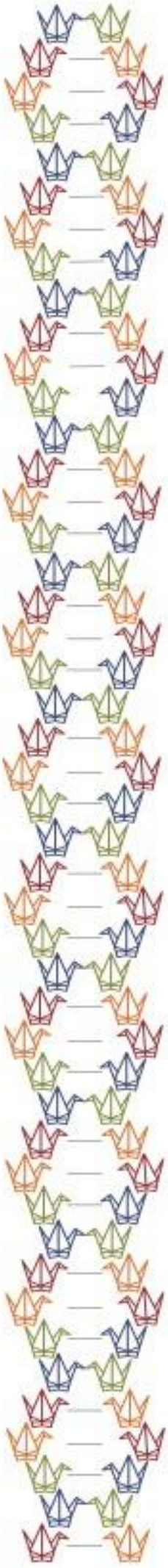


Theoretical Exam 1

2020.8.12.

signature

IBO Challenge 2020

A Substitute for The 31st IBO 2020 Nagasaki, JAPAN

General instructions for theoretical examinations
理論題的一般說明

Exam 1

- Date: August 12th 2020
- Total time of Exam 1 is 3 hours. Follow the instruction by Jury members of your country.
  理論題第 1 部分的考試時間為 3 小時，依監考老師的指示進行。
- Exam 1 consists of 50 questions.
  理論題第 1 部分共有 50 題。
- Each correct answer scores 1 marks, each incorrect or missing answer score 0 marks.
  每答對 1 題得 1 分，答錯或未達者為 0 分。

Instruction and regulations

規則說明

- Make sure that you are using the correct answer sheet (Theoretical exam 1).
  先確定答案紙是對的(Theoretical exam 1)。
- Write your **Country code** and **student ID number** (provided by a jury member or supervisor) in the given box of the answer sheets provided, and write down **your name**.
  在答案紙的適當空格中，填寫**國家編號**以及**學生 ID** (將由監考老師提供)，並填寫你的**姓名**。
- Make sure to **sign all the answer sheets and the cover page of question sheets**.
  答案紙的每一頁，以及**試題卷的封面**，都要**簽名**。
- You must mark your answer to the answer sheets properly, using a pen or a pencil.
  用原子筆或鉛筆，在答案紙上清楚劃記。
- You must have the following equipment for this exam.
  本考試中，你應有下列工具
  ① Pen or pencil to mark answer sheets.
  原子筆或鉛筆，作答用。
  ② Scratch paper sheets provided by Jury member. (You must not bring any paper into the examination room by yourself.)
  由監考老師所提供的計算紙 (你不能自行攜帶任何紙張至考場中)。
  ③ Ruler and eraser.
  尺和橡皮擦。
- The use of a calculator is prohibited, including a calculator application on your PC or a web browser.
  禁止使用計算機，包括電腦或網路上的計算機。
- You must not communicate with any other people in the room during the examination.
  考試時，不能和考場中的任何人交談。
- You must not access any information that could unfairly help you answer the questions during the examination.
  考試時，不能使用任何可以不正當幫助你作答的資訊。

- Stop answering immediately at the end of examination time.
  考試時間結束時，立即停止作答。
- After the examination:
  考完之後：
  ① If you are under **on-site supervision, a jury member / supervisor** will collect your question and answer sheets immediately after each exam. Your country coordinator will later scan and submit the sheets to the IBO2020 Organizing Committee.
  屬於**現場被監考試**者，在每部分考試之後，將由監考老師立即收回試題卷和答案紙。然後再經由掃描所有相關紙張，並繳交檔案給 IBO2020 主辦大會。
  ② If you are under **online supervision**, **you (competitor)** must scan (or take photos of) the answer sheets. Then, digitally send the scanned files/photos and the PDF question sheets (with your signature on the cover page) to your country coordinator as soon as possible. Your country coordinator will submit the file to the IBO2020 Organizing Committee. Make sure the answer sheets are scanned correctly. The IBO2020 office may ask you to resubmit the sheet, so don't discard them.
  屬於**線上被監考試**者，參賽者必須掃描(或拍照)答案紙，然後儘快傳送檔案/照片及試題卷(封面有簽名)的 PDF 給你的主試者，他將繳交檔案給 IBO2020 主辦大會。須確切掃描答案紙。主辦單位得要求你再繳交答案紙，所以請勿丟棄。

Biochemistry
生物化學

Q1

The citric acid cycle is central to metabolism, for the supply energy and various key compounds. In citric acid cycle, the enzyme aconitase catalyzes the reversible conversion between citrate and isocitrate. In this reaction, OH group at C3 and H group at C4 of citrate are removed as water, thereafter a water molecule is added back in a reverse manner to generate isocitrate (Figure 1). However, OH group is never added at C2.

檸檬酸循環對代謝極為重要，可提供能量與各種關鍵的化合物。在檸檬酸循環中，烏頭酸酶 (aconitase) 可催化一個轉換檸檬酸 (citrate) 與異檸檬酸 (isocitrate) 之間的可逆反應。在這個反應中，檸檬酸 C3 位置的 OH 官能基與 C4 位置的 H 基會形成水分子而被移除，因此在進行逆反應產生異檸檬酸時，需要添加一個水分子 (Figure 1)。然而，OH 官能基則永遠不會加到 C2 位置。

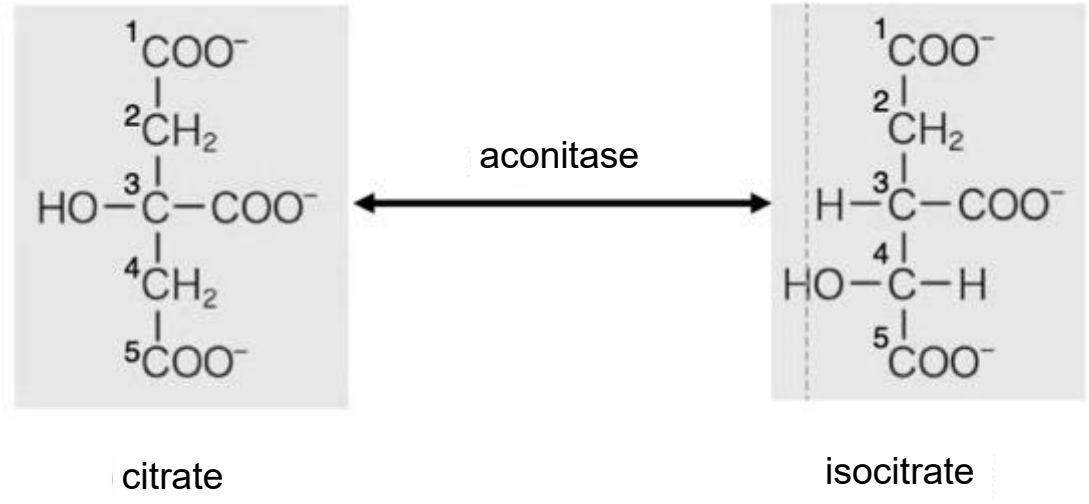


Figure 1

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤

A. Citrate has enantiomers. [1]

檸檬酸具有鏡像異構物

B. Isocitrate has enantiomers. [2]

異檸檬酸具有鏡像異構物

C. Two $-CH_2COO^-$ groups are stereochemically equivalent when citrate is free in solution. [3]

當檸檬酸在溶液中自由存在時，二個 $-CH_2COO^-$ 官能基在立體化學上是相同的。

D. Two $-CH_2COO^-$ groups are stereochemically equivalent when citrate is bound to aconitase. [4]

當檸檬酸與烏頭酸酶結合時，二個 $-CH_2COO^-$ 官能基在立體化學上是相同的。

Biochemistry
生物化學

Q2

The figure 1 illustrated below shows oxygen consumption (respiration) in aqueous suspension of intact animal mitochondria with additions of ADP or chemical compounds (dinitrophenol (DNP) or N,N'-dicyclohexylcarbodiimide (DCCD)). The suspension already contains respiratory substrates, oxygen, and inorganic phosphate.

