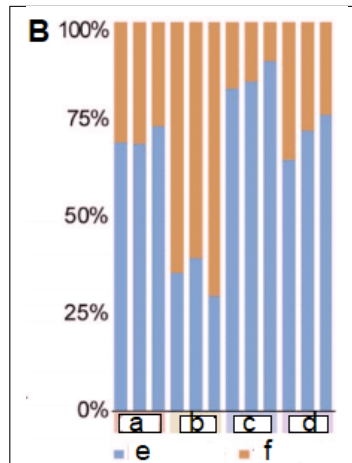
However, within the host coral cells, there is a dramatic change in *Symbiodinium* life history, with a marked reduction in cell proliferation and a severe reduction in the number of mastigotes. It is assumed that the coral host regulates the metamorphosis of *Symbiodinium*, and evidence suggests that certain nutrients may serve as limiting factors.

In an experiment, *Symbiodinium microadriaticum* cells were cultured outside their host cells, under nutrient-limited free-living conditions, to determine the importance of different nutrients for regulating cell proliferation and differentiation.



X	Days
Y	10^5 Cells / ml
a	Control
b	Nitrogen
c	Iron
d	Phosphate

Figure A shows cell proliferation curves of *S. microadriaticum* from Days 6 to 16, after subculturing in free-living conditions, with the selective depletion of the indicated nutrients. The error bars represent standard errors of the mean.



a	Control
b	Nitrogen
c	Iron
d	Phosphate
e	Mastigote
f	Coccoid

Figure B shows the relative proportions of mastigotes and coccoid cells of *S. microadriaticum* (one replicate culture per column), again under free-living conditions, with the depletion of the indicated nutrients.

True or False?

Q.33.1 All three nutrients tested affected the mean values of both proliferation and differentiation of *S. microadriaticum* cells. 1.0pt

Q.33.2 Nitrogen was the only limiting nutrient for the differentiation of *S. microadriaticum* cells within host coral cells. 1.0pt

Q.33.3 Given the above data, it is possible that the changing coccoid / mastigote ratios in the cultures are a side effect of the marked reduction in cell proliferation. 1.0pt

Q.33.4 Phosphate had relatively the greatest restrictive effect on cell proliferation over the experimental period. 1.0pt

Q.33.5 These results suggest that it may be possible for coral host cells to increase the levels of certain nutrients to regulate the differentiation of *S. microadriaticum* cells. 1.0pt



Q.34

The age/sex composition of a population of bonnet macaques, a social primate that lives in groups with multiple females and males, over several years is given below.

	2005	2009	2013
Estimated Population Size	40	45	30
<i>Percentage composition</i>			
Adult Male	6.67	13.11	20.00
Adult Female	10.00	13.56	32.50
Subadult Male	20.00	13.67	25.00
Subadult Female	16.67	17.33	10.00
Juvenile Male	22.33	19.67	5.00
Juvenile Female	24.33	22.67	7.50

True or false?

Q.34.1 The percentage annual population growth was relatively faster in 2013 than in other years. 1.0pt

Q.34.2 The relatively more equal adult male-to-female ratio in 2009 may have been responsible for the overall smaller population size in 2013. 1.0pt

Q.34.3 The age pyramid, shown by the population in 2005, as compared to that of 2009, is characterized by a higher birth rate and relatively lower life expectancy. 1.0pt

Q.34.4 The male-to-female ratio of subadults reflects the male-to-female ratio of juveniles in this population in subsequent years. 1.0pt

Theory 2



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United Arab Emirates 2023

P3-11

English (Official)

Q.35

In many species of nonhuman primates, morphology, social behaviour and mating system are tightly interlinked, making it possible to predict some traits once certain others are known.

Some traits of three primate species, A, B and C, are given in the table below.

	A	B	C
Average male body mass (kg)	160.00	55.00	0.255
Male to female body mass ratio	2.00	1.25	1.10
Testes mass to body mass ratio	0.2×10^{-3}	5×10^{-3}	1×10^{-3}
Usual number of offspring per birth	1	1	2

Q.35.1 Which of the species is expected to have the highest levels of within-group male aggression? 1.0pt

- A. Species A
- B. Species B
- C. Species C

Q.35.2 Which of the species is expected to have the highest variance in number of matings per male? 1.0pt

- A. Species A
- B. Species B
- C. Species C

Q.35.3 Which of the species is most likely to live in multi-male multi-female groups, in which receptive females could mate with multiple males? 1.0pt

- A. Species A
- B. Species B
- C. Species C

Q.35.4 In which of the species are males most likely to be involved in parental care? 1.0pt

- A. Species A
- B. Species B
- C. Species C

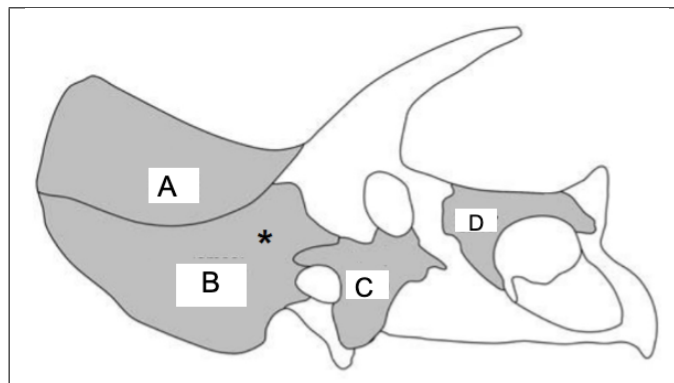


Q.36

Some fossilised skulls of triceratops (a type of dinosaur) show injuries sustained while the animal was alive.

The figure shows a drawing of a triceratops skull. Injuries in the highlighted bones were assessed across many fossils. The numbers give the number of individuals with injuries found in that bone, out of the total number of individuals in which that bone was analysed. The Squamosal bone is marked with asterisk.

Two main causes of triceratops skull injuries are attacks by large predators (e.g. *T. rex*), or combat between adult male triceratops. Note that *T. rex* stood much taller than triceratops.



A	1/45
B	10/58
C	7/39
D	0/47

True or False?

Q.36.1 Nasal bones are the most abundant of fossilised triceratops skull bones. 1.0pt

Q.36.2 Triceratops collars were formed as outgrowths of parietal bones (which form the roof of the skull). 1.0pt

Q.36.3 The squamosal bone has the highest frequency of injuries compared to all the analysed bones. 1.0pt

Q.36.4 The distribution of injuries is better explained by combats between triceratops males, rather than *T. rex* attacks. 1.0pt

**Q.37**

According to a particular hypothesis, individuals of certain species tend to decrease their use of resources for the benefit of other individuals. If they themselves feed less, for example, there may be more food left for other individuals in the population.

Analyse the following statements about this evolutionary hypothesis.

True or False ?

Q.37.1 The above hypothesis represents a classic group-selection argument, in which natural selection acts to increase the fitness of a population.	1.0pt
--	-------

Q.37.2 Group selection is now considered to be the most accepted mechanism to explain the evolution of the group behaviours of animals, in contrast to individual selection, which explains the behaviour of individual animals.	1.0pt
---	-------

Q.37.3 Logical evidence in favour of group selection could be obtained if different individuals within a group adopted completely different strategies to increase their own fitness.	1.0pt
--	-------

Q.37.4 The ability of one individual, within a group of animals, to adopt a strikingly different behavioural strategy from the others, could arise by chance.	1.0pt
--	-------

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P4-1

English (Official)

Theory 2

Q.38

It has been observed that natural populations of a large majority of animal species have evolved a numerical sex ratio at birth of 1:1 (excluding sterile offspring).

True or false?

Q.38.1 A 1:1 ratio has evolved to ensure that each individual is equally likely to encounter an individual of the opposite sex as another individual of the same sex.	1.0pt
--	-------

Q.38.2 A 1:1 ratio would be preferred by individuals of a particular generation if they are likely to obtain the same number of grandchildren through both, their daughters and their sons.	1.0pt
--	-------

Q.38.3 If sons and daughters require different amounts of parental investment, the ratio is more likely to deviate from 1:1.	1.0pt
---	-------

Q.38.4 A closed population, such as that presented by fig wasps, in which females mate with a single male and full brothers compete to mate with their full sisters, is likely to display a deviation from the 1:1 ratio.	1.0pt
--	-------

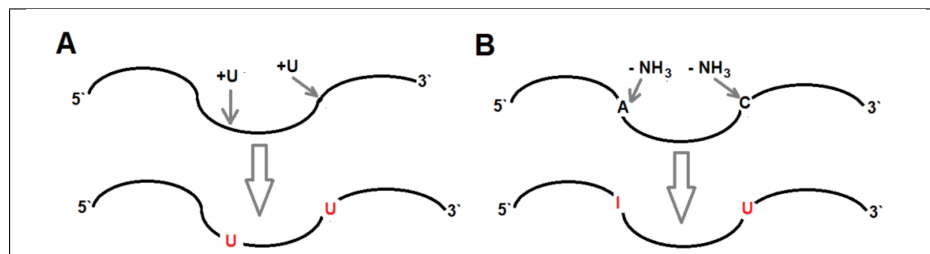


Q.39

RNA editing is the process of RNA sequence modification by different enzymes.

RNA editing was discovered in the *Trypanosoma* kinetoplast, where a specific mechanism adds several uridine nucleotides into specific mRNA sites using a guide RNA (Figure A).

Another RNA editing mechanism was discovered in mammals: specific APOBEC enzymes deaminate cytosine to uracil, and specific ADAR enzymes deaminate adenine to hypoxanthine (inosine nucleotide) (Figure B).



True or False?

Q.39.1 RNA editing processes are highly conserved, with similar mechanisms in all eukaryotes, from trypanosomes to mammals. 1.0pt

Q.39.2 RNA editing can shift the reading frame in mRNA. 1.0pt

Q.39.3 RNA editing can result in protein isoforms with different molecular weights 1.0pt

Q.39.4 RNA editing occurs only in the nucleus. 1.0pt

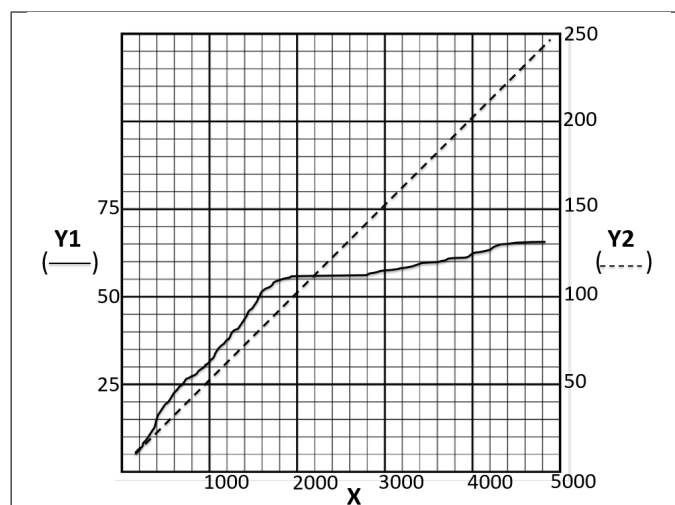


Q.40

Christiane Nüsslein-Volhard and Eric F. Wieschaus carried out an extensive mutation screen to identify all genes involved in segmentation of *Drosophila*.

In their experiment, adults were exposed to a mutagen, then crosses were carried out. The progeny were analysed for changes in segmentation patterns (such as missing segments).

The graph shows results of analyzing mutations on chromosome 2.



X	number of progeny analysed
Y1	number of segmentation genes identified by mutagenesis
Y2	number of segmentation mutants

True or false?

Q.40.1 The number of segmentation genes identified on chromosome 2 is between 60 and 70. 1.0pt

Q.40.2 Analysing 10000 progeny would have led to the identification of substantially more segmentation genes 1.0pt

Q.40.3 Analysis of more than 2000 progeny tended to lead to the identification of new alleles of genes which had already been identified, rather than more new genes. 1.0pt

Q.40.4 The frequency of obtaining recessive mutants is higher than dominant mutants as a greater number of progeny are analyzed. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P4-4

English (Official)

Q.41

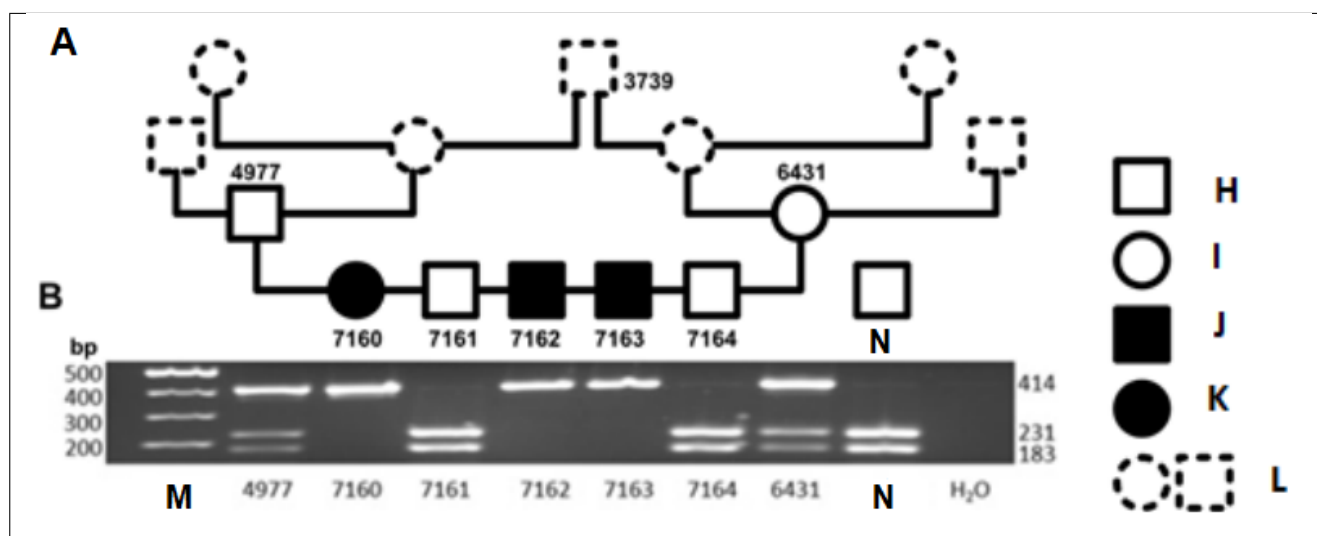
Restriction fragment length polymorphism (RFLP) analysis consists of:

1. amplification of a DNA fragment by PCR,
2. digestion of the PCR product with a restriction enzyme,
3. DNA electrophoresis.

The RFLP method was used to detect the recessive allele of the *GNPTAB* gene, which causes a genetic disease in cats – mucopolipidosis II. A point mutation in the recessive allele changes the sequence of the 882nd codon of the gene from CAG to TAG.

The diagram shows the result of analysis the *GNPTAB* gene of related cats. A 414 bp fragment of the *GNPTAB* gene was amplified and digested with the restriction enzyme PstI. PstI recognises and cuts the sequence: 5'-CTGCAG-3'.

Part A presents the family tree with a legend, while part B presents the result of the RFLP analysis. The analysis was also performed using the genetic material of an unrelated healthy cat (designated as "Normal"). There was another sample which contained water during PCR, instead of template DNA (designated as "H₂O").



H	Male, healthy
I	Female, healthy
J	Male, affected
K	Female, affected
L	Not studied
M	Marker
N	Normal



True or false?

Q.41.1 The recessive allele of <i>GNPTAB</i> gene makes the encoded protein shorter.	1.0pt
---	-------

Q.41.2 The 414 bp-long DNA fragment corresponds to the recessive allele of <i>GNPTAB</i> gene.	1.0pt
---	-------

Q.41.3 Mucopolipidosis II in cats is inherited as X-linked recessive disease.	1.0pt
--	-------

Q.41.4 Cat number 3739 must be homozygous for the recessive allele of <i>GNPTAB</i> gene	1.0pt
---	-------



Q.42

As more and more human genomes are being sequenced, storing this information has become an issue.

One way to reduce the size of the files containing sequence data is to store only the information about the differences between the sequenced genomes and a “reference genome”. (The reference genome is haploid).

Such file format is called Variant Call Format (vcf), and is in essence a table like the one below. In this example there is information about the genomes of 2 individuals, but any number of genomes (from 1 to many thousands) can be stored in one file.

Chromosome	Position	Reference allele	Alternative alleles	Genotypes	
				Individual 1	Individual 2
1	5897	G	A	0/1	0/0
1	6908	C	T	0/0	1/1
1	7100	A	C,T	0/2	1/2
...	...	...	...	...	...