圖一顯示，當添加 ADP 或化合物 (二硝基酚 (DNP) 或二環己基碳二亞胺 (DCCD)) 到含有完整動物粒線體的水溶液中時，氧氣的消耗情形 (呼吸作用)。懸浮液中已具有呼吸作用所需基質，氧氣與無機磷酸鹽。

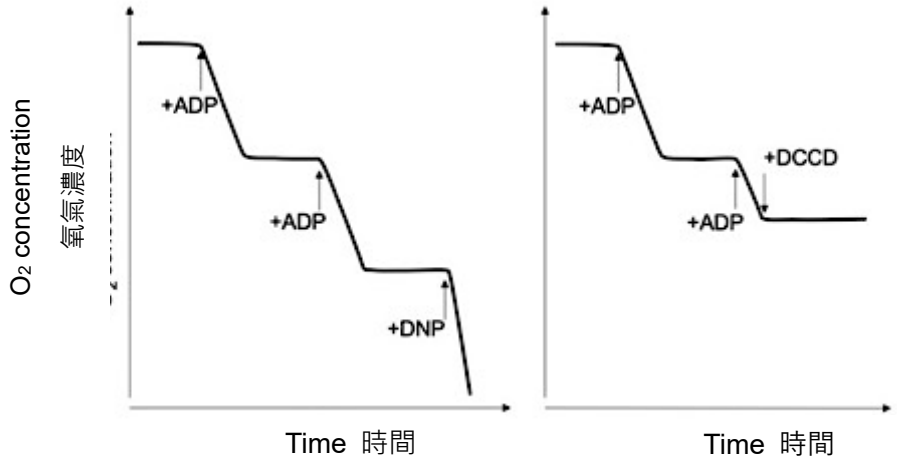


Figure 1. Oxygen consumption of mitochondria in suspension. Identical aliquots of ADP were added in both experiments.

懸浮液中粒線體的氧氣消耗情形。兩個實驗皆添加等量的 ADP。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤

A. The mitochondria are able to incorporate exogenously added ADP. [5]

粒線體能夠併入外加的 ADP

B. Before addition of chemical compounds, the mitochondria respire only when ATP can be produced. [6]

在加入化合物之前，粒線體只能在可製造 ATP 時才發生呼吸作用。

C. The reason why DNP stimulates oxygen consumption is that ATP synthesis is stimulated by DNP. [7]

DNP 能夠激發氧氣消耗的原因，是由於 ATP 的合成受到 DNP 的激發。

D. DCCD inhibits ATP synthesis. [8]

DCCD 會抑制 ATP 的合成。

Biochemistry
生物化學

Q3
When carbon isotopes (^{13}C and ^{12}C) are analyzed, plants can be categorized into two groups (Figure 1), based on the isotope fractionation ($\delta\,^{13}C$, equation 1). This is because of the slight differences in molecular mass between $^{13}CO_2$ and $^{12}CO_2$, although there are no known chemical differences between them. In photosynthesis, two types of carboxylase enzymes fix carbon from CO_2 in the two groups, provided that CO_2 is converted to H_2CO_3 by an enzyme carbonic anhydrase.

當以同位素化學分析法來分析碳同位素 (C^{13} 與 C^{12}) 時，基於同位素的化學分離 ($\delta\,^{13}C$, 公式 1) ，可將植物分成二類 (Figure 1)。這是由於 $^{13}CO_2$ 與 $^{12}CO_2$ 的分子質量有少許的差異，雖然二者在化學結構上並無不同。進行光合作用時，這二類植物利用二種不同類型的羧酶從 CO_2 來進行固碳，而 CO_2 的供應則來自一個碳酸酐酶將之轉換成 H_2CO_3。

Reaction 1: $C_3H_5O_6P + H_2CO_3 \rightarrow C_4H_4O_5 + H_3PO_4$ (C4 plants)
Reaction 2: $C_5H_{12}O_{11}P_2 + CO_2 + H_2O \rightarrow 2\ C_3H_7O_7P$ (C3 plants)

$$\delta^{13}C = \left(\frac{\left(\frac{^{13}C}{^{12}C}\right)_{樣本}}{\left(\frac{^{13}C}{^{12}C}\right)_{標準品}} - 1 \right) \times 1000 \qquad \text{(公式 1)}$$

Sample: a plant material 樣本:一個植物材料
Standard: the reference represents the typical carbon on the Earth.
標準品:此參考值代表地球上典型的碳

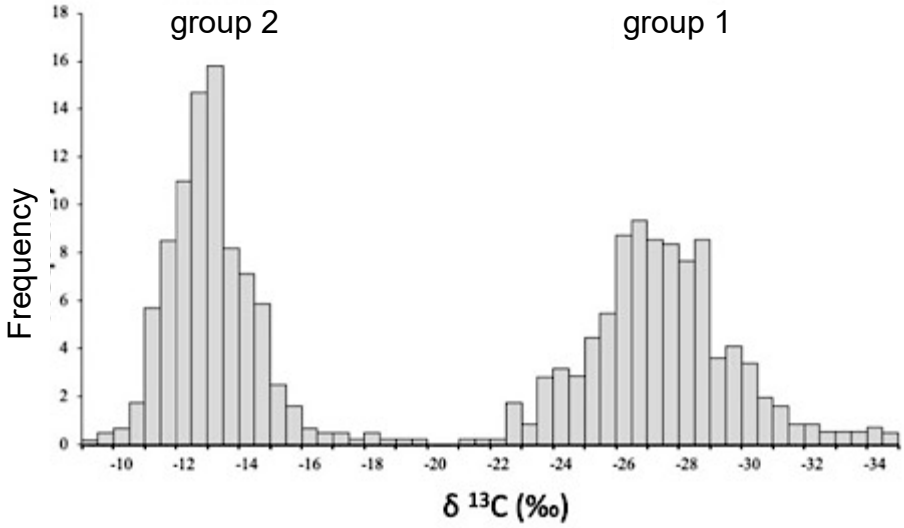


Figure1: Distribution of the carbon isotope fractionation ($\delta^{13}C$ value) of various plants.
圖 1: 不同植物碳同位素化學分離之分布 ($\delta\,^{13}C$ 值)

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. The relative difference in molecular mass due to the carbon isotopes is larger in CO_2 than H_2CO_3.
9

基於碳同位素所導致對分子量的相對差異，其對 CO_2 的影響大於 H_2CO_3。

B. Reaction 1 is catalyzed by ribulose 1,5-bisphosphate carboxylase/oxygenase (RubisCO). 10
反應 1 是被核酮糖-1,5-雙磷酸羧化酶/加氧酶 (RubisCO) 所催化。

C. Both groups of plants discriminate between the isotopes. 11
二類植物能夠區別不同的同位素。

D. Rice belongs to group 1 and corn (maize) belongs to group 2. 12
水稻屬於第 1 類植物，而玉米則屬於第 2 類植物。

Cell Biology
細胞生物學

Q4

Centrifugation is one of the most important biochemical techniques in the separation and purification of biomolecules and organelles. The sedimentation speed (v) of specimens during centrifugal operation is proportional to the applied acceleration rate (g_c), as shown in equation (1).

離心是分離與純化生物分子和胞器的最重要生化技術之一。在離心操作中，樣品的沉降速度 (v) 是與施加的加速度 (g_c) 成正比，如公式 (1) 。

$$v = S \times g_c. \qquad (1)$$

S in the equation is called the sedimentation coefficient and is determined by the ratio between the centrifugal force applied to the object in the solvent (numerator) versus a parameter reflecting the magnitude of viscous resistance against sedimentation (denominator), as shown in equation (2).

公式中的 S 稱為沉降係數，由在溶劑中施加在物件的離心力 (分子) 與相對之對抗沉降的黏性阻力幅度 (分母) 二者的比例所決定，如公式 (2)。

$$S = \frac{V_m(\rho - \rho_0)/N_A}{6\pi\eta r}, \qquad (2)$$

Vm : the molar volume of a sedimenting specimen 沉降樣品的莫耳體積

ρ : the densities of the specimen 樣品的密度

ρ_0 : the densities of the solvent 溶劑的密度

r : the radius of the specimen when it is assumed to be spherical 樣本的半徑，假設其為球狀

η : the viscosity coefficient of the solvent 溶劑的黏度係數

N_A : the Avogadro constant, 6.02×10^{23}. 亞佛加厥常數, 6.02×10^{23}.

Indicate whether the following descriptions are true or false.

指出下列各敘述是正確或錯誤

A. For organelles of the same size and shape, S can be used to estimate differences in organelle density. 13

對相同大小與形狀的胞器，S 可用來估計胞器密度的差異

B. Since many protein molecules have densities between 1.3 and 1.4 (g/mL), we can use S to distinguish sizes of spherical protein molecules. 14

由於大多數蛋白質的密度介於 1.3 和 1.4 (g/mL)，我們可利用 S 來辨別球形蛋白質分子的大小。

C. Assuming that two ribosomal subunits of similar size are combined to form a large complex, S is approximately doubled. 15

假設二個大小相似的核醣體次單元結合成為一個大的複合體，S 值也會大約加一倍。

D. Since it is commonly expected that the viscosity of a solvent will increase at low temperatures, S also decreases when chilled. 16

通常預期一溶劑在低溫時黏度會增加，因此當冷卻時 S 值也會降低。

Cell Biology
細胞生物學

Q5
ATP is an important energy source for maintaining normal membrane potential in nerve cells. Figure 1 shows the result of an experiment demonstrating Na^+ efflux from an isolated squid giant nerve axon after injecting a buffer solution (artificial cytoplasm) that contains radioactive $^{24}Na^+$.
ATP 是一用來維持神經細胞正常膜電位的重要能源。Figure 1 為一個實驗的結果，展示出一個分離的烏賊巨大神經細胞軸突，於注射含有放射性 $^{24}Na^+$緩衝溶液 (人工細胞質) 之後，鈉離子之流出情形。

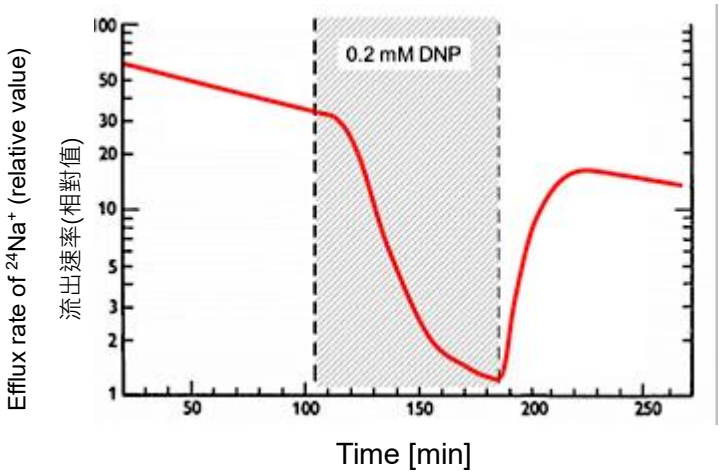


Figure 1 Investigation of the efflux rate of radioisotope ^{24}Na from a squid giant axon to the external solution (seawater). At 0 min, a buffer solution containing $^{24}Na^+$ was injected into the giant axon. For 100-190 min, the external seawater was replaced with a solution (seawater) containing 0.2 mM DNP (dinitrophenol), an uncoupler of oxidative phosphorylation.
圖 1: 從一個烏賊巨大神經元軸突觀測放射性 $^{24}Na^+$ 流出到溶液 (海水) 中的速率。在第 0 分鐘，含有 ^{24}Na 的緩衝溶液被注射進入巨大軸突。在第 100-190 分鐘，外界的海水替換成一個含有 0.2 mM DNP (二硝基苯酚) 的溶液 (海水)，DNP 是一種氧化磷酸化的解聯劑。

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. This experiment should have been carried out under the condition with sufficient oxygen to maintain the activity of ATP production by mitochondria. 17
這個實驗必須在具有充分氧氣的條件下進行，以維持粒線體生產 ATP 的活性。

B. The efflux of $^{24}Na^+$ observed in seawater without DNP indicates the leaking of Na ions out of the cell by nonspecific transportation. 18
從缺乏 DNP 海水所觀察到的 $^{24}Na^+$ 流出，顯示出鈉離子是以非專一性的運輸從細胞漏到外界。

C. Delayed decrease of $^{24}Na^+$ efflux after using DNP reflects some amount of ATP storage inside the axon, including that being produced by glycolysis. 19
於使用 DNP 後產生 $^{24}Na^+$ 流出降低的延遲現象，顯示出軸突內貯存有一些 ATP，包括那些於糖解作用時所產生的。

D. Active transport of sodium ions was estimated to increase internal sodium concentration by 10% in 50 min. 20
鈉離子的主動運輸估計可在 50 分鐘內增加內部 10%的鈉離子濃度。

Cell Biology
細胞生物學

Q6
For the growth of plants, the supply of nutrient inorganic ions is essential. A certain crop was grown in two different soils (X, Y). The concentrations of nutrients (potassium ions and chloride ions) in each type of soil are shown in the table. The estimated cytosolic concentrations of each ion in the root epidermal cells of this crop are also shown. When the membrane potential of the epidermal cell is −150 mV, how is each ion transported into the cell?
植物生長時，提供無機離子營養鹽是必須的。某一種作物生長於二種不同土壤 (X, Y)，下表中顯示出二種土壤的營養鹽濃度 (鉀離子與氯離子)。表中也顯示出此作物根部表皮細胞細胞液中所含的二種離子之估計濃度。當此表皮細胞的膜電位為 −150 mV 時，每一種離子如何運送進入細胞？

Ion movement is determined by electrical and concentration gradients. The membrane potential which would counterbalance the concentration gradient is given by the Nernst equilibrium potential equation:
離子的移動是由電性梯度與濃度梯度來決定。能抗衡濃度梯度的膜電位，則如下列的能斯特平衡電位方程式所示。

$$E = -\frac{60}{\mathbf{z}} \log \frac{\mathbf{C_i}}{\mathbf{C_o}} \text{ (mV)}$$

E : the Nernst equilibrium potential 能斯特平衡電位

z : the charge of the ion, e.g. z for Ca^{2+} = +2 離子的電荷，例如 Ca^{2+} 的 z= +2

$\mathbf{C_i}$: the molar concentration of the ion in the cytosol 細胞液所含離子的莫耳濃度

$\mathbf{C_o}$: the extracellular molar concentration (here, the concentration in the soil) of that ion. 細胞外此離子的莫耳濃度 (此處為土壤中的濃度)

The direction of ion transport is determined by comparing the Nernst equilibrium potential with the membrane potential of the cell. Here, transport against the electrochemical gradient of each ion is called “active transport” and transport according to the electrochemical gradient of each ion is called “passive transport.”
離子運輸的方向，是經由比較能斯特平衡電位與細胞膜電位來決定。於此處，逆化學電位梯度的運輸稱為”主動運輸”，而順化學電位梯度的運輸則稱為”被動運輸”。

	Soil X	Soil Y	The estimated cytosolic concentrations of each ion in the root epidermal cells 根部表皮細胞細胞液中所含的每種離子之估計濃度
K^+	1 mM	0.01 mM	100 mM
Cl^-	0.5 mM	5 mM	5 mM

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. In soil X, potassium ions are absorbed by the active transport system. 21
於土壤 X，鉀離子是以主動運輸系統來吸收。

B. In soil Y, potassium ions are absorbed by the active transport system. 22
於土壤 Y，鉀離子是以主動運輸系統來吸收。

C. In soil X, chloride ions are absorbed by the passive transport system. 23
於土壤 X，氯離子是以被動運輸系統來吸收。

D. In soil Y, chloride ions are absorbed by the passive transport system. 24
於土壤 Y，氯離子是以被動運輸系統來吸收。

Cell Biology
細胞生物學

Q7
"Secondary metabolism" in microorganisms and plants is not essential for their survival, but is a metabolic process that plays an important role depending on species or in environmental adaptation. Many secondary metabolites accumulated by plants, such as nicotine and caffeine, play a role in resistance to damage from herbivorous insects.
微生物與植物的"次級代謝"對其生存並非是必要的，但依物種與環境的適應性，此代謝過程也可扮演重要的角色。植物累積許多次級代謝物，如尼古丁與咖啡因，扮演了對抗草食性昆蟲所造成損傷的角色。

Glucosinolate, which is accumulated in the leaves of *Arabidopsis thaliana*, is a repellent for herbivorous insects (*Helicoverpa armigera*). The leaves of the wild type (Wild) and the leaves of the mutant (Mutant) incapable of synthesizing glucosinolate are arranged as shown in Figure 1.
累積在阿拉伯芥葉片中的硫化葡萄糖苷，是一種草食性昆蟲 (番茄夜蛾) 的忌避劑。野生種葉片 (Wild) 與無法合成硫化葡萄糖苷的突變種葉片 (Mutant) 安排如圖 1 所示。

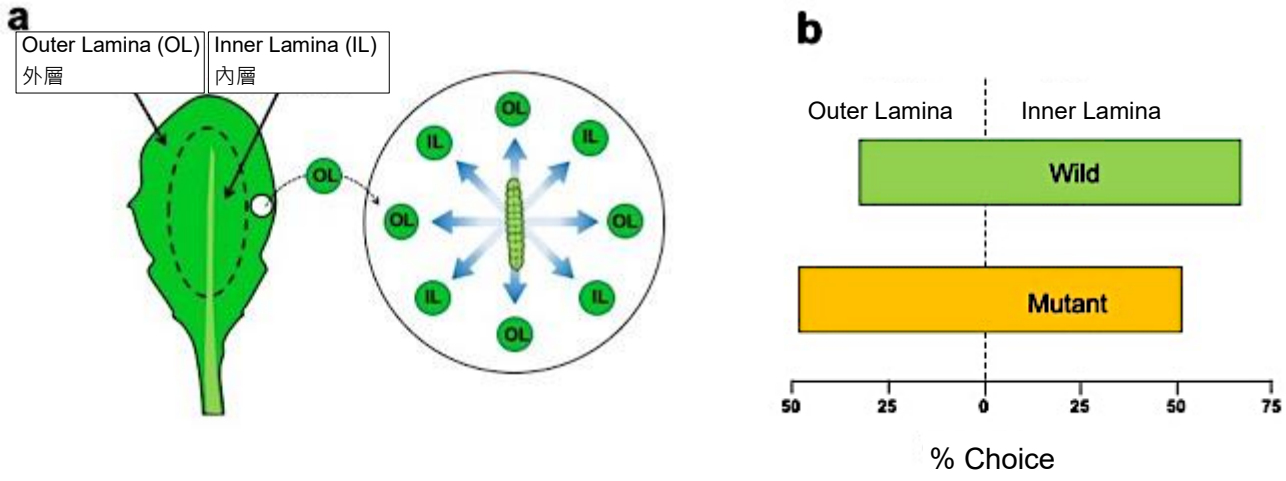


Figure 1 (**a**) Experimental design, (**b**) Result of choice by insect larvae.
圖 1 說明: (a) 實驗設計，(b) 昆蟲幼蟲的選擇結果