In the columns “Genotypes” 0 stands for the nucleotide being the same as the reference allele, while other numbers stand for the nucleotide being the same as alternative alleles in the order they appear in the “Alternative alleles” column.

Note, In this question **ONLY** consider single nucleotide variants (SNVs, SNPs, switches of a single base) and consider the genomes of all people to be exactly equal length.

True or false?

Q.42.1 Individual 1 from the example above is homozygous at the position 7100 on chromosome 1. 1.0pt

Q.42.2 At any given chromosomal position 25% of individuals in the population are expected to have 1/1 genotype. 1.0pt

Q.42.3 The size of a vcf file storing the genome of a single individual increases with increasing genetic difference between this individual and the reference genome. 1.0pt

Q.42.4 The size of a vcf file storing the genomes of two individuals and their daughter is expected to be smaller than a vcf file storing the genomes of the same two individuals and a genome of an unrelated female. 1.0pt



Q.43

Most human quantitative traits are affected both by genetics and environment. One way to quantify the relative contribution of genetics versus environment to a given trait, is to compare trait covariance (a measure of joint variability of the trait) in pairs of monozygotic (MZ) versus dizygotic (DZ) twins.

True or false?

Q.43.1 Such studies assume that all trait covariance between DZ twins is due to shared environment.	1.0pt
--	-------

Q.43.2 Such studies assume that all trait covariance between MZ twins is due to shared genetics.	1.0pt
---	-------

Q.43.3 Such studies assume that environmental exposure covariance is the same between MZ and DZ twins.	1.0pt
---	-------

Q.43.4 For a trait with a very strong genetic contribution, the trait covariance in MZ twins is expected to be higher than in DZ twins.	1.0pt
--	-------

Q.43.5 Non-twin siblings are equally as suitable as DZ twins for such studies as genetically they are equally similar.	1.0pt
---	-------



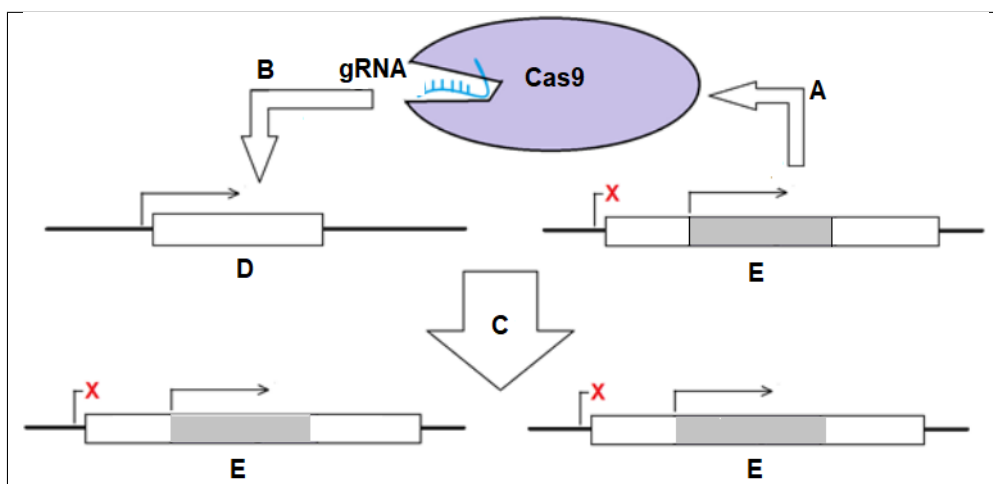
Q.44

Gene drives (mutagenic chain reaction) are a modern technology which causes highly efficient conversion of wild type alleles to non-functional alleles in all progeny of a carrier.

Gene drives are based on a transgenic construct containing genes of a target-locus-specific guideRNA (gRNA) and Cas9 RNA-guided DNase. If this transgenic construct co-occurs in a cell with the wild type target locus, Cas9 cleaves the target DNA. Next, a copy of the construct is inserted into the target locus by the homology directed repair (HDR) mechanism. This transgene insertion disrupts the target locus and leads to a loss-of-function mutation (see the figure).

Initially gene drive technology was tested on fruit flies. The mutagenic construct *yellow^{mut}*, was integrated into the X-linked gene *yellow*; loss-of-function in *yellow* leads to the flies having yellow bodies (wildtype flies have brown bodies). The Y-chromosome does not contain a copy of the gene *yellow*.

Assume sex is determined in the same way as in humans.



A	Expression
B	Cleavage
C	Homology-directed repair
D	Target
E	Target with Cas9/gRNA insertion

True or false?

Q.44.1 All progeny of *yellow^{mut}* males will have yellow bodies.

1.0pt

Q.44.2 All progenies of *yellow^{mut} / yellow^{mut}* females will have yellow bodies.

1.0pt



Q.44.3 Gene drives targeting genes involved in sex determination and reproduction, could become an efficient tool in pest insect population control. 1.0pt

Q.44.4 Lethal loss-of-function mutations could be successfully introduced in insect populations by gene drive technology. 1.0pt

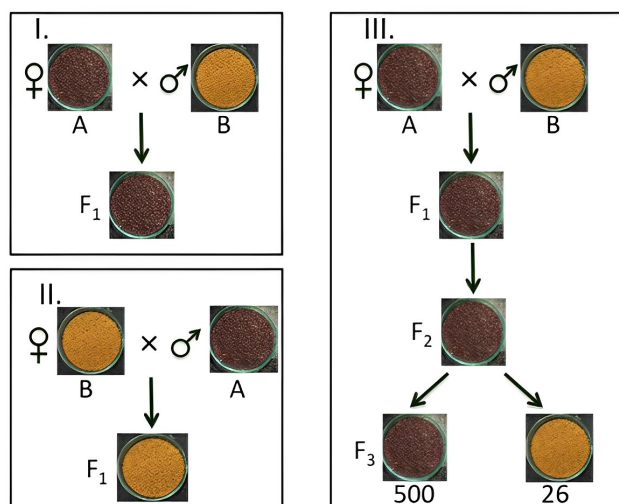


Q.45

Mustard (*Brassica juncea*) seeds are used as spice in Arabian cuisine. Mustard seeds have either brown or yellow seed coat color.

To study the inheritance of seed coat color in mustard, crosses were made with plants producing either brown seeds (A) or yellow seeds (B). *B. juncea* is amphidiploid.

Amphidiploids originate from hybridisation between two species, and the chromosome number of the hybrid is the sum of the chromosome numbers of both parental species.



The figure represents results from 3 different crosses. Pure lines have been used for parental crosses.

Cross I: A cross between a plant with brown seeds as female parent and a plant with yellow seeds as male parent produces F_1 with brown seeds.

Cross II: A reciprocal cross produces F_1 with yellow seeds.

Cross III: Self-pollinating the F_1 plants from cross I gives F_2 plants which have only brown seeds. Selfing the F_2 plants produces seeds (F_3 generation), which are either brown or yellow. The ratio of brown (500) to yellow (26) seeds is 15:1.

True or false?

Q.45.1 There are two copies of the seed coat color gene in the *B. juncea* genome. 1.0pt

Q.45.2 The gene for seed coat color is present in the chloroplast genome. 1.0pt

Q.45.3 Brown is dominant over yellow. 1.0pt

Q.45.4 F₃ progeny from cross II will produce plants with brown and yellow seeds in a ratio of 15:1. 1.0pt



Q.46

- A green and wrinkled seeds pea strain was crossed with a yellow and round seeds pea strain.
- All F_1 seeds were yellow and round.
- In F_2 progenies statistically large number of pea seeds show inheritance according to Mendel's laws. However, small numbers of seeds could demonstrate other distributions in analysis.

Imagine you get a pea pod from an F_1 plant containing F_2 progeny with 4 pea seeds inside and make guesses about their phenotypes.

You can estimate the probability of a particular phenotype pattern using the following steps:

1. Find the probability of the particular seeds phenotype combination, based on Mendelian probabilities ($1/4$, $9/16$, etc.), 2)
2. Find the total number of possible combinations giving that phenotype pattern
3. Multiply result 1 and result 2.

For example, to calculate the chance of all 4 seeds being yellow, we need calculate

$$1 \times \left(\frac{3}{4}\right)^4$$

(The probability of any one seed being yellow is $\frac{3}{4}$, we have 4 independent yellow seeds, and we have only one combination).

True or false?

Q.46.1 The probability of all 4 seeds being green is $1/256$	1.0pt
Q.46.2 The probability of 3 round and 1 wrinkled seed is 1	1.0pt
Q.46.3 The probability of 2 green and 2 yellow seeds is $27/128$	1.0pt
Q.46.4 The probability of 4 different seed phenotypes in the pod is $243/8192$	1.0pt
Q.46.5 The probability of all 4 seeds having identical phenotypes for both traits is $1/32$	1.0pt



Q.47

The 2022 Nobel Prize was awarded for sequencing ancient DNA to study the human past.

This work produced whole genomes of several Neanderthals and one Denisovan (another group of archaic hominins).

The figure depicts trees showing phylogenetic relationships between those archaic specimens and different groups of modern humans.

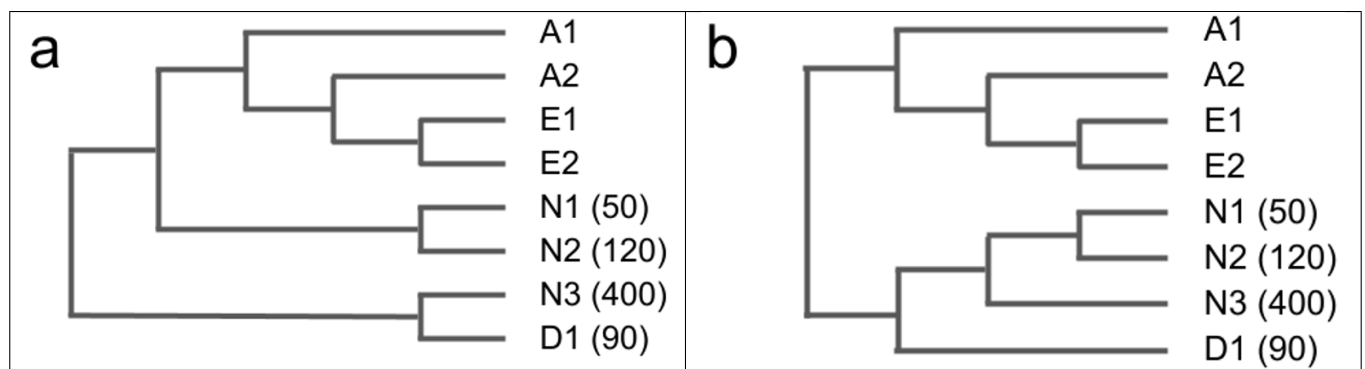


Figure 1. Cladograms based on mitochondrial DNA sequence (a), and average genetic distances across autosomal genomes (b).

Modern humans are represented by 2 African (A1, A2) and 2 Eurasian (E1, E2) individuals.

Archaic hominins are represented by 3 Neanderthals (N1, N2, N3) and one Denisovan (D1).

Numbers in brackets next to archaic hominins indicate the approximate age (in thousands of years ago) of each specimen.

Note: **Branch length is arbitrary and conveys no information here,**

The split between modern humans and Neanderthals occurred 750-550 thousand years ago.

60-50 thousand years ago, there was a Neanderthal-to-human gene flow event, which occurred in Eurasia (so did not affect African human populations). All non-African modern humans have 2-3% Neanderthal DNA derived from that gene flow event.

However, present-day humans also have sequence segments similar to Neanderthals' because of common human-Neanderthal ancestry, and not just because of gene flow. This phenomenon is called 'Incomplete Lineage Sorting' (ILS).

True or False?

Q.47.1 Neanderthal-like sequences in present-day humans, which result from gene flow, are on average shorter (fewer base pairs long), than those resulting from ILS. 1.0pt

Q.47.2 If branch length in tree b was proportional to the number of accumulated mutations, the branch leading to N2 would be expected to be shorter than the branch leading to N1. 1.0pt



Q.47.3 A possible explanation for the difference between the mitochondrial and autosomal trees, is a gene flow event from humans (populations branching off before A1) to Neanderthals between 400 and 120 thousand years ago, that resulted in human-like mitochondrial DNA being introduced into the gene pool of Neanderthals. 1.0pt

Q.47.4 By combining Neanderthal-like sequence segments from many (>100) unrelated modern humans, one can only recover around 2 – 3% of the whole Neanderthal genome. 1.0pt

Q.47.5 The maximum frequency of any Neanderthal allele in any present-day non-African population is 3% 1.0pt

Q.47.6 Neanderthal-like segments in present-day humans are expected to have identical sequences to the corresponding genome segments of the N1 specimen. 1.0pt

Q.47.7 Present day Africans share no alleles in common with Neanderthals. 1.0pt



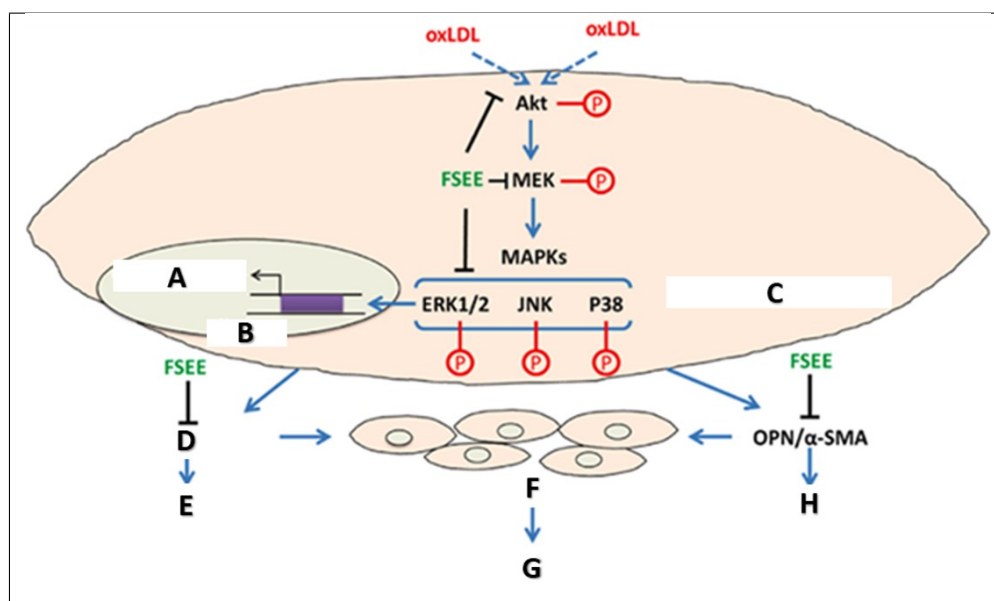
Theory 2

Q.48



The national plant of UAE, *Tribulus omanense*, is a desert plant containing various secondary metabolites, including flavonoids, saponins and alkaloids. These have multiple potentially therapeutic bioactivities.

Furostanol saponin enriched extract (FSEE) from *Tribulus* was recently tested for their potential anti-atherosclerotic activity. The model was vascular muscle cells. These cells play a key role in the formation of atherosclerotic plaques when they over proliferate and differentiate into inappropriate cell types (myofibroblast and microphage like cells) when triggered by oxidised LDL (oxLDL).



Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-2

English (Official)

A	Gene expression
B	Nucleus
C	Vascular smooth muscle cell
D	G0/G1 to S phase
E	Cell cycle acceleration
F	Vascular smooth muscle cell proliferation
G	Atherosclerosis
H	Phenotype switching

True or False?

Q.48.1 Inhibition of the signalling cascade could be explained by inhibition of kinase activities. 1.0pt

Q.48.2 Generally, inhibition of the transition from the G0/G1 phase to S phase could at least be partly explained by inhibition of phosphatases. 1.0pt

Q.48.3 Oxidised LDL particles (oxLDL) direct smooth muscle cells towards senescence (senescent cells are 'exhausted' and will never divide, but do not die). 1.0pt

Q.48.4 Smooth muscle cells are terminally differentiated, and under physiological circumstances, rest for the life in a G0 phase. 1.0pt



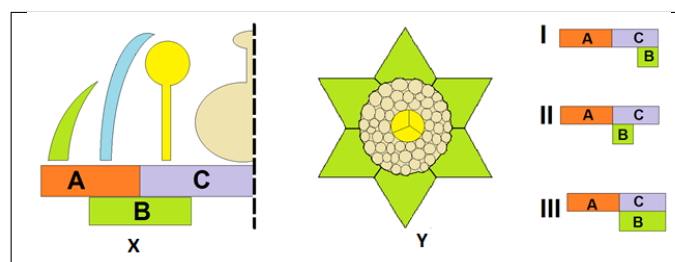
Q.49

The ABC-model of flower development explains the regulation of whorl differentiation in flower meristems.

There are three groups of master genes, A, B and C genes, each determining a type of whorl:

- Sepals need only A gene expression.
- Petals need simultaneous expression of A and B genes.
- Stamens need simultaneous expression of B and C genes.
- Carpels need only C gene expression.

The tropical American plant, *Lacandonia schismatica*, has inverted flowers (see Figure), with stamens located in the center of flower, and individual carpels located between tepals and stamens.



X	ABC - model
Y	Lacandonia flower

True or false?

Q.49.1 *Lacandonia schismatica* flower morphology could be explained by gene expression pattern I. 1.0pt

Q.49.2 Flowers of *Lacandonia schismatica* would have neither petals nor carpels, if flowers followed gene expression pattern II. 1.0pt

Q.49.3 The only whorls flowers of *Lacandonia schismatica* would be missing, if they followed expression pattern III, is petals. 1.0pt

Q.49.4 *Lacandonia* flowers form typical berries after pollination and fruit ripening. 1.0pt

Q.49.5 Tepals, like sepals, need only A gene expression. 1.0pt



Q.50

Photomorphogenesis of plant seedlings has been extensively studied, using light inhibition of *Arabidopsis thaliana* hypocotyl elongation as a model system. This phenomenon involves phytochrome as a photoreceptor.

Phytochrome exists in two forms: the red-light absorbing Pr form and far-red light absorbing Pfr form. Pr absorbs red light and gets converted to Pfr while Pfr absorbs far-red light and is quickly converted to Pr form via photochemical conversion. Pfr can also be converted to Pr form via non-photochemical conversion that is independent of light in addition to photochemical conversion (Figure 1).

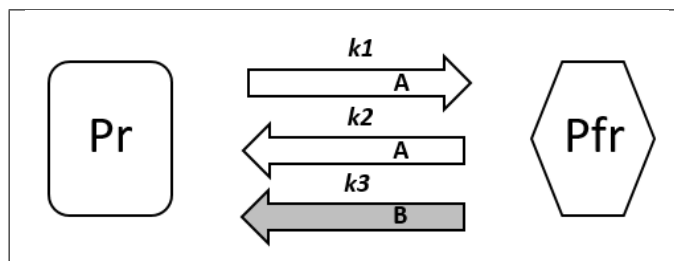


Figure 1

A	Photochemical
B	Non-photochemical

Phytochrome may act as a thermosensor, as well as a photoreceptor: the effect of temperature on the rate constant of the non-photochemical reaction is plotted in figure 2.

The photochemical reactions are not sensitive to temperature.

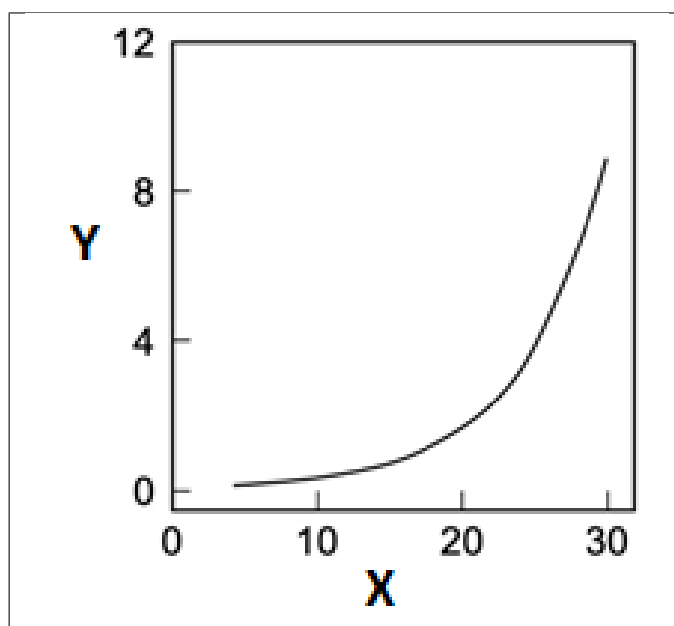




Figure 2

X	Temperature ($^{\circ}\text{C}$)
Y	Rate constant, k_3 (min^{-1})

True or False ?

Q.50.1 At equilibrium during the photochemical process, proportion of total phytochrome in the Pfr form is larger at higher temperatures.	1.0pt
--	-------

Q.50.2 In natural day-night conditions, the hypocotyl is more elongated at temperatures above the optimal temperature required for the plant.	1.0pt
--	-------

Q.50.3 Phytochrome-deficient mutant seedlings, grown at high temperatures, show similar hypocotyl elongation to wild-type seedlings grown at low temperatures.	1.0pt
---	-------

Q.50.4 The effect of temperature on hypocotyl elongation is reinforced in total darkness.	1.0pt
--	-------



Q.51

The photosynthetic rate can be expressed as a function of the concentration of CO_2 in the intercellular air space (C_i) within leaves. This makes it possible to evaluate limitations to photosynthesis imposed by CO_2 supply, independently to the functioning of stomata.

The CO_2 compensation point reflects the balance between photosynthesis and respiration.

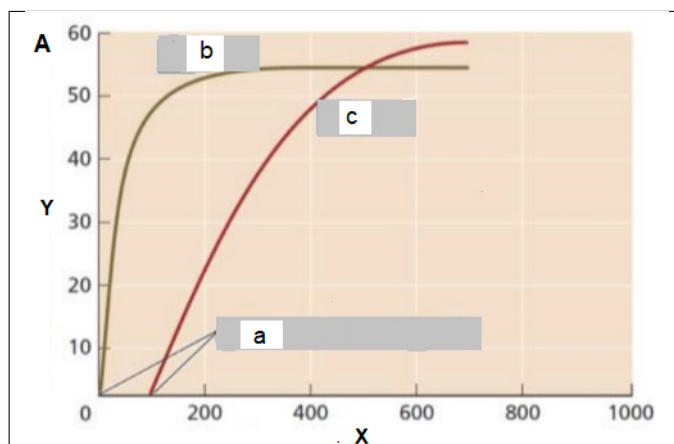


Figure A: Changes in photosynthesis as a function of intercellular CO_2 concentration in a C4 plant and a C3 plant.

Figure A	
X	Intercellular CO_2 concentration, C_i (ppm)
Y	Net CO_2 assimilation $\mu mol\ m^{-2}\ s^{-1}$
a	CO_2 Compensation points
b	Plant species R
c	Plant species Q

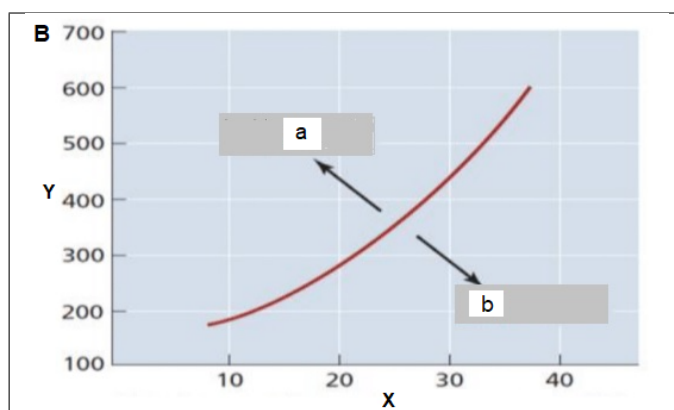


Figure B: Combination of global atmospheric CO_2 levels and daytime growing-season temperatures.

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-7

English (Official)

X	Daytime growing season temperature ($^{\circ}\text{C}$)
Y	Atmospheric CO_2 (ppm)
a	Conditions favouring plant W
b	Conditions favouring plant Z

True or False?

Q.51.1 Species R is C4 plant and Species Q is C3 plant.	1.0pt
Q.51.2 At 400 ppm C_i , net CO_2 assimilation of plant species R is limited by carboxylation capacity of Ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO).	1.0pt
Q.51.3 At 700 ppm C_i , net CO_2 assimilations of both plants R and Q are limited by Ribulose-1,5-bisphosphate (RuBP) regeneration.	1.0pt
Q.51.4 At ambient atmospheric CO_2 concentration, plant R has greater photosynthetic water use efficiency (i.e., more CO_2 may be taken up per unit of water transpired) than plant Q.	1.0pt
Q.51.5 Reducing oxygen concentration (for example: from 20% to 2%) would shift the C_i response curve of plant Q to the left, toward that of plant R.	1.0pt
Q.51.6 In figure B, W is C4 plant while Z is C3 plant.	1.0pt



Q.52

Scientists studied how water stress intensity affects the relationship between photosynthesis and phloem transport (translocation) rate.

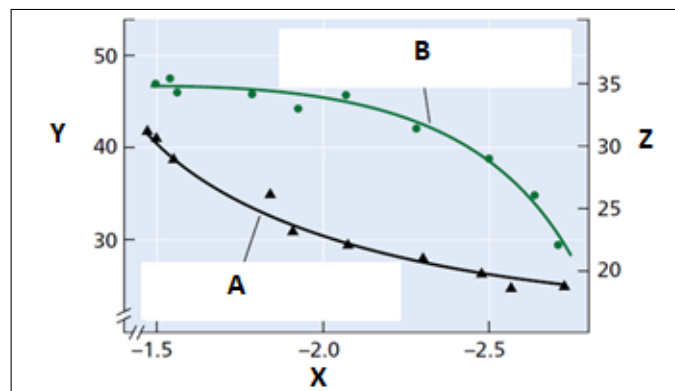


Figure 1. Relative effects of water stress on photosynthesis and translocation in sorghum (*Sorghum bicolor*).

X	Leaf water potential (MPa)
Y	Photosynthesis rate ($\mu\text{mol } ^{14}\text{CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)
Z	Phloem transport rate (percent ^{14}C removed per hour)
A	Photosynthesis
B	Phloem transport

True Or False ?

Q.52.1 Decreased water potential in the phloem during water stress may inhibit the movement of assimilates because phloem transport depends on turgor. 1.0pt

Q.52.2 Decreased consumption of assimilates in the sink organs could not be the cause in the decrease in phloem transport of photosynthate exported from leaves during severe water stress. 1.0pt

Q.52.3 Severe water stress (leaf water potentials of -2.7 MPa), did not completely inhibit photosynthesis. 1.0pt

Q.52.4 Photosynthesis is more sensitive to water stress compared to phloem transport. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-9

English (Official)

Q.52.5 The effect of different levels of water stress in different parts of the root system on transport of assimilates, favours root expansion into more moist patches of soil. 1.0pt

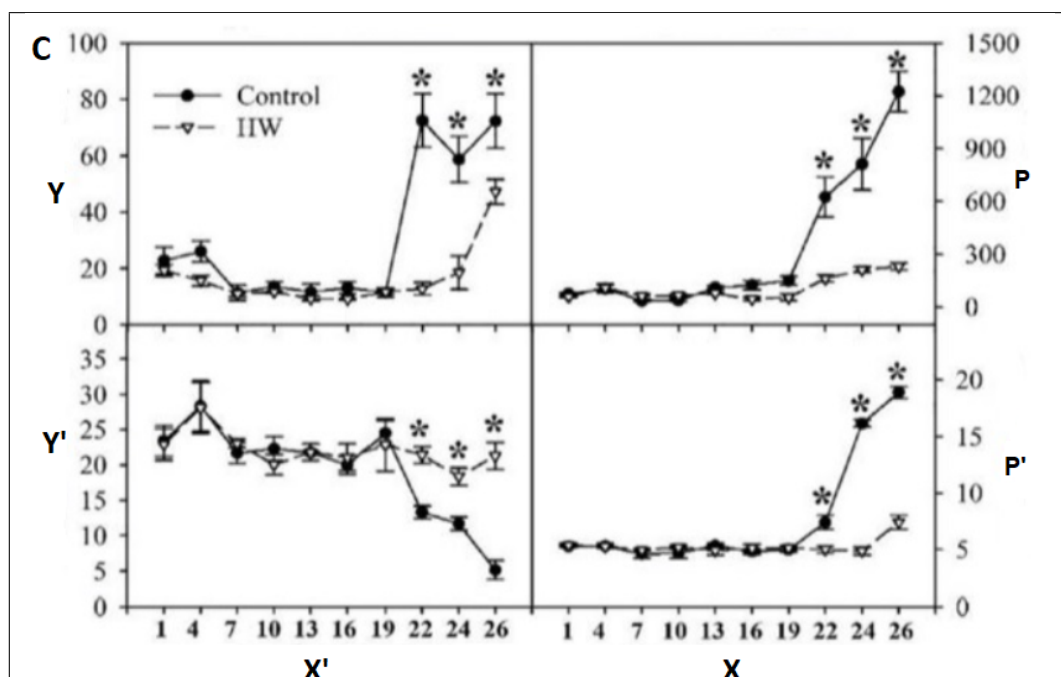
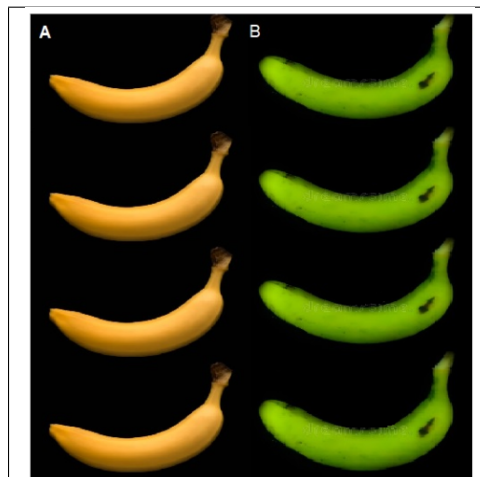


Q.53

As a typical climacteric fruit, banana fruit need to undergo a ripening process from harvest to consumption, characterized by an increase in respiration at the onset of ripening.

Experiments were conducted to investigate the potential of post-harvest treatment of bananas with water containing dissolved H_2 (hydrogen water; HW) as a simple, non-toxic treatment for delaying post-harvest ripening.

The banana fruit fingers were soaked in ultrapure water (control) or hydrogen water (0.8 ppm) at 25 ± 1 °C for 10 min. After 2h air drying, fruit fingers were stored. At day 1, 4, 7, 10, 13, 16, 19, 22, 24 and 26 after treatment, fruit fingers were analysed (figure 1).





X'	Days after Treatment
X	Days after Treatment
Y'	Firmness (g cm^{-2})
Y	Respiratory Rate ($\text{CO}_2 \text{ mg kg}^{-1} \text{ s}^{-1}$)
A	Yellow Banana
B	Green Banana
P'	Total Soluble Solids (%)
P	Ethylene production ($\mu \text{g kg}^{-1} \text{ s}^{-1}$)

Figure 1. A: control fruit at Day 26. B: HW-treated fruit at Day 26.

C: respiratory rate, ethylene production rate, firmness and total soluble solid (TSS). The mark * displayed significant ($P < 0.01$) differences for each storage time, according to the independent samples t -test. HW: HW-treated fruit.

True or False?

Q.53.1 HW treatment delays ripening of banana.	1.0pt
Q.53.2 HW treatment may inhibit the up-regulation of cell wall degradation-related genes.	1.0pt
Q.53.3 The ripening of control and HW-treated fruit differed significantly on the 19 th day of storage.	1.0pt
Q.53.4 HW treatment delayed the development of flavour	1.0pt



Q.54

Plant oils are a dietary and bio-energy resource.

Namazkar et al. (2016) measured changes in the oil quality and quantity of rapeseed grown in climates with elevated $[\text{CO}_2]$, $[\text{O}_3]$ and temperature (T), either in combination, or as single factors.

When $[\text{CO}_2]$ and T were elevated at the same time, seed biomass was reduced by half.