The following conclusions can be assumed from this experiment. 此實驗可推論出下列結論
Indicate whether each of the following statements is true or false
指出下列各敘述是正確或錯誤

A. In the *Arabidopsis* wild strain, glucosinolate is accumulated more in the outer lamina of the leaves. 25
對阿拉伯芥的野生品系來說，葉片的外層會累積較多的硫化葡萄糖苷。

B. In this mutant, glucosinolate is evenly accumulated at any region of the leaf. 26
對突變品系來說，硫化葡萄糖苷會均勻累積與於葉片的各區域。

C. *Arabidopsis* accumulates only glucosinolate as a repellent in its leaves. 27
阿拉伯芥於其葉片僅貯積硫化葡萄糖苷作為忌避劑。

D. For *Arabidopsis*, inner lamina is likely to be more physiologically important than outer lamina. 28
對阿拉伯芥來說，內層在生理學上可能比外層重要。

Cell Biology
細胞生物學

Q8
Isoetes howelli is an amphibious plant that can live in both aerial and submerged conditions. In a completely submerged condition in shallow fresh water, *Isoetes howelli* shows characteristic metabolism; CO_2 is fixed to malate in a certain time period and released in another period to be used in photosynthetic carbon assimilation. This metabolism is not seen in the aerial condition. There shall be a strong photosynthetic competition in daytime between *Isoetes howelli* and other photosynthetic organisms.

水韭 (*Isoetes howelli*) 是一種兩棲植物，能生活在水面上與水面下的條件中。完全浸沒於淺水環境下，水韭會展示出特殊的代謝方式；CO_2 在某一時段會被固定成為蘋果酸，而在另一時段則釋出，被用於光合作用的碳同化作用。在水面上的環境條件下，不會進行這種代謝方式。在白晝下，水韭與其他進行光合作用的生物一定有很強的光合競爭。

Indicate whether each of the following statements is true or false
指出下列各敘述是正確或錯誤

A. The malate concentration in the leaves is the highest just before sunrise. 29
在日出之前，葉片中的蘋果酸濃度最高。

B. The characteristic metabolism is adaptive because it reduces water loss. 30
這種特殊的代謝是具有適應優勢的，因為它能減低水分的喪失。

C. This species has characteristic bundle sheath cells with well-developed chloroplasts. 31
此物種具有明顯的維管束鞘細胞，且其中具有發育良好葉綠體。

D. In the submerged condition to which this species is adapted, it is more difficult to use CO_2 in daytime than in nighttime. 32
於此物種適應的浸水條件下，白晝獲取 CO_2 較夜間來得更困難。

Genetics
遺傳學

Q9
Both eukaryotes and prokaryotes have a common feature that mRNA starts translation at the AUG codon. Eukaryotic mRNA is usually a monocistron that encodes only one protein, whereas prokaryotic mRNA is often a polycistron that encodes multiple proteins. The following experiments were performed to investigate the mechanism of the AUG codon that initiates translation. Post-translation decomposition need not be considered.
真核及原核細胞皆具有其 mRNA 由 AUG 密碼開始轉譯的共同特徵。真核細胞的 mRNA 常為單順反子，亦即其只編碼一條蛋白質。但原核細胞的 mRNA 常為多順反子可編碼多條蛋白質。以下實驗用以探討 AUG 密碼子起始轉譯的機制，不需考慮轉譯後分解狀況。

(1) For several operons of *Escherichia coli*, the promoter was replaced with a yeast promoter and introduced into yeast cells. Although all full-length mRNAs were transcribed for all operons, some operons translated only the first gene correctly, while other operons did not translate any genes.
將數個大腸桿菌的操縱組的啟動子置換成酵母菌啟動子後，將其送進酵母菌細胞內，雖然所有操縱組的全長 mRNAs 都被轉錄出來，有些操縱組只正確轉譯第一個基因產物，其它操縱組則無法轉譯任何基因產物。

(2) The promoters derived from *E. coli* were ligated to cDNAs obtained by removing introns from several yeast genes and introduced into the *E. coli* host. Full-length mRNA was transcribed for all operon genes, but there was little translation of any genes.
大腸桿菌的啟動子與數個已去除內含子的酵母菌基因的 cDNAs 連接後。再送到大腸桿菌細胞內。所有操縱組基因都轉錄成全長 mRNA，但都只轉譯出微量產物。

From these experiments, it is considered that the AUG codon that initiates the translation of *Escherichia coli* and yeast is determined through the following mechanism.
這些實驗認為大腸桿菌及酵母菌的 AUG 密碼子起始轉譯，是經由下列機制來決定的。

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. In *E. coli*, the translation starts with the first AUG codon of the mRNA as the start codon. 33
大腸桿菌是以 mRNA 上的第一個 AUG 作為起始密碼子開始進行轉譯的

B. In yeast, translation starts with the first AUG codon of the mRNA as the start codon. 34
酵母菌是以 mRNA 上的第一個 AUG 作為起始密碼子開始進行轉譯的

C. In *E. coli*, translation starts with the AUG codon designated by the specific sequence in the mRNA as the start codon. 35
大腸桿菌的轉譯作用由在 mRNA 內的特定序列上的 AUG 作為起始密碼子開始轉譯。

Genetics
遺傳學

Q10
There are four types of bases used for RNA – A, C, G and U – while for DNA there are four types of bases, A, C, G, and T. I wondered why thymine T could only be used for DNA and looked closely at the base-pairing pattern (Figure 1).

RNA 含有 A, C, G 及 U 四種鹼基，DNA 含有 A, C, G 及 T 四種鹼基。何以 T 只用於組成 DNA，請看清楚圖 1 中的鹼基配對型式。

It is reported that the mutant strain of the certain gene in *Escherichia coli* sometimes incorporates dUTP in place of thymine to include bases in the DNA strand. This frequently results in a new mutation. In a chemistry lecture, I learned that compounds such as bases could undergo chemical changes (mainly hydrolytic deamination) by reacting with certain water molecules even under *in vivo* conditions.

文獻報導顯示大腸桿菌某些基因的突變株有時會將 dUTP 取代胸腺嘧啶而嵌到其 DNA 中，這經常造成新突變。由化學課中我們學到鹼基在活體細胞中常因與水分子反應而起化學變化(主為水解脫氨作用)。

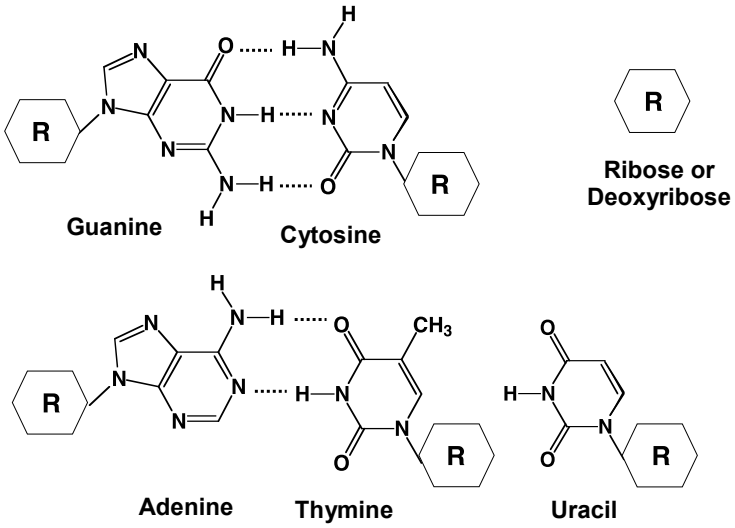


Figure 1

Indicate whether each of the following statements is true or false

指出下列各敘述是正確或錯誤

A. Chemical changes made to RNA bases are not repaired. 36

發生在 RNA 鹼基上的的化學改變不會被修補

B. Chemical changes that occur in cytosine bases are the main reason that thymine bases are used only in DNA. 37

胞嘧啶鹼基結構上的化學改變，是胸腺嘧啶鹼基只用於 DNA 的主要原因

C. *E. coli* mutant strains that incorporate uracil instead of thymine are more likely to mutate the A-T base pair. 38

會以脲嘧啶取代胸腺嘧啶的大腸桿菌突變株較可能會造成 A-T 鹼基對的突變

D. *E. coli* mutant cells containing uracil bases in the DNA chain are susceptible to chemical changes in uracil bases, so that new mutations occur frequently. 39

其 DNA 鏈中含有 uracil 鹼基的大腸桿菌突變細胞對 uracil 鹼基化學變化較敏感，所以經常發生新的突變。

Genetics
遺傳學

Q11
For the three heritable features, Alfa, Baker, and Charlie, pedigree analysis was performed on pedigree A, pedigree B, and pedigree C, respectively, and the results in Figure 1 were obtained.
圖 1 為針對 Alfa, Baker, 及 Charlie 三個家庭遺傳特徵的族譜分析所對應的(A)族譜、(B)族譜、及(C)族譜的結果圖。

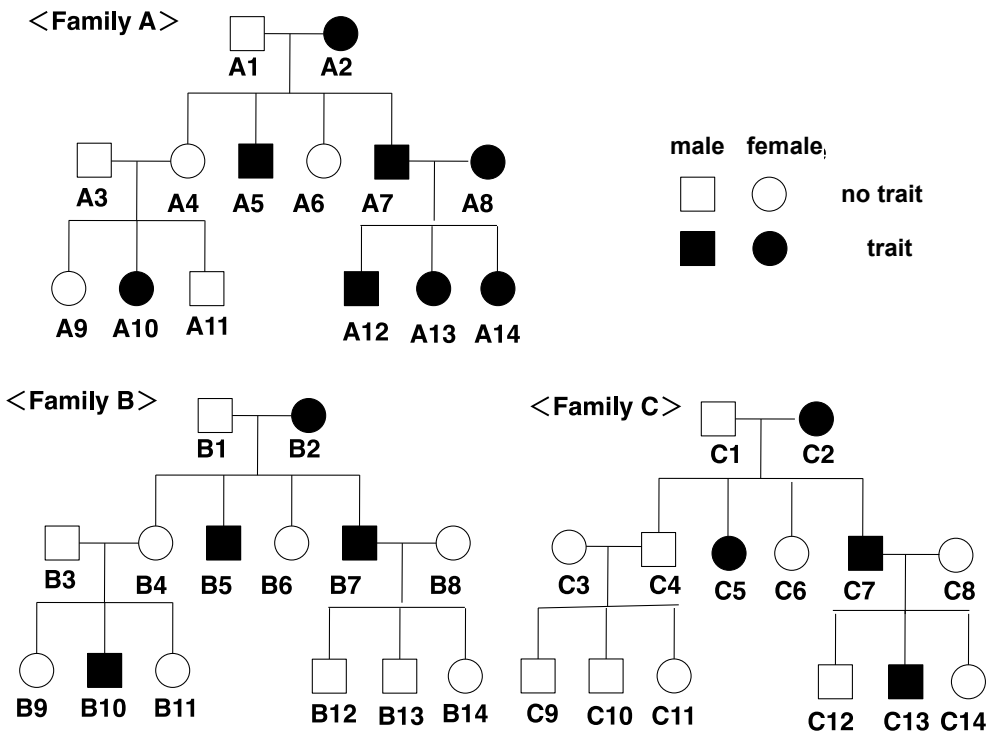


Figure 1

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

1. An analysis of pedigree **A** suggests that the inheritance pattern of characteristic Alfa could be due to a dominant allele. 40
A 族譜分析顯示 Alfa 家族遺傳可能是顯性等位基因遺傳

2. An analysis of pedigree **C** suggests that the inheritance of the characteristic Charlie could be due to a dominant allele. 41
C 族譜分析顯示 Charlie 家族遺傳可能是顯性等位基因遺傳

A subsequent detailed analysis revealed that all of the inheritance patterns of Alfa, Baker, and Charlie were due to recessive alleles on the autosome.
後續詳盡分析顯示所有 Alfa, Baker 及 Charlie 家族的遺傳特徵都是由體染色體上隱性等位基因所造成

3. **B1** and **B3** of family **B** are definitely carriers. 42
B 家庭的 B1 及 B 3 一定是基因攜帶者

4. **C1** and **C3** of family **C** are definitely carriers. 43
C 家庭的 C 1 及 C 3 一定是基因攜帶者

Genetics
遺傳學

Q12
In *Escherichia coli*. the *rutA - G* gene cluster activates when pyrimidine is decomposed and used as a nitrogen source. The *rutA - G* genes constitute a single *rut* operon, and a single P_{rut} promoter regulates the expression. The expression of the P_{rut} promoter is regulated by a RutR repressor using uracil as an inducer.

大腸桿菌在將嘧啶分解以作為其氮源時，其 *rutA-G* 基因簇會被活化，這些基因組成單一個 rut 操縱組，由單一 *Prut* 啟動子調節其表現，且此 *Prut* 啟動子之表現受到 RutR 抑制蛋白調控，並以脲嘧啶當誘導物。

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. As the concentration of uracil increases, the expression level of the *rut* operon decreases. 44
當脲嘧啶增加時，*rut* 操縱組表現量降低

B. When a mutation occurs in the RutR repressor and the affinity for uracil is reduced, the expression level of the *rut* operon is reduced. 45
當 RutR 抑制蛋白因突變使其對脲嘧啶親和力下降時，*rut* 操縱組表現量降低

C. If a mutation occurs in the DNA binding domain of the RutR repressor and the affinity for the DNA sequence decreases, the expression level of the *rut* operon increases. 46
當 RutR 抑制蛋白的 DNA 結合區發生突變，使其對 DNA 序列的親和力下降時， rut 操縱組表現量增加

D. When a mutation occurs in the nucleotide sequence of the operator to which the RutR repressor in the P_{rut} promoter binds, the expression level of the *rut* operon always becomes high. 47
當 *Prut* 啟動子上 RutR 抑制蛋白結合的操作子核酸序列發生突變時，rut 操縱組表現量會變高

Genetics
遺傳學

Q13
Bacteria regulate gene expression through transcription factors that sense environmental changes in order to adapt to the ever-changing environment. One transcription factor often controls multiple genes. Since the expression of a gene consumes energy, the selection of the gene group to be expressed is important for the survival strategy of the bacterium. It is often observed that bacteria move vigorously in search of nutrients in the aquatic environment, while bacteria in biofilms rarely move.

為了適應環境的不斷改變，細菌會透過轉錄因子來調控基因的表現。一種轉錄因子常控制多個基因，由於基因表現會消耗能量，故哪些基因群該表現是細菌重要生存策略，在水域環境中，細菌常因搜尋營養而激烈移動，而形成生物膜後則很少移動。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤

A. Generally, transcription factors, which induce the expression of glucose utilizing genes, suppress the expression of lactose-metabolizing genes. 48

通常那些會誘發細菌利用葡萄糖基因表現的轉錄因子，會抑制乳糖代謝基因的表現。

B. Transcription factors activated by phosphate depletion activate the expression of glycogen-utilizing genes. 49

會被磷酸匱乏所活化的轉錄因子，也會活化肝醣利用相關基因的表現

C. Transcription factors that activate the expression of fatty acids-metabolizing genes are generally activated under oxygen depleted conditions. 50

會活化脂肪酸代謝基因的轉錄因子，也常會在氧匱乏狀況時被活化

D. Transcription factors that activate the expression of biofilm-forming genes usually suppress the expression of the genes of flagella formation. 51

會活化生物膜形成基因表現的轉錄因子，也常會抑制鞭毛形成基因之表現

Genetics
遺傳學

Q14
With the advancement of DNA research, various technologies have been developed, and it has become important to select appropriate research methods according to one's research purpose. Among the research methods M1 to M7, mark (T) if it is appropriate as the method that provides the most direct information on the following research purpose A – D, and mark (F) if it is inappropriate.