Table 1. Climate treatments tested:

Environmental factors:	Ambient	Elevated
$[\text{CO}_2]$	390 ppm	650 ppm
$[\text{O}_3]$	20/20 ppb (day/night)	60/20 ppb (day/night)
Temperature	19/12 °C (day/night)	24/17 °C (day/night)

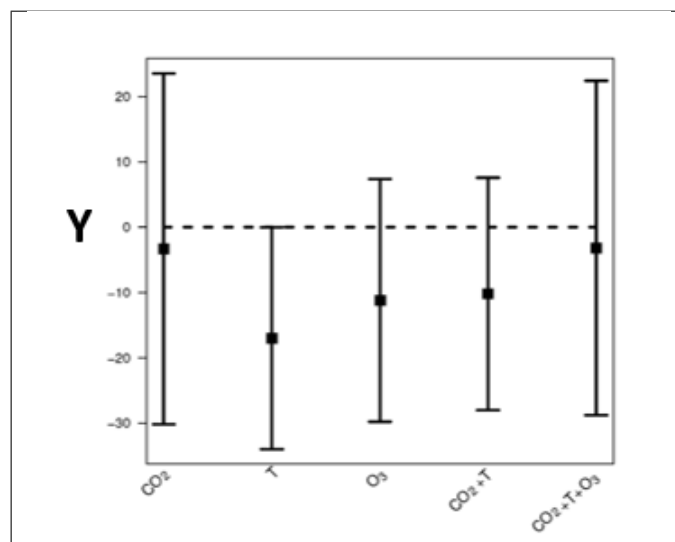


Figure 1. Change in total rapeseed oil content in each climate treatment, relative to the ambient climate (% change $\pm$ standard error).

Y	Change in total oil content (%)
----------	---------------------------------

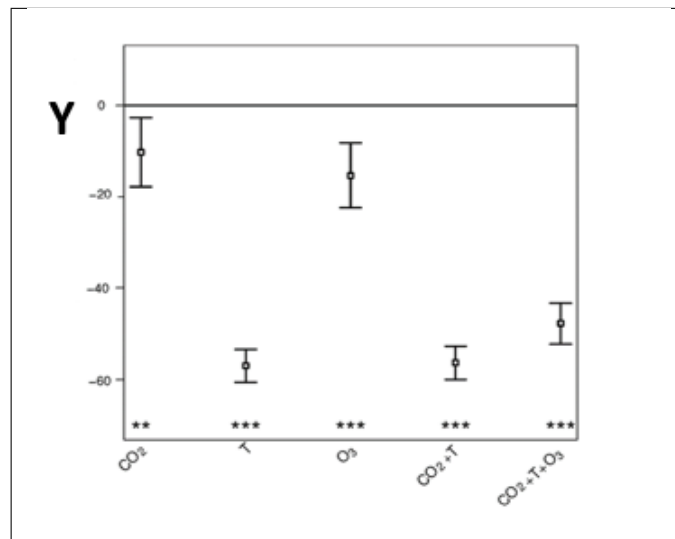


Figure 2. Change in the polyunsaturated fatty acid relative to the ambient climate (% change ± standard error). The polyunsaturated fatty acids (FAs) were C18:2 and C18:3. (*** $P < 0.0001$, ** $P < 0.01$, * $P < 0.05$.)

Y	Change in polyunsaturated FA _s (%)
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True or False?

Q.54.1 The negative impacts of T treatment on polyunsaturated fatty acid content were lessened by adding [O ₃] and [CO ₂].	1.0pt
---	-------

Q.54.2 A [CO ₂] increase of +260 ppm was the single factor with the biggest detrimental effect on the quantity of the seed oil.	1.0pt
--	-------

Q.54.3 The polyunsaturated FAs, C18:2 and C18:3, were significantly decreased by all climate treatments	1.0pt
--	-------

Q.54.4 The results demonstrate why prediction of climate effects requires experiments with combined factors and should not be based on extrapolation from single factor experiments.	1.0pt
---	-------



Q.55

Plants have limited resources for defenses and species that invest in biotic defenses might exhibit fewer other types of defense.

Leaves, with or without extrafloral nectaries (EFNs), from six tropical savanna species in Brazil were investigated. Herbivory (% of leaf area eaten) and specific leaf area- SLA (leaf area vs leaf weight) were measured.

EFNs provide food to reward patrolling ant 'guards'. Plants without EFNs have tougher leaves.

Plants with EFNs are: *Heteropterys umbellata*, *Banisteriopsis campestris* and *Peixotoa tomentosa*

Plants without EFNs are: *Byrsonima coccolobifolia*, *Byrsonima verbascifolia* and *Byrsonima intermedia*

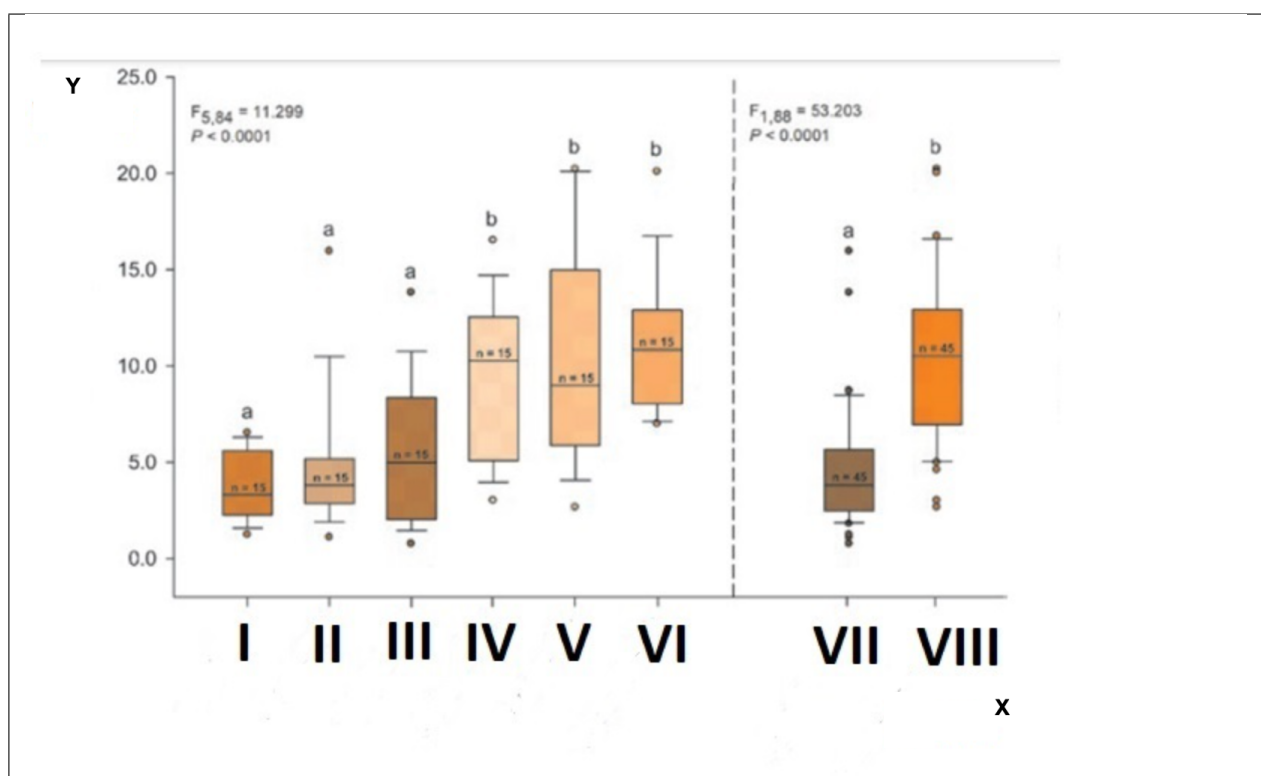


Figure 1. Herbivory levels. In the right panel, plant species were grouped according to presence or absence of EFNs.

Lines within bars represent the median and dots represent outliers.

Bars labelled with the same lowercase letters (a and b) are not significantly different from each other.



X	Plant species and on right side of graph plants with or without EFNs
Y	Herbivory (%) levels
I	<i>H.umbellata</i>
II	<i>P.tomentosa</i>
III	<i>B. campestris</i>
IV	<i>B. verbascifolia</i>
V	<i>B. intermedia</i>
VI	<i>B. coccolobifolia</i>
VII	Plants with EFNs
VIII	Plants without EFNs

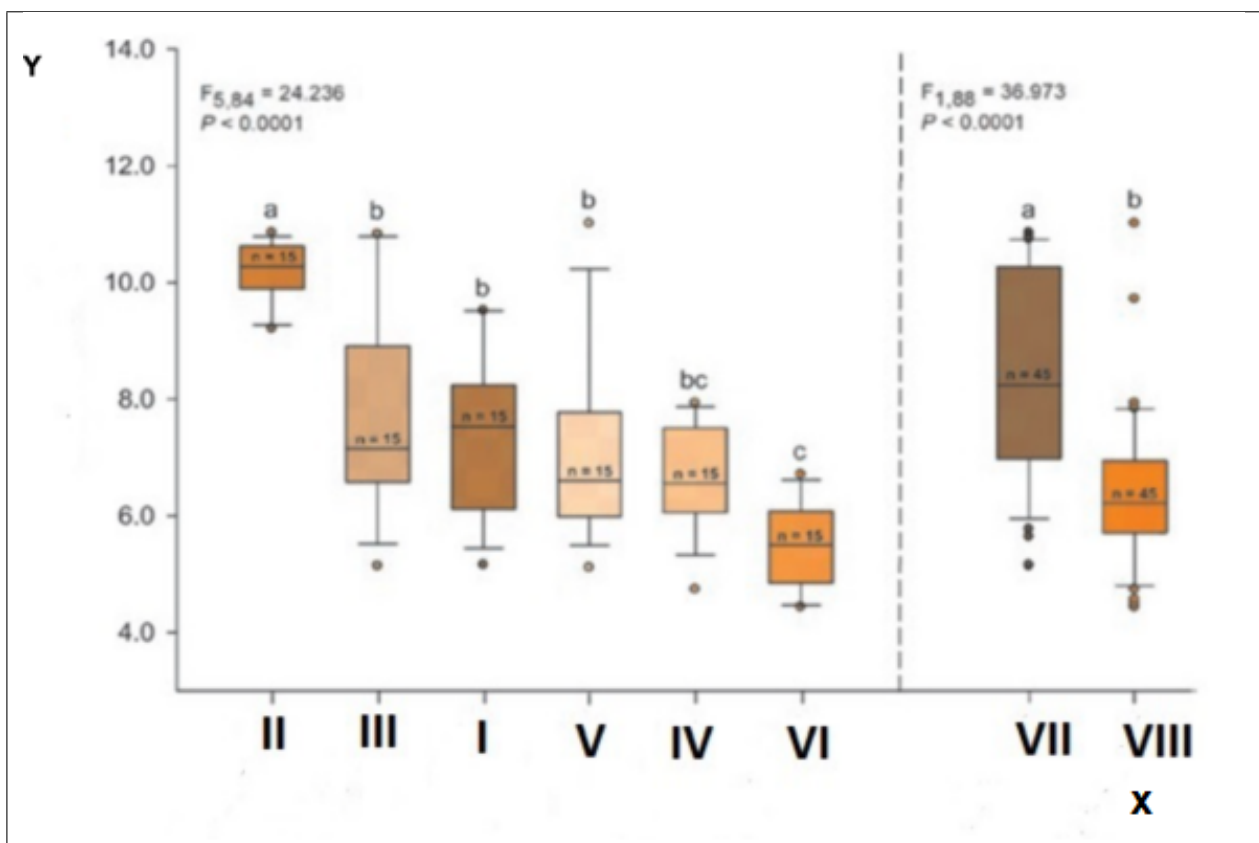


Figure 2. Specific Leaf Area. (Note the order of I to VI on the x-axis)

Bars labelled with the same lowercase letters (a and b) are not significantly different from each other.

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-16

English (Official)

X	Plant species and on right side of graph plants with or without EFNs
Y	SLA ($\text{mm}^2 \text{mg}^{-1}$)
I	<i>H. umbellata</i>
II	<i>P. tomentosa</i>
III	<i>B. campestris</i>
IV	<i>B. verbascifolia</i>
V	<i>B. intermedia</i>
VI	<i>B. coccolobifolia</i>
VII	Plants with EFNs
VIII	Plants without EFNs

True or False?

Q.55.1 Insects feeding on plants may trigger plant responses leading to increased costs associated with the expression of physical and/or chemical defenses. 1.0pt

Q.55.2 Plants with biotic defense experienced the lowest levels of leaf area loss to herbivory. 1.0pt

Q.55.3 In this study, species that invest in biotic defenses invested less in leaf mechanical defenses. 1.0pt

Q.55.4 The increase in leaf toughness of plants without EFNs was not sufficient to reduce herbivore feeding to the same extent as biotic defense. 1.0pt

Q.55.5 The biotic defense performed by patrolling ants was more effective than investment in mechanical defenses. 1.0pt



Q.56

The amount of rubber tree growth and latex production are mainly determined by the carbon budget. A negative relationship normally exists between latex production and wood biomass production.

The effect of tapping (harvesting for rubber latex) on stem radial growth was studied using sensors.

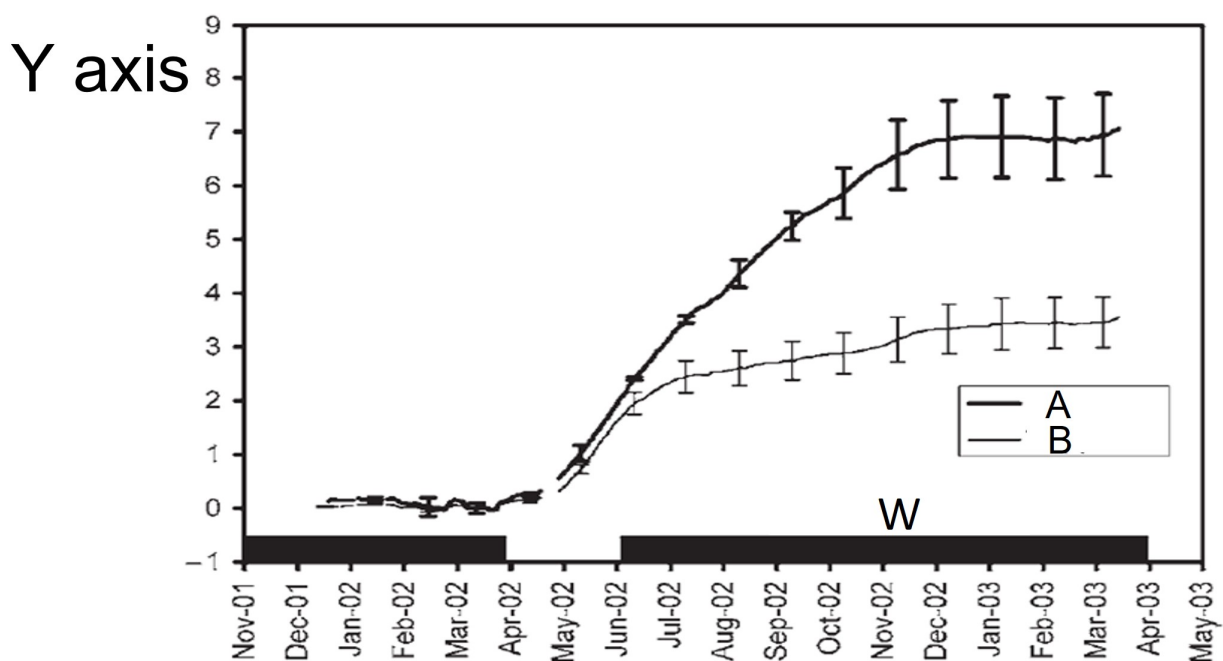


Figure 1. Time course of radial growth increment (increase) of untapped and tapped trees. Filled horizontal bars show the tapping period. Vertical bars indicate the standard error for each month.

Y axis	Radial increment (mm)
X axis	Months and year
W	Tapping period
A	Untapped
B	Tapped

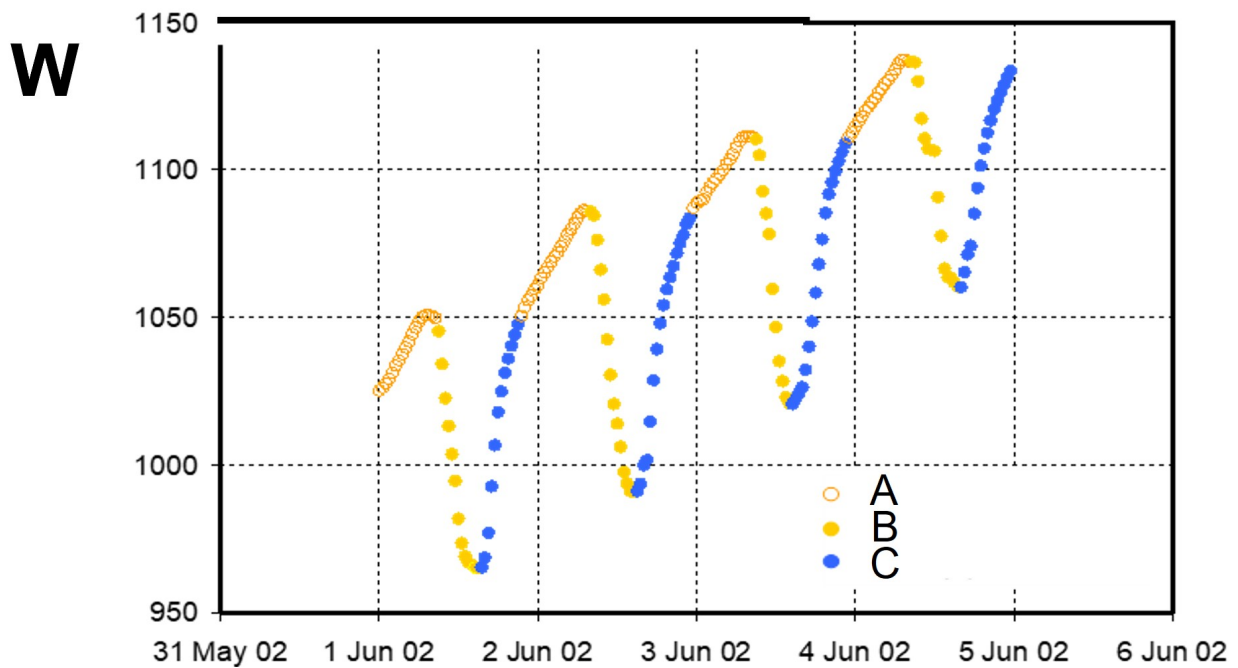


Figure 2. Fine-scale measurement of stem diameter variation of untapped control trees.

A	Trunk radius increment
B	Contraction phase
C	Recovery phase
W	Trunk Radius Variation (μm)- untapped tree

True or false?

Q.56.1 Rubber trees normally only show radial growth from the onset of the rainy season (April) until the onset of the dry season (November). 1.0pt

Q.56.2 Until tapping was resumed, the growth dynamics of tapped and untapped trees were similar. 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-19

English (Official)

Q.56.3 Trunk radius shows an increment (increase) in the daytime, and a contraction in the night-time. 1.0pt

Q.56.4 The daily variations in stem diameter would be a consequence of variations in stem water content. 1.0pt

Q.56.5 The effect of tapping on radial growth rate shows very strong competition for carbon between the artificial sink (latex production) with the naturally dominant sink (trunk growth). 1.0pt

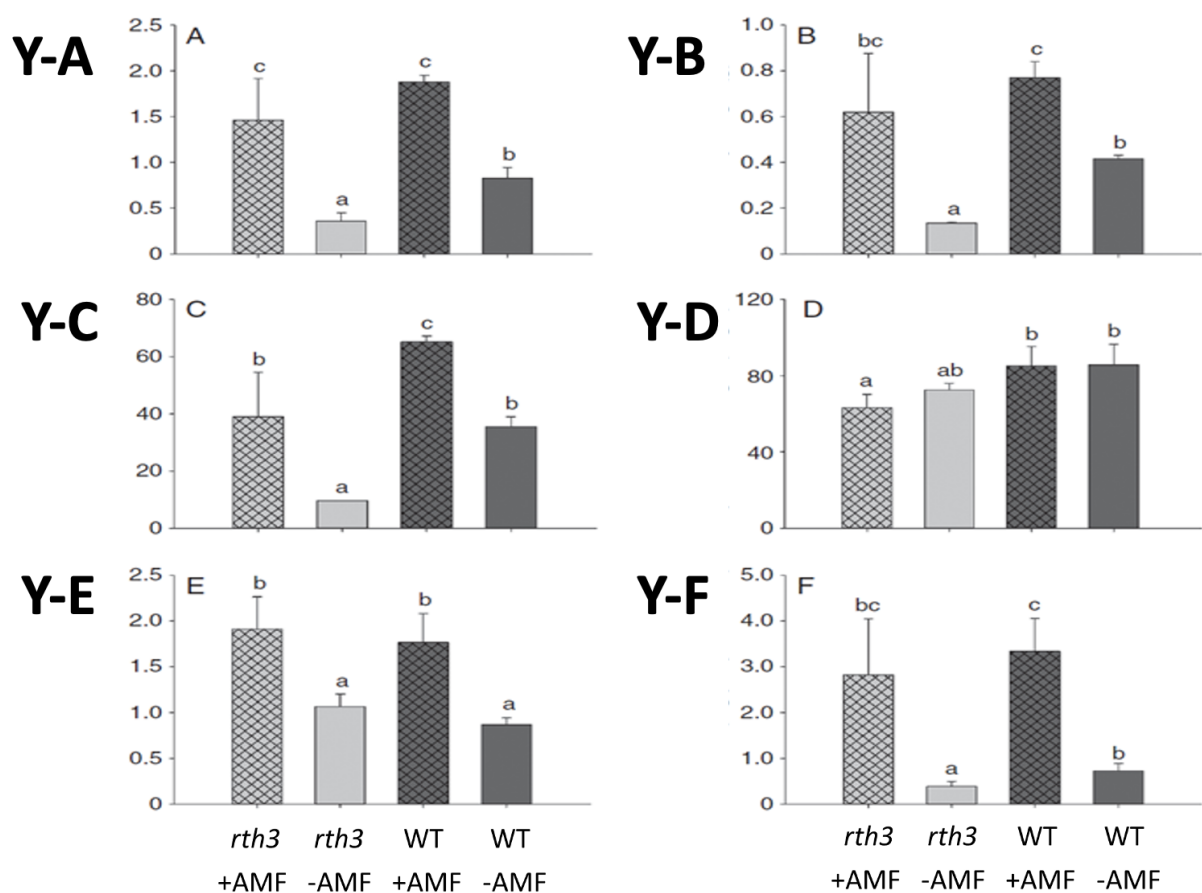


Q.57

To increase root-soil surface area when phosphorus (P) deficient, plants can increase root hair length and density, and/or develop arbuscular mycorrhiza (AMF) symbioses.

Ma et al. (2020) used wild type maize, and the *rth3* root hairless mutant, to quantify the effects of root hairs and AMF infection in P deficient soil.

Note: the soil was confirmed to be severely P-deficient.



• **Figure 1.** Shoot dry weight (A), root dry weight (B), total root length (C), specific root length (root length vs weight) (D), shoot P concentration (E) and shoot P content (F) of maize.

• **Genotypes:** *rth3* root hairless mutant or wild type (WT)

• **Treatments:** with AMF inoculation (+AMF) or without AMF inoculation (-AMF)

Different letters indicate significant differences ($P < 0.05$, Duncan's test) among 4 combinations of treatments and genotypes.

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

P5-21

English (Official)

Y-A (Y axis for graph A)	Shoot dry weight (g)
Y-B (Y axis for graph B)	Root dry weight (g)
Y-C (Y axis for graph C)	Total root length
Y-D (Y axis for graph D)	Specific root length (m g^{-1})
Y-E (Y axis for graph E)	P concentration (mg g^{-1})
Y-F (Y axis for graph F)	P content (mg per plant shoot)

rth3+AMF: root hairless mutant with arbuscular mycorrhiza (AMF) inoculation.

rth3-AMF: root hairless mutant without arbuscular mycorrhiza (AMF) inoculation.

WT+ AMF: Wild type with arbuscular mycorrhiza (AMF) inoculation.

WT- AMF: Wild type without arbuscular mycorrhiza (AMF) inoculation.

True or false?

Q.57.1 Additional acquired P by AMF greatly increased shoot/root biomass, root length, P content. 1.0pt

Q.57.2 Maize root hairs improved plant growth independently to P acquisition, compared with the *rth3* hairless mutant. 1.0pt

Q.57.3 Hyphae can greatly increase exploration of the soil volume for phosphate. 1.0pt

Q.57.4 Root hairs can compensate for lack of AMF in maize. 1.0pt

Q.57.5 Both the growth and P-acquisition defects of the root hairless mutant *rth3* are compensated by AMF inoculation 1.0pt

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

A6-1

English (Official)

Question title

Q.1 (5 pt)

Q.2 (6 pt)

Q.3 (5 pt)

Q.4 (5 pt)

Q.5 (5 pt)

Q.6 (4 pt)

Q.7 (4 pt)

Q.8 (4 pt)

Q.9 (4 pt)

Q.10 (4 pt)

Q.11 (5 pt)

Q.12 (4 pt)

Q.13 (5 pt)

Q.14 (4 pt)

Q.15 (5 pt)

Q.16 (5 pt)

Q.17 (5 pt)

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

A6-2

English (Official)

Q.18 (5 pt)

Q.19 (4 pt)

Q.20 (5 pt)

Q.21 (5 pt)

Q.22 (4 pt)

Q.23 (4 pt)

Q.24 (4 pt)

Q.25 (4 pt)

Q.26 (5 pt)

Q.27 (4 pt)

Q.28 (5 pt)

Q.29 (4 pt)

Q.30 (4 pt)

Q.31 (4 pt)

Q.32 (5 pt)

Q.33 (5 pt)

Q.34 (4 pt)

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

A6-3

English (Official)

Q.35 (4 pt)

Q.36 (4 pt)

Q.37 (4 pt)

Q.38 (4 pt)

Q.39 (4 pt)

Q.40 (4 pt)

Q.41 (4 pt)

Q.42 (4 pt)

Q.43 (5 pt)

Q.44 (4 pt)

Q.45 (4 pt)

Q.46 (5 pt)

Q.47 (7 pt)

Q.48 (4 pt)

Q.49 (5 pt)

Q.50 (4 pt)

Q.51 (6 pt)

Theory 2



34th International
Biology Olympiad
United Arab Emirates 2023

A6-4

English (Official)

Q.52 (5 pt)

Q.53 (4 pt)

Q.54 (4 pt)

Q.55 (5 pt)

Q.56 (5 pt)

Q.57 (5 pt)

Q1. (43)

1.1 true

1.2 false, this is a desert species that does not encounter such conditions; the tail has a different purpose (applied to the ethology of the species)

1.3 true, the hairless or sparsely furred areas serve as thermal windows

1.4 false, active flight is instead extremely energy consuming

1.5 true, bats form colonies of considerable size in suitable roosts and fly considerable distances to dispersed food sources

Q.2 (42)

Solution:

Q.2.1 **True:** Assuming the pictures were taken in daylight, lizards 3 and 6 are nocturnal lizards.

Q.2.2 **True:** Lizard 1 could be adapted to live in limestone caves.

Q.2.3 **False:** Lizards 7 and 8 are both grounds-dwelling predators.

Q.2.4 **False:** Compared to other lizards in the pictures, lizards 2 and 5 display a morphological characteristic typical of animals adapted to living in colder areas.

Q.2.5 **False:** Lizards 3 and 8 are fully homeothermic.

Q.2.6 **False:** Lizards 5 and 6 have the necessary adaptations for burrowing.

Q.3 (5)

True or false?

3.1 False

Hunting snails prefer to drill the anterior end of sea carpet bags and avoid the distal end of shells. (FALSE, because the distribution of holes shows that drilling in areas A and D is equally preferable: 49 holes in A, 51 holes in D, 17 holes in C, 14 holes in B)

3.2 True

Sea carpet bag probably have two muscle-adductors, the first in the area A and the second in the area D. (TRUE, because the distribution of holes shows that drilling in areas A and D is equally preferable for hunting snail, this indicate muscle-adductors both in A and D)

3.3 True

Hunting snails are one of the major threats of sea carpet bags. (TRUE, because 94 shells from 100 have drilling holes)

3.4 True

From these data, we could conclude that if the first drilling does *not* result in bivalve opening, hunting snails prefer to repeat their attack on the same sea carpet bag, (TRUE, because 35 shells demonstrate multiple attacks of snails)

3.5 True

These data suggest some hunting snails could be drilling sea carpet bags which are already dead. (TRUE, because 11 single holes are placed in B and C areas, far from muscle-adductors and could not improve shell opening).

Q.4 (80)

True or false?

4.1 True

White flies have acquired *BtPMT1* by horizontal gene transfer. [T]

By definition, Horizontal Gene Transfer refers to the movement of genetic material between two uni-/multicellular organisms by non-sexual means. In this study a plant gene has moved and integrated in a whitefly genome, hence it is an example of HGT.

4.2 False

BtPMT1 plays a pivotal role in the detoxification of all phenolic glycosides produced by the tomato leaves. [F].

It is clear from the stem and the figure, that *BtPMT1* expression reduced the mortality of whiteflies against B, C, and D compounds but not against E and F as there is no statistically significant difference.

4.3 False

Expression of *BtPMT1* in all the developmental stages of *B. tabaci* indicates that it is a plant gene contaminant, rather than part of the fly genome. [F].

Since the expression was found in the eggs, a stage which does not feed on plants, it is obvious that the expression did not come from the plant gene.

4.4 False

BtPMT1 must be present in all the whiteflies belonging to genus *Bemisia*. [F].

It is clearly stated in the stem that the gene has closest homologs in plants, but no homologs in other arthropods.

4.5 False

Whiteflies feeding on siRNA expressing tomato plants had reduced ability to neutralise the phenolic glycosides because siRNA expressing plants started overproducing the phenolics.[F]

False, because the whiteflies feeding on the transformed tomato leaves (harbouring siRNAs against *BtPMT1*) and as a result the acquired plant gene was silent, leading to the loss of their ability to neutralise the phenolic glycosides.

Reference: Xia, J., Guo, Z., Yang, Z., Han, H., Wang, S., Xu, H., ... & Zhang, Y. (2021). Whitefly hijacks a plant detoxification gene that neutralises plant toxins. *Cell*, 184(7), 1693-1705.

Q.5 (4)

True or false?

5.1 False

All angler fishes have an adaptive immune system which works in a similar way to humans.

(FALSE, in this question we have three immunodeficient angler fish species)

5.2 True

Lack of some immune system components could help anglerfish male and female bodies to sustainably connect. (TRUE, females lack transplantation immunity and does not reject attached males)

5.3 True

The angler fish *Haplophryne mollis* females uses mating strategy 3 (several miniature anglerfish fish males fused to a female body). (TRUE, two males is shown on the picture)

5.4 True

The angler fish *Diceratias pileatus* probably have problems with B cell immunity. (TRUE, *Diceratias pileatus* lack *Aicda* gene, so this angler fish should lack antibody class switch and affinity maturation)

5.5 True

The angler fish *Ceratias tentaculatus* probably have problems with T cell immunity. (TRUE, *Ceratias tentaculatus* lack both *Cd8* genes needed for T killer antigen recognition)

Q.6 (17)

Solution:

6.1 False

In the adult body are still present brown fat tissue rudiments – in the neck region and around the kidneys

6.2 True

Ameloblasts are responsible for the formation of the enamel. When enamel is formed in the second denticle, ameloblasts are lost from the teeth structure. In some species with life-long teeth growth these cells are kept functional.

6.3 False

In opposite to the odontoblasts forming enamel (which is not able to regenerate during adult life, odontoblasts forming dentin are present life-long inside the teeth.

6.4 True

Totipotent stem cells are present only during the very early ontogeny (zygote and early blastomeres). Formation of the embryo in the mother is not a right answer – these cells are missing in a fully developed human body”.

Q.7 (21)

Correct answers and comments

7.1 True

By comparing figures A and B it is deducible that the head begins to regenerate other parts of the body.

7.2 False

There is no digestive tract because it was removed with the remaining part of the body.

7.3 True

In the initial phase of the body regeneration (when there is still no digestive tract), photosynthesis run by chloroplasts is the only source of organic compounds needed by Elysia marginata. On the other hand, chloroplasts once taken out of the original cell, need Elysia marginata cells to be operative.

7.4 True

This conclusion comes from merging the above information.

Q.8 (84)

SOLUTION:

a) B

Langerhans pancreatic islet cells B - the only cell type expressing simultaneously actin, histone H2A and insulin.

b) A

could be negatively identified – when other cell types are positively identified.

c) D

the cell type, where histones (synthesise in all other cell types) are replaced with the protamines.

d) C

Skeletal muscle cell - the only cell type from the listed which expresses acetylcholine receptor - which is used to bind acetylcholine in the neuromuscular junction.

Q.9 (7)

Solution:

9.1 TRUE – the change in forgetting levels is mediated specifically by the microglial depletion

9.2 TRUE – microglia are an example of the tissue resident macrophages derived from the first haematopoietic event which are generally self-renewable in the tissue generally independent of the bone marrow haematopoiesis. This could be deduced.

9.3 FALSE – from the data the opposite is true

9.4 TRUE – this could be deduced as a potential explanation of the link between the phagocytosis and memory clearance. It is an extremely intriguing observation from the article provided.