許多技術因應先進 DNA 研究的進步而被開發出來，因此依據研究目的選擇適當的研究方法非常重要，M1-M7 羅列的為各種研究方法，這些研究方法若能針對研究目的 A-D 提供最直接資訊者以(T)標示，如為不恰當者則以(F)標示。

Research methods
研究方法

(M1) DNA microarray DNA 微陣列分析

(M2) Quantitative RT-PCR 量化 RT-PCR

(M3) CRISPR-Cas9 method 基因編輯

(M4) In situ hybridization 原位雜合

(M5) Reproductive cloning 生殖複製

(M6) Construction of iPS cell 建構誘導性多能幹細胞

(M7) Metagenome analysis 總體基因體分析

Purpose of research
研究目的

A. To examine the site where a specific gene is expressed in a mouse tissue, it is appropriate to perform (M4). 52

M4 用以檢測小鼠組織中某一基因表現的位置

B. To analyze the expression level of a specific gene in maple leaves, it is appropriate to perform (M2). 53

M2 適用於分析楓葉中特定基因表現量

C. To search the *Bacillus subtilis* genome for genes the expression of which is induced when the nitrogen source is depleted. (M1) 54

M1 用於探討當氮源匱乏時枯草桿菌基因體中被誘導表現的基因

D. To identify microbial species from microbial communities thriving in compost. (M7) 55

M7 可用以鑑定在堆肥內存活菌叢中的細菌菌種

Genetics

遺傳學

Q15

The seed germination of plants is mainly controlled by the action of two plant hormones called gibberellin and abscisic acid. Gibberellin promotes germination and abscisic acid suppresses germination. Through the actions of these two plant hormones, plant seeds are regulated so that germination is induced in an appropriate environment.

植物種子萌芽主要由吉貝素及離層素兩種植物荷爾蒙控制，吉貝素促進萌芽而離層素抑制萌芽。經由此兩種荷爾蒙之作用，可以誘導植物種子在適當的環境中萌芽。

In plants, gibberellin is biosynthesized from a molecule called geranylgeranyl diphosphate. Geranylgeranyl diphosphate is converted into *ent*-kaurene through the action of *ent*-kaurene synthase. *ent*-Kaurene is then converted into gibberellin through the action of several enzymes such as GA20 oxidase. Biosynthetic intermediates such as *ent*-kaurene do not have germination-inducing activity (Figure 1).

植物中吉貝素一種稱為 geranylgeranyl diphosphate 的分子生合成。 Geranylgeranyl diphosphate 經由 ent-kaurene 合成酶被轉化形成 ent-kaurene 後，再由數種酵素如 GA20 氧化酶轉變成吉貝素。生合成的中間產物 ent-kaurene 不具有誘導萌芽的活性(圖 1)

On the other hand, abscisic acid is biosynthesized from carotenoid pigments. Abscisic acid is converted into 8'-hydroxyabscisic acid by an oxidase called CYP707A. Seeds of Arabidopsis mutants lacking the gene encoding CYP707A were observed to have significantly delayed germination as compared to seeds of wild-type plants. In addition, the germination of the seeds of plants in which the CYP707A gene was overexpressed were promoted more than the wild-type seeds. In this experiment, the administered compounds play a similar function of endogenous hormones.

離層素由類胡蘿蔔素生合成，離層素會被 CYP707A 氧化酶轉化成 8'-hydroxyabscisic acid，缺乏 CYP707A 的阿拉伯芥突變株的種子萌芽顯著比野生型植株種子延遲，此外過度表達 CYP707A 植株種子比野生型植株種子萌芽顯著的被促進，在此實驗中所給予的複合物扮演與內源荷爾蒙相類似的功能。

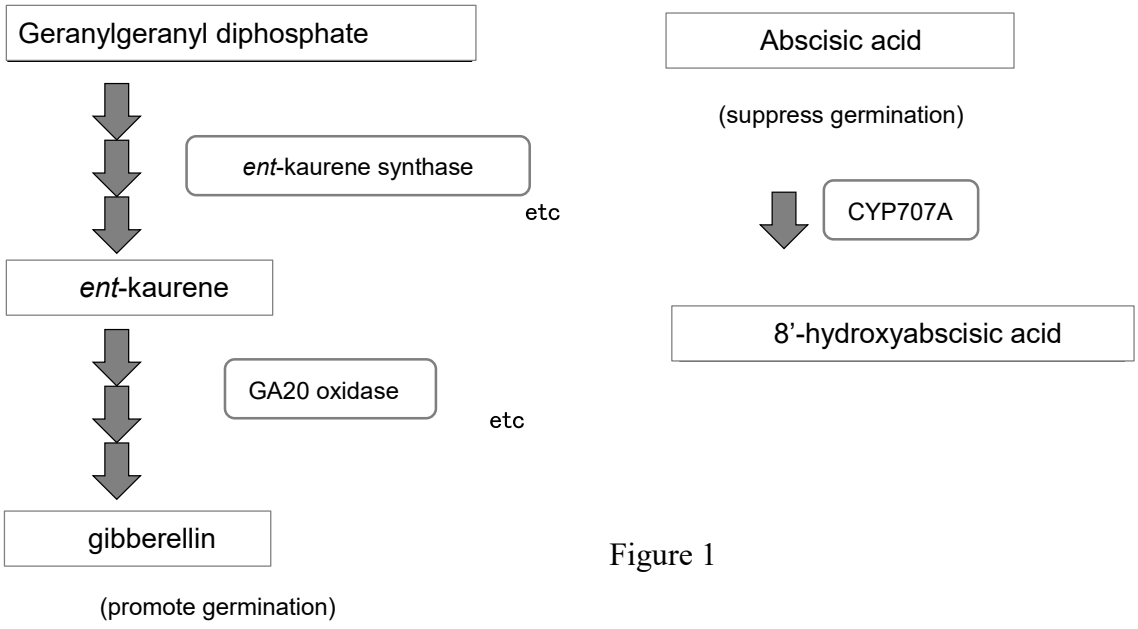


Figure 1

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤

A. In the mutant lacking the *ent*-kaurene synthase gene, germination is delayed compared to the wild-type plants. 56

在缺乏 ent-kaurene 合成酶的突變株種子，萌芽會比野生型植株延遲

B. When a mutant lacking the *ent*-kaurene synthase gene is treated with *ent*-kaurene, germination is promoted. 57

當缺乏 ent-kaurene 合成酶的突變株以 *ent*-kaurene 處理時其萌芽會被促進

C. ent-Kaurene treatment to a mutant lacking the gene encoding GA20-oxidase promotes germination. 58

以 ent-Kaurene 處理缺乏 GA20 氧化酶編碼基因的突變株會促進萌芽

D. 8'-Hydroxyabscisic acid has a stronger germination-inhibiting activity than abscisic acid. 59

8'-Hydroxyabscisic acid 比起離層素具有更強的抑制萌芽的活性

Genetics

遺傳學

Q16

Part of the sequence of vector A, which is for protein expression using *Escherichia coli* as a host, is shown. It was planned to express a plant-derived gene X using vector A. Vector A is a plasmid vector that expresses a protein fused to the N-terminus His-tag, which enables efficient purification of the expressed protein. As shown in Figure 1, translation of the protein occurs from the start codon immediately before the His tag with six consecutive His residues. The DNA sequences of the 5' and 3' regions of gene X are shown in Figure 2.

以大腸桿菌為宿主進行蛋白質表現的載體 A，其部分序列顯示如下，此載體 A 計畫將用以表現植物基因 X。載體 A 為質體，使其表現的蛋白與 N 端的 His-tag 相融合，如此可以更有效率的純化所表現的蛋白。如 Figure 1 所呈現的，轉譯的蛋白由 His-tag 前方的起始密碼子開始，後面具有連續的六個 His 胺基酸。基因 X 的 5'及 3'DNA 序列如圖 2 所示。

We planned to clone gene X using restriction enzyme sites, EcoRI, SmaI, or SalI in vector A. When the gene X is amplified by PCR, a fragment with a restriction enzyme site at the end can be amplified using the primer with a restriction enzyme site. Since the restriction enzyme site is not recognized if it is located at the end of the DNA fragment, three "Cs" were also attached in addition to the restriction enzyme site.

我們利用載體 A 的 EcoR1, SmaI 或 SalI 限制酶切割位點來選殖基因 X。當基因 X 以 PCR 擴增時，我們使用末端具有限制酶切割位序列的引子，因 DNA 片段末端的限制酶序列會無法被辨識，因此除了限制酶切位外再多加入三個 Cs。

For example, in order to add the EcoRI site to 5'-XXXXXXXXXX----, the primer is designed as below.
5'-CCCGAATTCXXXXXXXXXX----,

例如在加入 EcoRI 切位到 5'-XXXXXXXXXX----序列時引子的序列設計如下:
5'-CCCGAATTCXXXXXXXXXX----,

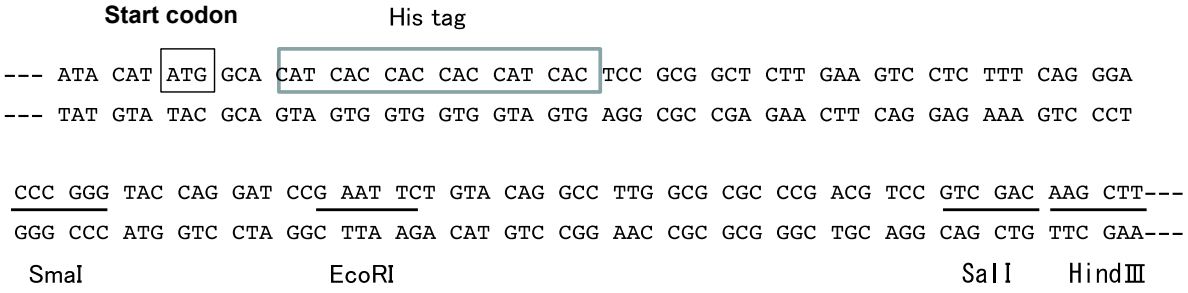


Figure 1. DNA sequence of the cloning region of vector A (double strands).