Q.10 (6)

10.1 FALSE - the only molecules with the chance to be physically maintained for the decades in the cell is the DNA – the protein examples are rare e.g. crystalline in the eye lens

10.2 TRUE – the only explanation of the experimental results. Graph shows the constant number of the cardiomyocytes – but obviously, the heart grows substantially during childhood and puberty. Also could be enlarged by the training. One of the mechanisms is multiplication of the cell nuclei.

10.3 True – it is in agreement with the data on the graph

10.4 FALSE – carbon-14 is unstable and has a half-life of 5700 ± 30 years, well known fact, it is used for the dating of fossils

Based on the publication: Dynamics of Cell Generation and Turnover in the Human Heart.

Bergmann O, Zdunek S, Felker A, Salehpour M, Alkass K, Bernard S, Sjostrom SL, Szewczykowska M, Jackowska T, Dos Remedios C, Malm T, Andrä M, Jashari R, Nyengaard JR, Possnert G, Jovinge S, Druid H, Frisén J. Cell. 2015 Jun 18;161(7):1566-75.)

<https://doi.org/10.1016/j.cell.2015.05.026>

Q.11 (116)

11.1 T

11.2 F

11.3 T

11.4 T

11.5 T

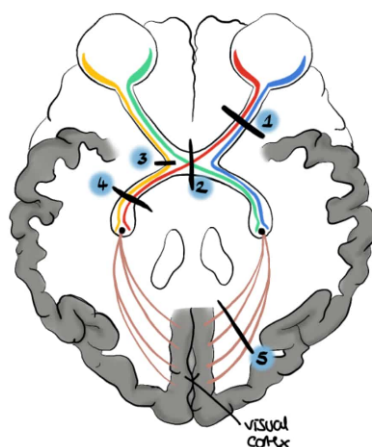
SOLUTION: Competitors should identify microtubular organisation in the motile flagella/cilia first and dynein as affected molecular motor. Kartagener syndrome (primary ciliary dyskinesia) is a ciliopathy disorder affecting motile cilia due to mutation in the components of ciliary motor structures – dynein arms. As a consequence, it causes defects in the action of cilia lining the upper and lower respiratory tract (any impairment can result in poor mucociliary clearance, with subsequent upper and lower respiratory infection), sinuses, Eustachian tube, middle ear, fallopian tube and flagella of sperm cells and the primary node cilia (resulting in *situs inversus*). All true answers involve activity of motile cilia.

Q.12 (12)

Solution:

The task is based on the understanding of the visual paths, including the existence of chiasma and orientation of the image on the retina.

- A: 3
B: 4
C: 2
D: 1



- | | | |
|---|--|---|
| 1 | | Total right eye visual loss |
| 2 | | Bitemporal hemianopia |
| 3 | | Left nasal hemianopia |
| 4 | | Right homonymous hemianopia |
| 5 | | Left homonymous hemianopia with macular sparing |

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Q.13 (118)

What is/are the *main* reason(s) warm-blooded animals intolerant to changes in body temperature?

13.1 F

13.2 F

13.3 F

13.4 T

13.5 T

Thermal denaturation of enzymes and other proteins with increasing temperature.

FALSE. Thermal denaturation of enzymes and other proteins begins at much higher temperatures than 37-47 °C.

Thermal denaturation (melting) of DNA with increasing temperature.

FALSE. Thermal denaturation (melting) of DNA begins at much higher temperatures than 37-47 °C.

C) Changes in the microviscosity of lipids of cellular and intracellular membranes with increasing temperature.

FALSE. Cells have enzyme systems that maintain the microviscosity of lipids of cellular and intracellular membranes at the required level at a wide range of temperature.

D) Different temperature sensitivity (Q10-coefficient) of biochemical reactions in cells.

TRUE. Different temperature sensitivity (Q10-coefficient) of biochemical reactions occurring in cells, primarily reaction of production and consumption of ATP, leads to a lethal metabolic disorder.

E) For Passerines birds (body temperature is 40-41 °C) lethal core body temperature will be about 47 °C. ??

TRUE. It can be seen from the Table that the lethal temperature for all groups of animals is about 6 °C higher than the normal body temperature.

Q.14 (100)

14.1 F

14.2 F

14.3 F

14.4 F

Answers

Normal air is 760 mmHg, 21% oxygen (PPO₂ = 159 mmHg)

At 130% pressure, 16% oxygen, PPO₂ = $760 \times 1.3 \times 0.16 = 158$ mmHg

- False. PPO₂ is unchanged, so haemoglobin loading is unchanged. Note, they can answer this using proportions, even if they don't know normal atmospheric pressure. Units also don't matter at all.
- False. Same reasons
- False. This increases flammability, even if the % O₂ was high enough to maintain a safe PO₂.
- False. PPO₂ is fixed, but % O₂ is increasing, therefore atmospheric pressure must be decreasing, so a greater % O₂ of a lower pressure gives a fixed PPO₂.

Q.15 (101)

15.1 T

15.2 F

15.3 F

15.4 F

15.5 F

Answers

These curves are generated as increased ventilation increases O₂ delivery to the alveolae, and therefore PPO₂. This causes haemoglobin to bind more O₂ following its classic sigmoidal curve. Increased ventilation also allows the lungs to blow off more CO₂, driving down PPCO₂.

Deoxyhaemoglobin binds CO₂ in a non-cooperative way, to form carboxyhaemoglobin. Binding of O₂ drives off the CO₂, so the lungs can vent CO₂ more efficiently than simple mechanics would suggest.

- True. The total amount of carbon dioxide in blood falls more steeply than PPCO₂. The previous part explained that PPCO₂ in alveolar air is in equilibrium with blood, which is directly proportional to the concentration of a solution. Therefore, the amount of dissolved CO₂ should fall exactly with PPCO₂. Therefore, something in blood must be binding to the CO₂.
- False. Cutting these sensors removes their stimulation. Stimulation normally increases as the need to breathe increases, so the body interprets this as a reduced need to breathe.
- False. The total amount of oxygen in the blood, and therefore the supply of oxygen to sensors in the body, is overwhelmingly dominated by haemoglobin. Haemoglobin binds O₂ tightly until PPO₂ falls suddenly and dangerously. Therefore, oxygen levels cannot be used to maintain ventilation in the safe region. CO₂ levels are much more tightly coupled to ventilation rate across a whole range of rates, so should be used to control breathing within the safe range.
- False. At very high altitude PO₂ falls enough to drive increased breathing. This results in more CO₂ being blown off, rising pH.
- False. They do not need to breathe quicker as PPO₂ and haemoglobin are unaffected. Therefore they won't vent CO₂. Note; the amount of CO₂ in the atmosphere is trivial compared to the amount vented in alveolae, therefore, increasing atmospheric pressure will not shift the equilibrium in a significant way, so this will not affect pH.

Q.16 (23)

16.1 F

16.2 T

16.3 T

16.4 T

16.5 F

Explanations

16.1 (False) *E. coli* has maximal S/V ratio among mentioned cells

16.2 (True). S/V ratio is proportional to the difference in linear sizes

16.3 (True) Activity of cytoplasmic enzymes could be limited by plasma membrane transport, so in case of low S/V ratio it should be compensated by increased plasma membrane transport.

16.4 (True) Because of low S/V ratio the plant cells are needed in decreasing volume of metabolically active cytoplasm and active cytoplasm mixing, that is why they use vacuoles and cytoplasmic streaming.

16.5 (False) Because S/V ratio limits metabolic rate in round cells

Q.17 (36)

- 17.1 T
- 17.2 F
- 17.3 F
- 17.4 T
- 17.5 F

Correct answers and comments

1. True – By definition, the lower the K_M value, the greater the affinity of the enzyme to the substrate.
2. False – For accurate measurement of blood glucose concentration, the only redox reaction occurring on the strip should be the oxidation of glucose. Thus, the metre needs to use strips containing the enzyme with very narrow substrate specificity.
3. False – The measurement should be done in the range of $0-K_M$ to assure the appropriate sensitivity of the meter. Otherwise, if the measurement is conducted in the $P-Q$ range of the substrate concentration, large differences in glucose concentration would result in small differences in the reaction velocity, or electric current.
4. True – O_2 generated in the second step is in a gas state and will be released to the atmosphere. As a result, there will be less substrate for a reverse reaction.
5. False. H^+ needs to be mopped up. H_2O_2 is oxidised more effectively in alkali solutions. In acidic conditions, H_2O_2 is powerfully oxidising, having the opposite to intended effect.

Calculate the V_{max} value of the reaction catalysed by glucose oxidase in a glucose metre strip. Give an appropriate unit for the V_{max} value.

Examples of correct answer and comments

- $0.3 \text{ mmol} \cdot \text{l}^{-1} \cdot \text{s}^{-1}$
- $300 \text{ } \mu\text{M/s}$

The Michaelis-Menten equation should be transformed as follows:

$$V_{max} = (v \times (K_M + [S])) / [S]$$

Next, appropriate values should be inserted:

- K_M value is given in the stem: 25 mmol/l
- The glucose concentration ($[S]$) should be calculated as molar concentration, thus $0.9 \text{ mg/ml} = 900 \text{ mg/l} = 900/180 \text{ mmol/l} = 5 \text{ mmol/l}$

- Reaction velocity is given in the stem: $50 \mu\text{mol}\cdot\text{l}^{-1}\cdot\text{s}^{-1}$, which should be transformed into $0.05 \text{ mmol}\cdot\text{l}^{-1}\cdot\text{s}^{-1}$ to unify the molar unit.

$$V_{\max} = (0.05(25 + 5))/5$$

$$V_{\max} = 0.3 [\text{mmol}\cdot\text{l}^{-1}\cdot\text{s}^{-1}]$$

Q.18 (26)

- 18.1 F
- 18.2 T
- 18.3 T
- 18.4 F
- 18.5 F

1. All substances (SI-SV) on the scheme are organic substances (F)
2. The process shown on the scheme proceeds at a high rate in cancer cells (T)
3. In aerobic eukaryotic cells, substance SI can be synthesised at a high rate in mitochondria (T)
4. The last reaction in this process (pyruvate $\rightarrow$ lactate) is needed only for the reduction of the substance SIV (F)
5. Many yeasts, for example, *S.cerevisiae*, use this process in carbohydrate metabolism under anaerobic conditions (F)

Q.19 (37)

19.1 T

19.2 T

19.3 T

19.4 T

1. True – *Enzyme activation is a single event which results in the continuous synthesis of the product, in this case, cAMP molecules. Thus, even weak signals may be amplified thanks to this event.*
2. True – *Caffeine has an inhibitory effect on the A_{2A} receptor, by preventing the interaction of adenosine with the receptor. Thus, this statement itself should be considered true.*
3. True – *Caffeine inhibits phosphodiesterase, so in this way it'll reduce the decomposition of cAMP.*
4. True – *It may be directly deduced from the figure.*

Q.20 (34)

20.1 T

20.2 T

20.3 F

20.4 T

20.5 T

1. Inhibition of procaspase 9 cleavage.
2. Disruption of expression of Gasdermin E.
3. Induction of intracellular ROS (reactive oxygen species) by a chemotherapy drug
4. Acetylation of surface cysteine in the N-terminal domain of Gasdermin D.
5. Inhibition of the cleavage of Gasdermin E.

Q.21 (33)

21.1 T

21.2 F

21.3 T

21.4 T

21.5 F

Explanation:

1. True: Performing reaction in D_2O did not produce any labelled product, so it means enzyme separated Hydrogen from substrate and then it will be given back to the intermediate.
2. False: When reaction started with cis-aconitate in D_2O brought about with D attraction in the product, then it can be concluded intermediate (cis-aconitate) is not bound in the whole reaction.
3. True: Performing reverse reaction in D_2O did not bring any labelled Citrate.
4. True: If the reaction goes through 2 general bases, then one of them should be labelled with D and then D incorporation in the product should have been obtained.
5. False: FAD centres are cofactors in oxidation reactions and not dehydration reactions.

Q.22 (105)

22.1 F

22.2 T

22.3 F

22.4 T

Correct answers and comments

1. False – *Glycolysis and oxidative decarboxylation of pyruvate also produces NADH molecules. Moreover, one glucose molecule produces two acetyl-CoA molecules. Thus, about 34 ATP molecules are produced as a result of the oxidation of a single glucose molecule.*
2. True – *Metformin inhibits the complex I. Thus, the number of protons pumped into the intermembrane space decreases.*
3. False – *Metformin does not affect the turnover of FADH₂ molecules.*
4. True – *If the amount of adenosine triphosphate is decreased, the amount of its diphosphates and monophosphates becomes higher. Thus, this metformin effect indirectly activates AMPK.*

Q.23 (22)

Answer keys

Q.23.1 - True

Q.23.2- False

Q.23.3- True

Q.23.4 - True

Explanation

This question tests the understanding of the electric potential across the membrane as well as a concept of "volume conductor" in the context of medical physiology. Thus, this question combines both basic knowledge (statements 1 and 2) and the understanding of newly introduced information. For the latter, the principle is simple and the answer is easy if the reader can distinguish between the site where electricity flows out (source, resting region) and the site where it flows in (sink, active excited part), and predict how it will change over time based on knowledge of the time course of action potential generation and excitation conduction. Thus, the statement 3 tests whether the reader understands the discussion of "sink" and "source", as defined in the battery example, although it is considered unfamiliar to the candidate.

In the nerve fibre, a positive current should be initially observed because the cell body is excited (working as a sink), thus a positive electric current is observed as the recording cathode is placed near the sink side (anode placed farther away) until the excitement reaches the recording point along the nerve fibre. Eventually, when the excitement passes, the observed voltage value is reversed (statement 4).

Q.24 (38)

24.1 T

24.2 T

24.3 T

24.4 T

Correct answers and comments

1. True – *It may be directly deduced from the figure.*
2. True – *It may be directly deduced from the text.*
3. True – *It may be directly deduced from the figure.*
4. True – *To correctly evaluate the influence of C-STAR on blood glucose level one should compare data against WT mice (ultimate goal) as well as DIO mice (starting point).*

Q.25 (89)

The correct answer is b

- a) False
- b) True
- c) False
- d) False

Q.26 (29)

26.1 T

26.2 F

26.3 T

26.4 T

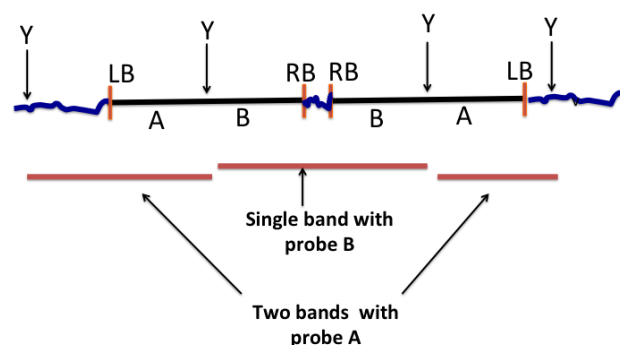
26.5 F

As the T-DNA integrates randomly, digestion of the genomic DNA with the RE will lead to different sized fragments at each locus of integration. This is because the RE sites in the region flanking the T-DNA will be at variable positions.

27.1 TRUE. Digestion with RE 'X' would have given a minimum of 2 bands when probed with A. Though RE Y is present twice in the vector, it is unique within the T-DNA.

27.2 FALSE. Each of the fragments will have portion of the T-DNA and the flanking genomic DNA.

27.3 TRUE. As probe 'A' shows two hybridization signals, there is likely to be 2 copies. One band with probe B would mean that the two copies are integrated at the same locus OR the restriction site in the genomic DNA towards the right is of the same distance in the two copies. In the first case the organization will be



27.4 TRUE. Single bands from both the probes indicate one copy of integration.

27.5 FALSE. No hybridization signal with probe A indicates that complete transfer has not taken place.

Q.27 (28)

27.1 F

27.2 T

27.3 T

27.4 F

Explanation:

This is a hypothetical example. Chemical X is an inducer of gene A. This is evident from the 120 fold activation of the gene in presence of X. See activation ratio (presence/absence) in wild type (WT).

Protein Y is a positive regulator, which acts through the *cis*-elements R1 to R3. That protein Y is a positive regulator is evident from the mutant M7, when deleting the 3 binding sites leads to no activation.

Strain	R 1	R 2	R 3	Ratio of activity of enzyme A in the presence: absence of chemical 'X'	Enzyme activity in absence of X	Enzyme activity in presence of X
WT	✓	✓	✓	120	15	180
M1	✓	✓	×	87	15	1300
M2	✓	×	✓	2	15	30
M3	×	✓	✓	107	15	1600

M4	×	✓	×	30	15	450
M5	✓	×	×	1.0	15	15
M6	×	×	✓	1.0	15	15
M7	×	×	×	1.0	15	15

1. If gene Y is deleted, the ratio of activity will increase. **FALSE**

Deletion of the 3 binding sites lead to NO activation, thus loss of the protein would also not lead to any activation.