圖 1. 載體 A(雙股)轉殖區域的 DNA 序列

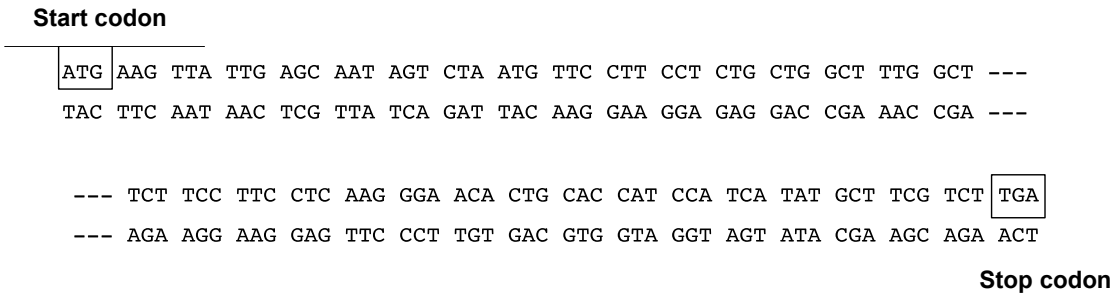


Figure 2. DNA sequence of the gene X showing 5' region and 3' region:1566 base pairs

圖 2. 基因 X 的 5'端及 3'端的 DNA 序列:1566 鹼基對

Choose true if the primer is a correct one to use, if not, choose false.
如引子使用正確請選 True，否則就選 False

A. Forward primer (☐: the start codon)
前置引子(☐:起始密碼子)
5'-CCC GAA TTC ATG AAG TTA TTG AGC AAT A-3' 60
EcoRI site

B. Forward primer (☐: the start codon)
前置引子(☐:起始密碼子)
5'- CCC CCC GGG ATG AAG TTA TTG AGC AAT A-3' 61
SmaI site

C. Reverse primer (☐: the stop codon)
反置引子(☐:終止密碼子)
5'-CCC GTC GAC TCA AGA CGA AGC ATA TGA T-3' 62
SalI site

D. Reverse primer (☐: the stop codon)
反置引子(☐:終止密碼子)
5'-CCC AAG CTT GTA GGT AGT ATA CGA AGC AGA ACT -3' 63
HindⅢ site

Genetics
遺傳學

Q17
In recent years, a genome editing technology called the CRISPR-Cas9 method has been widely used for biology research. In the CRISPR-Cas9 method, an enzyme called Cas9 is guided to the target gene by forming a complex with a guide RNA with a sequence complementary to a part of the target gene. Then, Cas9 cleaves the double-stranded DNA of the target gene specifically with its activity of cleaving double-stranded DNA. Cas9 recognizes a 3-base sequence (NGG) called PAM sequence and cuts the DNA strand 3 to 4 bases upstream of PAM. The cleaved DNA chain is repaired by the DNA repair system, but at that time, a few bases are frequently deleted or inserted.

近年來一種稱為 CRISPR-Cas9 的基因編輯技術廣泛被用於生物研究上，在此種 CRISPR-Cas9 研究方法中 Cas9 酵素與一嚮導 RNA 形成複合體，而被導向具有互補序列的標的基因，具有雙股 DNA 切割活性的 Cas9 酵素會切割其標的基因上的特定序列，Cas9 會辨認一個稱為 PAM 的 3-鹼基 (NGG) 組成的序列，並在 PAM 序列上游 3 到 4 個鹼基位置進行 DNA 切割，切斷的 DNA 鏈會被 DNA 修補系統進行修復，但修復的同時也常會有幾個鹼基丟失或被插入。

The CRISPR-Cas9 method was applied by targeting the region close to the translation start codon of the most upstream exon of a gene encoding enzyme A of a certain animal. The base sequence of the target region was determined for each of the four mutants obtained (Figure 1)

CRISPR-Cas9 方法被用於標靶動物的酵素 A 基因中，最上游外顯子中轉譯起始密碼子的鄰近序列，此實驗所獲得的四種標靶區突變序列如下圖(Figure 1)所示

Original sequence	TA TCT TAC ATG ATC CTA CAA GTA CCT TAC GCT CGG CAG GAA G
Mutant 1	TAT CTT ACA TGA TCC TAC AAG TAC CTT ACA GCT CGG CAG GAA G
Mutant 2	TAT CTT ACA TGA TCC TAC AAG TAC CTT GCT CGG CAG GAA G
Mutant 3	TA TCT TAC ATG ATC CTA CAA GTA CCT GCT CGG CAG GAA G
Mutant 4	TA TCT TAC ATG ATC CTA CAA GTA CCT TAA CTC GCT CGG CAG GAA G

[ ]: Pam sequence recognized by Cas9

Start codon : ATG (underlined)

Stop codon : TAA, TAG, TGA

Figure 1

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤

A. It is highly likely that the activity of enzyme A is retained in mutant 1. [64]
突變型 1 非常可能仍保有酵素 A 活性

B. It is highly likely that the activity of enzyme A is retained in mutant 2. [65]

突變型 2 非常可能仍保有酵素 A 活性

C. It is possible that the activity of enzyme A is retained in mutant 3. 66

突變型 3 可能保有酵素 A 活性

D. It is highly likely that the activity of enzyme A is lost in mutant 4. 67

突變型 4 很可能失去酵素 A 活性

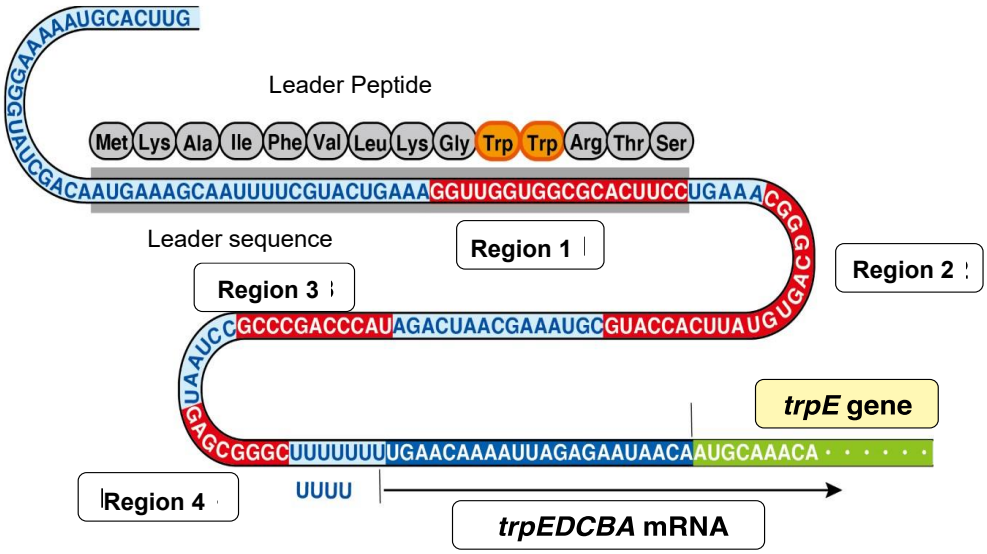
Genetics
遺傳學

Q18

The tryptophan operon (*trp* operon) of *E. coli* is transcriptionally regulated by a repressor that is activated by the binding of tryptophan. The active form repressor binds to the operator sequence located between the promoter and the transcription initiating point and blocks the RNA polymerase. There is another expression control system called the attenuator linked to transcription and translation in the *trp* operon.

大腸桿菌色胺酸操縱組的轉錄由一抑制蛋白所調控，此抑制蛋白能與色胺酸結合而被活化。活化態的抑制蛋白與位在啟動子與轉錄起始點間的操作子序列結合，而阻斷 RNA 聚合酶作用。另有一種與色胺酸操縱組轉錄及轉譯作用連結的基因表現調控系統稱為衰減子（attenuator）。

Between the operator sequence and the *trpE* gene, which is the first structural gene of the trp operon, there are four sequences of about 15 bases called Region 1-4 (Figure 1). Region 1 and Region 2, and Region 3 and Region 4 have complementary sequences, respectively. When these regions are transcribed as mRNA, they are paired with each other and form stem-loop structures (Figure 2). Furthermore, the sequences of Region 2 and Region 3 are also complementary, so a stem loop structure can be formed.