2. The binding activity of protein Y for the R2 site is expected to be highest. **TRUE**

Among the strains M1 to M3; M2 (where R2 is deleted) shows the least activation.

3. The sequence TGTGA is important for the binding of protein Y to the R sites. **TRUE**

As the sequence is conserved in all the 3 sites, it is likely to be important for the binding of protein Y

4. The binding of protein Y to R3 and R2 influences the gene activity in the same way as protein Y binding to R1 and R2 **FALSE**

Compare mutations M1 and M3, where M3 shows higher activation.

Q.28 (25)

- 28.1 T
- 28.2 F
- 28.3 T
- 28.4 F
- 28.5 T

Answer key and explanations.

- A. True. The adsorption of nucleic acids onto silica particles at high salt concentrations is based on general chemical properties of DNA and not on some properties specific to ancient DNA.
- B. False. Chromosomal DNA is very long and is sheared in the grinding step. Moreover, DNA-binding proteins, which are components of chromosomes, dissociate from nucleic acids under conditions of high salt concentration.
- C. True. The bone specimen is likely to contain bacterial DNA (for instance, from bacteria involved in decomposing the organic material of the animal or bacteria from the soil) and again, the method is based on chemical properties of DNA and in not discriminating between DNA from different organisms.
- D. False. All interactions between DNA and silica are undergoing through sodium ion bridges. Decreasing sodium concentration results in DNA detachment which elution is based on.
- E. True. Spontaneous deamination results in C to U conversion so the ancient DNA will contain U.

References

- M Höss and S Pääbo, (1993) DNA extraction from Pleistocene bones by a silica-based purification method. *Nucleic Acids Res.* 21: 3913–3914.
- M Hofreiter, et. al., (2001) DNA sequences from multiple amplifications reveal artifacts induced by cytosine deamination in ancient DNA. *Nucleic Acids Res.* 29:4793-9.
- AuthentiCT: a model of ancient DNA damage to estimate the proportion of present-day DNA contamination
<https://genomebiology.biomedcentral.com/articles/10.1186/s13059-020-02123-y>

Q.29 (108)

29.1 T

29.2 F

29.3 T

29.4 F

Answers:

- a) True, Paulinella chloroplast genome is 3-times smaller than Synechococcus genome, about 65% of genes was lost during evolution.
- a) False, Paulinella obtained chloroplast as a result of independent primary endosymbiosis.
- b) True, endosymbiosis occurred after divergence with Synechococcus and before species divergence in Paulinella genus.
- c) False, there are three types of genomes and rRNA in cell, because Paulinella also has mitochondria

Q.30 (92)

Statement	True	False
Q.30.1 Northern flying squirrels and red squirrels are likely to be vulnerable to parasite-mediated competition <i>True because both these species have significantly lower Scaled Mass Indices (indicating poorer body condition) when they are infected with the nematode.</i>	✓	
Q.30.2 Under conditions of high nematode infections, northern flying squirrels are likely to be outcompeted by grey squirrels <i>False: These species do not compete due to differences in their temporality of activity periods, diet and foraging strategies.</i>		✓
Q.30.3 Under conditions of high nematode infections, southern flying squirrels are likely to be outcompeted by northern flying squirrels <i>False: Although these species do compete, under higher nematode loads, the northern flying squirrels exhibit poor body condition. This suggests that northern flying squirrels will be outcompeted by southern flying squirrels.</i>		✓
Q.30.4 If we were to increase the sample size of one of these species, the best choice would be red squirrels. <i>True: As the relatively high standard error of the red squirrel samples suggests greater uncertainty of the estimates, this species would be the best choice for an increase in sample size during a re-evaluation.</i>	✓	

Paul P. O'Brien, Jeff Bowman, Sasha L. Newar, Colin J. Garroway, 2022. Testing the parasite-mediated competition hypothesis between sympatric northern and southern flying squirrels, *International Journal for Parasitology: Parasites and Wildlife*, 17, 83-90.

Q.31 (97)

31.1 T

31.2 F

31.3 T

31.4 T

EXPLANATIONS

A. True. As can be clearly seen from the figure, *A. agestis* and *A. cramera* have non-overlapping distribution.

B. False. Both these species are generalists.

C. True. This is clearly visible for *A. agestis* and *A. artaxerxes* as well as for *A. montensis* and *A. cramera*.

D. True. This is clearly visible, at least for *A. agestis* and *A. artaxerxes*.

REFERENCE

Voda, R. et al. 2015. Why do cryptic species tend not to co-occur? A case study on two cryptic pairs of butterflies. *PLoS One* 10(2): e0117802
<https://doi.org/10.1371/journal.pone.0117802>

Q.32 (94)

Statement	True	False
Q.32.1 The above foraging patterns indicate evidence of niche segregation: <i>True because based on both foraging and stable isotopes, the Atlantic Puffins (Black) and Razorbills (Blue) are foraging separately with some overlap in their distributions.</i>	✓	
Q.32.2 Based on stable isotope ratios, Common Murres (orange) and Thick-billed murres (pink) have similar diets.: <i>False, because stable isotope ratios show clear clustering indicating that Common Murres and Thick-billed murres are segregated by diet</i>		✓
Q.32.3 Atlantic Puffins mostly forage in near-shore areas (close to the coast): <i>False, because puffins (black) are foraging away from the shore</i>		✓
Q.32.4 Razorbills and common murres have similar diets: <i>True, because razorbills (blue) and common murres (Orange) have considerable foraging overlap (Fig A) and dietary overlap (Fig B)</i>	✓	
Q.32.5 Thick-billed murres and razorbills have considerable dietary overlap: <i>False, because thick-billed murres (pink) forage offshore compared to razorbills (blue). Further, they have no overlap in the stable isotope signatures.</i>		✓

Reference

Pratte, I., Robertson, G. J. & Mallory, M. L. Four sympatrically nesting auks show clear resource segregation in their foraging environment. *Mar. Ecol. Prog. Ser.* 572, 243–254 (2017).

Q.33 (96)

33.1 F

33.2 T

33.3 T

33.4 F

33.5 T

1. This statement is false because although all the three nutrients – nitrogen, iron and phosphate – did affect cell proliferation, phosphate did not affect differentiation, as is evident from Figure B.
2. This is evidently true from Figure B.
3. This is a valid hypothesis, admitted to by the authors as well, and can only be tested statistically, as the authors have done, or through more controlled experiments.
4. This is false as phosphate depletion affected cell proliferation the most between Days 6 and 11 but later, iron had the most limiting effect.
5. This is true as iron depletion promoted the development of mastigotes and hence, the host coral cells could conceivably increase iron levels to suppress mastigote development in vivo.

Reference

Cui et al. 2022. Nutritional control regulates symbiont proliferation and life history in coral-dinoflagellate symbiosis. BMC Biology 20: 103.
<https://doi.org/10.1186/s12915-022-01306-2>

Q.34 (114)

34.1 F

34.2 F

34.3 T

34.4 F

Statement 1 is obviously false as the inverse or constrictive pyramid structure of the population in 2013, with adults being the dominant age category, is typical of a shrinking population.

Statement 2 is false because, in multimale-multifemale species like the bonnet macaque, adult sex ratios are inconsequential for population growth; in fact, there is an increase in the number of males, relative to females, in 2009. Moreover, the absolute number of females was also higher in 2009 than in 2005 and so that is also unlikely to be a factor in overall population growth.

Statement 3 is obviously true, as indicated by the demographic structure of the group.

Statement 4 is not true, as can be seen between 2009 and 2013, when there is no correlation between sub adult- and juvenile male-to-female ratios.

References

The questions are based on well-established patterns, documented in various nonhuman and human population demography studies.

Q.35 (49)

35.1 - A

35.2 - A

35.3 - B

35.4 - C

1. A – Aggression between males is the selective pressure that makes them evolve larger bodies and more pronounced sexual dimorphism.
2. A – The biggest and strongest males are responsible for the majority of the matings, as they are able to effectively guard the females from other males. This also leads to prominent sexual dimorphism in such species.
3. B – Big testes are indicative of a social group, in which each receptive female mates with many males and the one producing more sperm cells is more likely to become a father.
4. C – Of the three species, C is most likely to form monogamous pairs, as it neither exhibits very low or very high testes mass to body mass ratios (typical of uni-male multi-female and of multi-male multi-female groups respectively) nor pronounced sexual dimorphism (typical of strong intragroup male competition). Male parental care is typically observed most often, if not exclusively, in species with strong pair-bonding. Giving birth to twins is also likely to require parental help from the male, as is typical for such monogamous mating systems.

References

Harcourt, A. H., Harvey, P. H., Larson, S. G. & Short, R. V. 1981. Testis weight, body weight and breeding system in primates. *Nature* 293: 55–57.

Smith, R. J. & Jungers, W. L. 1997. Body mass in comparative primatology. *Human Evolution* 32(6): 523–559.

<https://www.pnas.org/doi/10.1073/pnas.1316037111>

Evolutionary genetics and implications of small size and twinning in callitrichine primates

<https://www.pnas.org/doi/10.1073/pnas.1316037111>

Q.36 (48)

36.1 F

36.2 T

36.3 F

36.4 T

Solution

- a) False, because 47 preserved nasal bones is less than 58 squamosal bones
- b) True, we can see that the collar is outgrowth of one from lateral skull surface bones, but the squamosal bone is already marked with an asterisk. So remain parietal bones.
- c) False, jugal bones have $7/39 \times 100\% = 18\%$ injuries, squamosal bone has $10/58 \times 100\% = 17\%$ injuries.
- d) True, combating males could attack only the lateral head surface, but the giant predators could attack the upper head surface. Almost all injuries had occurred on the lateral skull surface.

Reference: <https://pubmed.ncbi.nlm.nih.gov/19172995/>

Q.37 (112)

37.1 T

37.2 F

37.3 F

37.4 T

Explanations

Q.37.1

True. This statement is true because the classic group-selection argument suggests that natural selection acts to increase the fitness of a population.

Q.37.2

False. Group selection is currently not the most accepted mechanism to explain natural selection; individual fitness is able to satisfactorily explain the evolution of both individual and group behaviours of animals.

Q.37.3

False. If different individuals within a group adopted completely different strategies to increase their own fitness, this would represent individual selection in operation, not group selection.

Q.37.4

True. A unique behavioural strategy could indeed arise within a group by chance, by genetic mutation/s or by innovative behavioural trial-and-error mechanisms.

Reference

Alcock, J. 2001. *Animal Behaviour: An Evolutionary Approach*, 7th Edition. Sinauer Associates, Sunderland, Mass., USA, pp. 19-20

Q.38 (115)

38.1 F

38.2 T

38.3 T

38.4 T

Statement 1 is obviously false, as can be deduced from common biological sense.

Statement 2 is true because, as Ronald Fisher (1930) showed, the only evolutionarily stable sex ratio, on an average, in all sexually breeding populations is 1:1. A initially female- or a male-biased sex ratio is not evolutionarily stable because a gene which causes parents to the bias the sex ratio of their offspring towards the rarer sex – males or females respectively – would rapidly spread, and the sex ratio would then gradually shift back to a 1:1 ratio. This follows the principle of frequency-dependent selection.

Statement 3 is true, as can be shown by an example. If, say, sons are twice as costly as daughters to produce and the sex ratio at birth is 1: 1, a son is a poor investment for a parent: each of its grandchildren produced by a son is twice as costly as one produced by a daughter. Parents should then favour having daughters. As the sex ratio swings towards a female bias, the expected reproductive success of a son goes up until at a ratio of two females to every male, an average son produces twice the number of children produced by an average daughter. At this point sons and daughters give exactly the same return per unit investment; a son costs twice as much to make but yields twice the return. This means that when sons and daughters cost different amounts to make, the stable strategy in evolution is for the parent to *invest* equally in the two sexes and not to produce equal numbers.

Statement 4 is true because when brothers compete with each other for mates ('local mate competition'), there can be a different outcome. Suppose, for example, that two sons have only one chance to mate and that they compete for the same female. Only one of them can be

successful in mating, so from their mother's point of view one of them is 'wasted'. Thus, when sons compete for mates, their value to their mother is reduced. The mother should therefore bias her ratio of investment towards daughters. In the extreme case of inbreeding within a closed fig, when all of a mother's daughters are fertilised by her sons, the best sex ratio is to produce just enough sons to fertilise the daughters, and the sex ratio at birth invariably becomes female-biased.

References

Fisher, R. A. 1930. *The Genetical Theory of Natural Selection*. Clarendon Press, Oxford.

Krebs, J. R. and Davies, N. B. 1997. *Behavioural Ecology: An Evolutionary Approach*, 4th Edn, Blackwell Scientific Publications, Oxford, pp. 177-

Q.39 (109)

39.1 F

39.2 T

39.3 T

39.4 F

Answers:

- a) False, there are two different independent mechanisms of RNA editing in trypanosomes and mammals.
- b) True, adding of U residues in the coding part of mRNA shifts the reading frame.
- c) True, stop codon could be introduced by RNA editing, so protein became shorter.
- d) False, RNA editing also occurs in mitochondria (kinetoplasts), cytoplasm and plastids.

Q.40 (88)

40.1 T

40.2 F

40.3 T

40.4 F

This is based on the concept of saturation mutagenesis and is from the publication of Volhard et al. (1984) Roux's Arch Dev Biol 193: 267-282. The above figure has been modified from the figure below.

40. 1 TRUE. This can be deduced from the plot

40. 2 FALSE. While a greater number of mutants may be obtained, mutation in new genes has come to saturation.

40.3 TRUE. While more mutants are observed when screened numbers increase but the number of genes does not increase proportionately, thus the new mutations would lie on the earlier identified genes.

40.4 FALSE There is no correlation between progeny number analysed and the nature (dominant/recessive) of mutation.

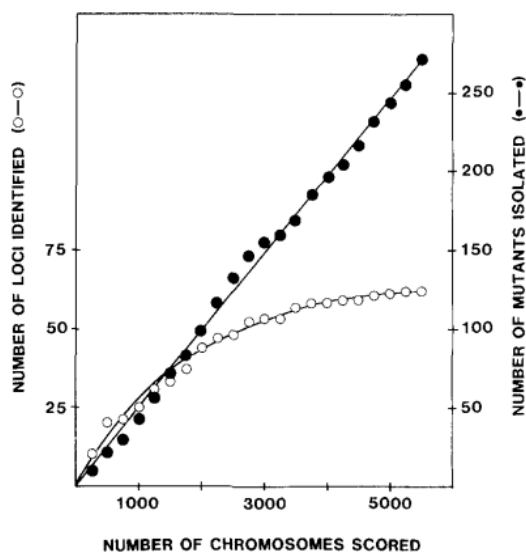


Fig. 5. The frequency of discovery of new loci compared to total number of mutants isolated during the screen

Q.41 (61)

41.1 T

41.2 T

41.3 F

41.4 F

Correct answers and comments

1. True – The mutation described in the stem is non-sense mutation (CAG-to-TAG), thus the amino acid sequence of the protein will be shorter.
2. True – PstI recognizes CAG (the 882nd codon) within the restriction site. Thus, in case of the mutant (recessive allele) there is no sequence recognized by PstI and 414 bp-long PCR product is retained.
3. False – In case of X-linked recessive disease, the individual no. 4977 would be affected, not heterozygous.
4. False – The pedigree may be explained assuming that the individual no. 3739 is just a heterozygote, because the same recessive allele could be inherited by individuals nos. 4977 and 6431.

Q.42 (65)

42.1 F

42.2 F

42.3 T

42.4 T

Answers:

A. FALSE. First, the students have to understand that as humans are diploid and the X/Y notation describes the alleles in the same position of the two homologous chromosomes. Next, as said in the text, the numbers refer to the allele. So at position 5897 ind1 has G on one chromosome and A on the other while ind2 is GG homozygote. At position 7100 individual 1 is A/T (T is the second alternative allele), so heterozygous.

B. FALSE. This is generally false because the frequency of any genotype depends on allele frequencies (which can be 50/50 only in some positions) and also on whether or not any forces affect the equilibrium (selection, assortative mating etc.). But there is no reason to think that at any position 25% of the individuals are 1/1 (or 0/0).

C. TRUE. The size of the file (given one individual so only one genotype column) mainly depends on the number of lines = number of differences from the reference genome. So if the individual is genetically very different (coming from a very diverged population) from those used to build the reference, it will have more positions with alleles different from the reference genome and hence more lines in the vcf file.

D. TRUE. In most positions where both the mother and the father have 0/0 genotypes the daughter will also be 0/0 so a daughter genome can't add new lines to the file. The only exception are de novo mutations which are extremely rare (a rough estimate is 60 per genome). While an unrelated genome will differ from genomes of the couple at multiple sites, including those where both parents are 0/0. And to store this info extra lines will be required.

References:

<https://www.ncbi.nlm.nih.gov/grc/help/faq/#human-reference-genome-individuals>

https://en.wikipedia.org/wiki/Variant_Call_Format

Q.43 (66)

- 43.1 F
- 43.2 F
- 43.3 T
- 43.4 T
- 43.5 F

Answers and explanation:

- A. FALSE. DZ twins have 50% shared genetics so both genetics and environment in common explains trait covariance between them. In other words, for a trait which is not 100% environmental there is more covariance between DZ than between non-siblings that were born on the same day, then were early adopted and raised as twins.
- B. FALSE. Logic is similar to that above: for a trait which is not 100% genetic there is more covariance between MZ twins raised together compared to separated MZ.
- C. TRUE. The assumption of the approach that the only thing that differs between MZ and DZ twins is the amount of shared genetics. Hence, all the increase in covariance from DZ to MZ can be attributed to genetics.
- D. TRUE. See above.
- E. FALSE. In general, one expects more differences in environmental exposure between non-twin siblings then between DZ twins: ranging from differences in *in utero* environment to non-symmetrical interactions between siblings of different age.

References

Virolainen et al. Gene–environment interactions and their impact on human health. Genes and immunity, 2023.

<https://www.nature.com/articles/s41435-022-00192-6>

M Sahu and JGPrasuna. Twin Studies: A Unique Epidemiological Tool. Indian J Community Med. 2016

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4919929/>

Q.44 (57)

44.1 F

44.2 T

44.3 T

44.4 F

True or false?

- a) All progeny of *yellow^{mut}* males will have yellow bodies. (False, only females in progenies will have yellow body, because males will receive Y-chromosome without *yellow^{mut}*)
- b) All progenies of *yellow^{mut}* / *yellow^{mut}* females will have yellow bodies. (True, all progenies will receive X-chromosome with *yellow^{mut}*, which continue convert wild type *yellow* to *yellow^{mut}*)
- c) Gene drives targeting genes involved in sex determination and reproduction, could become an efficient tool in pest insect population control. (True)
- d) Lethal loss-of-function mutations could be successfully introduced in insect populations by gene drive technology. (False, despite the multiplication of lethal transgenic construction during ontogenesis, it will be depleted from the population by natural selection)

References: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4687737/pdf/nihms745459.pdf>

Q.45 (87)

45.1 TRUE

45.2 FALSE.

45.3 TRUE

45.4 TRUE

This is an example of maternal effect gene. This can be derived from the crosses mainly cross III or from the knowledge that seed coat is derived from tissue of the mother plant. Thus coat color will be determined by the genotype of the female parent or part.

Lets denoted the two genes for seed coat as A and B, A and B being alleles for brown and a and b for yellow

Cross I: AABB(brown) X aabb (yellow), thus seed coat color of F1 seeds is brown.

Cross II: aabb (yellow) X AABB(brown), thus seed coat color of F1 seeds is yellow.

Cross III: When the F1 is selfed the cross is AaBb X AaBb and thus F2 seeds are brown. This also gives the information that brown is dominant over yellow. The F2 progeny plants will have the following genotypes:

A_ B_ (9 Brown)

Aa B_ (3 Brown)

A_ bb (3 Brown)

aa bb (1 yellow)

The plants with the first three genotypes will give rise to brown F3 seeds and the last one will give rise to yellow F3 seeds. The 15:1 ratio is indicative of duplicate genes for seed color.

45.1 TRUE

45.2 FALSE. It is nuclear encoded. If it were chloroplast genome encoded, yellow seeds would have appeared in F2 progeny

45.3 TRUE

45.4 TRUE as similar to cross III, in cross II the F1 will have the same genotype (AaBB).

Q.46 (56)

46.1 T

46.2 F

46.3 T

46.4 T

46.5 F

True or false?.

- a) The probability of all 4 seeds being green is $1/256$ (TRUE, because probability of this case is $1 \cdot (1/4)^4 = 1/256$)
- b) The probability of 3 round and 1 wrinkled seed is 1 (FALSE, the real probability of this case is $4 \cdot (3/4)^3 \cdot 1/4 = 27/64$)
- c) The probability of 2 green and 2 yellow seeds is $27/128$ (TRUE, $6 \cdot (1/4)^2 \cdot (3/4)^2 = 27/128$)
- d) The probability of 4 different seed phenotypes in the pod is $243/8192$ (TRUE, $4 \cdot 3 \cdot 2 \cdot 1 \cdot 9/16 \cdot 3/16 \cdot 3/16 \cdot 1/16 = 243/8192$)
- e) The probability of all 4 seeds having identical phenotypes for both traits is $1/32$ (FALSE, $(1/16)^4 + (3/16)^4 + (3/16)^4 + (9/16)^4 = 1681/16384$)

Q.47 (62)

47.1 F

47.2 T

47.3 T

47.4 F

47.5 F

47.6 F

47.7 F

A. FALSE.

The time to the most recent common ancestor between a Neandertal sequence and a present-day human sequence should be not younger than the admixture date (50 kya) for introgressed segments while it is not younger than the split date (550 kya) for segments coming from ILS. As recombination will break down Neandertal-like segments in humans over time, the introgressed segments are expected to be longer. In fact, this is used to discriminate between them.

B. TRUE.

The N2 specimen had 70 thousand years less time to accumulate mutations compared to N1 and hence is expected to be shorter (more or less proportionally to their age). Indeed, this phenomenon known as branch-shortening can even be used to date ancient samples that we have DNA sequence for.

C. TRUE.

In the autosomal tree tells us that a genome-average relationship is Neandertal being closer to Denisovans rather than humans (even though that in a small fraction of the genome non-African individuals are closer to Neandertals) while the mtDNA of sequenced Neandertals is closer to present-day humans but being equidistant to all humans, both Africans and non-Africans. If Neandertals got some gene flow from a human group more divergent than A1 affecting mtDNA as well as a not-too-big fraction of the nuclear genome, this is what we would expect.

D. FALSE.

Although each non-African has around 2-3 percent of Neanderthal DNA coming from the introgression event, each two non-Africans have mostly non-overlapping Neandertal segments. From all the sequences available now it was possible to reconstruct around 20% of the Neandertal genome from segments in present-day humans.

E. FALSE.

Although the mean expectation for frequency of a Neandertal allele in non-Africans is around 2-3% for a given allele it could have changed due to both genetic drift and natural selection leading to some segments having frequencies above 10% or even 40% in some particular population.

F. FALSE.

A) There is no reason to believe that the N1 Neanderthal is from exactly the same Neanderthal population (both in term of time and space) that admixed with humans; b) although Neanderthals had low genetic diversity there was still some differences even within a single population and c) mutations happened in the human lineage after the introgression on the Neandertal-like segments.

G. False

This is basically about understanding the ILS idea: human (including Africans) and Neanderthals had a common ancestor and hence share a big part of their gene pool in common.

References

Prufer et al., 2013, The complete genome sequence of a Neanderthal from the Altai Mountains

<https://www.nature.com/articles/nature12886>

Nuclear DNA sequences from the Middle Pleistocene Sima de los Huesos hominins

<https://www.nature.com/articles/nature17405>

Prufer et al., 2017, A high-coverage Neandertal genome from Vindija Cave in Croatia

https://www.science.org/doi/10.1126/science.aao1887?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%20pubmed

Q.48 (69)

48.1 T

48.2 T

48.3 F

48.4 F

- a) TRUE – could be directly deduced from the figure – competitors should be aware, that MAPKs reflects to kinases.
- b) TRUE – based on the understanding of the cell cycle regulation – where activatory phosphatases play a key role.
- c) FALSE – could be deduced from the information provided in the stem (...its over proliferation and anomalous differentiation to inappropriate cell types for the vascular wall – chondrocytes or osteocytes - triggered by the oxidised LDL)
- d) FALSE – from the figure could be deduced, that vascular smooth muscle cells could proliferate and cause the atherosclerosis.

Q.49 (68)

49.1 T

49.2 F

49.3 F

49.4 F

49.5 T

- a) *Lacandonia schismatica* flower morphology could be explained by gene expression pattern I. (True, we have inversion of BC (stamens) and Only-C (carpels) expression areas in *Lacandonia*)
- b) Flowers of *Lacandonia schismatica* will lose both petals and carpels if flowers follow gene expression pattern II. (False, in this case flower only lose petals)
- c) Flowers of *Lacandonia schismatica* will lose only petals if flowers follow gene expression pattern III. (False, in this case flower lose petals and carpels)
- d) *Lacandonia* flowers form typical berries after pollination and fruit ripening. (False, *lacandonia* flower have independent carpels, so it could not form berry. *Lacandonia* carpels transforms to achenes).
- e) Tepals, like sepals, need only A gene expression. (True, obvious from schemes I – III.)

Reference: <https://academic.oup.com/plcell/article/22/11/3543/6097061>

Q.50 (67)

Answer keys

50.1 False

50.2 True

50.3 False

50.4 False

Explanations

- A. Because the photochemical reaction rate constants k_1 and k_2 are not changed by temperature and only the non-photochemical reaction rate constant k_3 increases at higher temperatures, the proportion of the Pfr form in the total molecules of phytochrome at equilibrium is smaller at higher temperatures.
- B. From the basic knowledge of the phytochrome-mediated control of photomorphogenesis; in particular, that Pfr is an active form that suppresses elongation growth of the above-ground organs, it can be speculated that the smaller proportion of Pfr at higher temperature causes greater elongation of the hypocotyl.
- C. In phytochrome-deficient mutant seedlings, hypocotyl elongation is suppressed by Pfr at any temperature. Therefore, hypocotyl elongation in these seedlings is expected to be similar to that of wild-type seedlings grown not at low temperatures but at high temperatures, in which condition Pfr is less abundant.
- D. In total darkness, only non-photochemical conversions occur in phytochrome molecules, which eventually results in the conversion of all phytochrome to Pr at any given temperature. Therefore, the effect of temperature on hypocotyl elongation is expected to diminish in the total darkness.

References

- Jae-Hoon Jung, et. al., (2016) Phytochromes function as thermosensors in *Arabidopsis*. *Science* 354, 886–889.
- Martina Legris, et. al., (2016) Phytochrome B integrates light and temperature signals in *Arabidopsis*. *Science* 354, 897–900.

Q.51 (71)

51.1 T

51.2 F

51.3 T

51.4 T

51.5 T

51.6 F

- A. True: C4 plants has low CO_2 compensation point (10-20 ppm), while C3 plants has high CO_2 compensation point (100 ppm),
- B. False: At 400 ppm C_i , net CO_2 assimilation of plant number 1 is not sensitive to C_i and thus NOT limited by carboxylation, while in plant number 2 it is limited by carboxylation.
- C. True: At high CO_2 concentrations, photosynthesis is limited by the capacity of Calvin cycle to regenerate the acceptor molecule ribulose-1,5-bisphosphate, which depends on electron transport rates.
- D. True: At ambient atmospheric CO_2 concentration ($C_i < 400$ ppm), plant number 1 has much greater photosynthesis rate and thus greater photosynthetic water use efficiency than plant number 2.
- E. True: Reducing oxygen concentration (from 20% to 2%) would greatly reduce oxygenase activity of Rubisco and thus would shift the C_i response curve of plant #2 to the left toward that of plant #1.
- F. False: C3 is favored in high CO_2 concentration (plant #2, at $C_i > 500$ ppm) while C4 is favored in high(er) temperature.

Taiz L., and Zeiger E. 2015. Plant Physiology. 6th edition. (page 260, 261).

Q.52 (73)

52.1 T

52.2 F

52.3 T

52.4 T

52.5 T

Explanation:

- A. True: phloem transport ... Munch pressure flow theory.
- B. False: the decreased consumption of assimilates in the expanding sink leaves may reduce translocation.
- C. True: at 2.7 MPa, photosynthesis was about 25 $\mu\text{mol}/\text{m}^2/\text{s}$ while translocation was about 20.
- D. True: no significant change in translocation at -2.0 MPa while photosynthesis already decreased by 25%.
- E. True: preferential translocation to growing root tips in moist soil is very significant survival mechanism.

Sung, FJ and Krieg DR. 1979. Relative sensitivity of photosynthetic assimilation and translocation of carbon to water stress. *Plant Physiol.* 64(5): 852-6.

Q.53 (74)

53.1 T

53.2 T

53.3 F

53.4 T

- A. Degreening is a physiological process associated with ripening or senescence of various fruits after harvest, especially banana. Color is a key reference index for consumers to judge fruit ripeness.
- B. The integrity of cell wall may result from both reduction in cell wall degradation and increased cell wall synthesis.
- C. The ripening of control and HW-treated fruit mainly began differentiation after 19 days of storage.
- D. The HW treatment significantly reduced ethylene production (Figure 1C) in banana fruit, and delayed significantly the fruit ripening as manifested by impeding the color change from green to yellow (Figure 1 A+B) and the fruit softening (Figure 1C, firmness) and the formation of flavor (Figure 1C, TSS).

Yun et al. 2022. The role of hydrogen water in delaying ripening of banana fruit during postharvest storage. Food Chemistry 373, Part B, 30 March 2022, 131590.

Q.54 (75)

54.1 T

54.2 F

54.3 T

54.4 T

- A. True: $[O_3]$ + $[CO_2]$ +T treatment reduced the negative impacts on both total oil and polyunsaturated fatty acid content. $[CO_2]$ +T treatment also reduced the negative impacts on total oil content (polyunsaturated fatty acid remain unchanged).
- B. False: The $[CO_2]$ increase of +260 ppm was the single factor with the lowest detrimental effect on the quantity of the seed oil and polyunsaturated FA content.
- C. True: All 5 treatments have ** or ***.
- D. True: The results showed strong interactive effects of CO_2 , T and O_3 on oil quality.

Namazkar et al. 2016. Concurrent elevation of CO_2 , O_3 and temperature severely affects oil quality and quantity in rapeseed. Journal of Experimental Botany 67(14): 4117–4125.

Q.55 (76)

55.1 T

55.2 T

55.3 F

55.4 T

55.5 T

- A. True.
- B. True: Herbivory loss of plants without EFNs was approximately 3-fold greater.
- C. False: Both *H. umbellate* and *B. campestris* invest in EFNs, but had similar SLA to *B. verbascifolia* and *B. intermedia*.
- D. True: SLA of only 1/3 plants without EFNs was significantly lower than 3 plants with EFNs. But herbivory levels of all 3 plants were significantly greater.
- E. True: Biotic defense reduced herbivory level by more than 50% compared to mechanical defense.

Pereira CC et al. 2020. Are extrafloral nectaries efficient against herbivores? Herbivory and plant defenses in contrasting tropical species. J Plant Ecol 13:423–430.

Q.56 (78)

56.1 T
56.2 T
56.3 F
56.4 T
56.5 T

- A. True: Simple description of Figure 1.
- B. True: Simple description of Figure 1.
- C. False: The daily variations are: nighttime increment (likely driven by root pressure) and daytime contraction (caused by tension in the xylem).
- D. True: The daily variations in stem diameter is largely driven by pressure/tension in the xylem.
- E. True: The competition caused by tapping (latex production) reduced trunk increment by 50% (Fig. 1).

Silpi et al. 2006. Tree Physiology 26: 1579–1587.

Q.57 (77)

57.1 T

57.2 T

57.3 T

57.4 F

57.5 T

- A. True: Values for these traits in the wild type were 1.9- to 3.6-fold of those of the root hairless mutant *rth3*. Adding AMF to *rth3* (*rth3*+AMF) greatly increased shoot/root biomass, root length, P content.
- B. True: Shoot P content of WT was greater than *rth3*-AMF. Root length and dry weight of WT was greater than *rth3*-AMF. Both shoot and root biomass of WT-AMF were greater than *rth3*-AMF.
- C. True: Root Pi assimilation is mainly in the root hair zone while the AMF also colonizes more mature regions of the root and supplies these regions with assimilated Pi
- D. False: Shoot P concentration of WT-AMF was similar to *rth3*-AMF, but was significantly less than *rth3*+AMF. In addition, shoot biomass of WT-AMF was much less than *rth3*+AMF.
- E. True: AMF inoculation of the root hairless mutant *rth3* increased growth and P-acquisition to be at least similar to WT-AMF. (= AMF could compensate for lack of Root hairs)