Region 1/Region 2, Region 3/Region 4; complementary 區域 1/區域 2，區域 3/區域 4；互補
Region 2/Region 3; complementary 區域 2/區域 3；互補
Leader sequence (Region 1) encodes short peptide containing two tryptophan residues (Trp)
引導序列（區域 1）編碼中包含兩個色胺酸(Trp)的短肽

Figure 1

A short peptide of 14 amino acids containing two tryptophan codons called a leader peptide is encoded in Region 1 (Figure 1).

在操作子序列與操縱組第一個基因 trpE 之間，具有 1-4 四區序列，每區約由 15 鹼基組成（Figure 1），1 區與 2 區間，及 3 區與 4 區間彼此有相互補序列，當其轉錄成 RNA 會彼此形成莖環互補結構(Figure 2)。此外 2 區與 3 區之間也有互補序列可能形成莖環構造。

If the *trp* operon mRNA is not translated at the same time as it is transcribed by RNA polymerase, Region 1 and Region 2 of mRNA, and Region 3 and Region 4 pair with each other to form stem loop structures, respectively.

在 1 區可編碼一段具有 14 個胺基酸的前導胜肽(圖 1)。如色胺酸操縱組 mRNA 被 RNA 聚合酶轉錄後沒有同時被轉譯，則 1 區與 2 區，3 區與 4 區彼此對應互補形成莖環結構。

In this case, a consecutive U bases is located immediately after Region 4. Since the form in which U bases continue immediately after the stem loop structure functions as a transcription termination signal in the procaryote, the RNA polymerase is released and the transcription is terminated（Figure 2）

在此種狀況下，會有連續的 U 鹼基緊連在 4 區之後。由於這些連續的 U 鹼基緊隨著莖環結構之後，可作為轉錄的終止訊號，於是 RNA 聚合酶釋出使轉錄終止(圖 2)

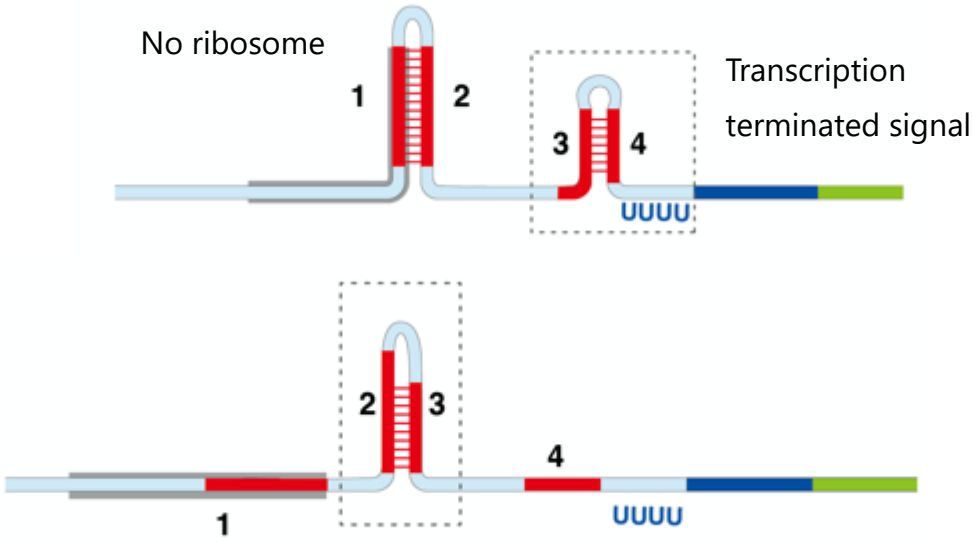


Figure 2.

When the translation of the leader sequence occurs at the same time as the transcription of the mRNA, the ribosome can translate the mRNA with the stem loop structure, but the transcription also ends by forming the stem loop structure of Region 3 and Region 4.

當 mRNA 轉錄與前導序列之轉譯同時進行，則核糖體可轉譯具有莖環結構之 mRNA，但轉錄作用則因 3 區及 4 區間形成莖環結構而終止

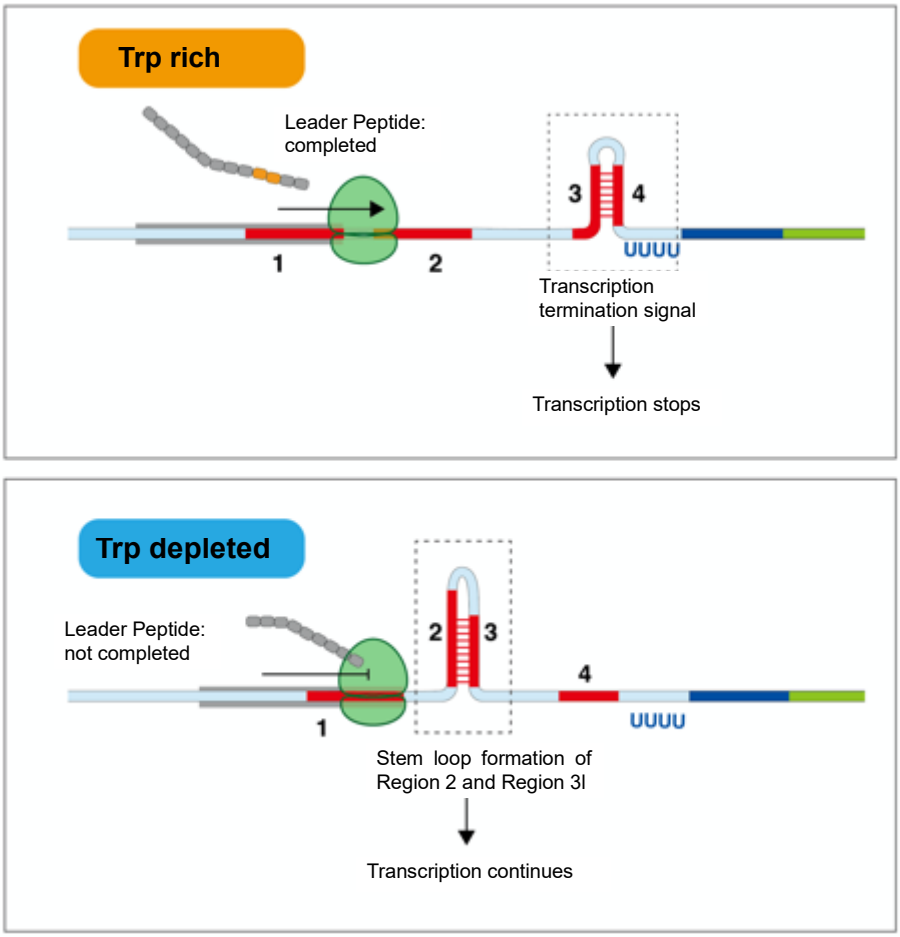


Figure 3

When tryptophan is deficient, it takes time to translate the Trp codons in the leader sequence, and the ribosome temporarily stays in Region 1. The mRNA transcribed during that time will be paired with Region 2 and Region 3 to form a stem loop structure. In this case, since Region 4 does not pair, a transcription termination signal is not formed, and RNA polymerase continues transcription of the *trpEDCBA* operon encoding the downstream Trp biosynthetic enzymes (Figure 3).

當色胺酸缺乏時，前導序列之色胺酸密碼子轉譯受阻而減緩，則核醣體暫停在 1 區，這時已轉錄出的 mRNA 在 2 區及 3 區間會形成莖環結構。在此狀況下，由於 4 區沒有互補對象，便不會形成轉錄終止訊號，故聚合酶繼續轉錄出 *trpEDCBA* 操縱組基因，以編碼色胺酸生合成酵素(圖 3)。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤

A. The transcription rate is much faster than the translation rate in the *E. coli* cell. 68

大腸桿菌細胞的轉錄作用之速率比轉譯作用速率快很多。

B. In a mutant strain of *E. coli* lacking the *trp* operator sequence, transcription-truncated mRNA is generated when tryptophan is present in the medium. 69

當培養基中具有色胺酸時，在缺乏色胺酸操縱組的大腸桿菌突變株細胞中，會轉錄出不完整的 mRNA。

C. In the mutant strain in which the tryptophan codons in the leader peptide is deleted, the growth is delayed when tryptophan is deficient in the medium. 70

當培養基中缺乏色胺酸時，前導胜肽序列中色胺酸密碼子缺損的大腸桿菌突變株，其生長會遲緩。

D. The tryptophan concentration in the cells increases in the mutant strain in which 10 tryptophan codons are present in the leader peptide. 71

在前導胜肽序列中具有 10 個色胺酸密碼子的突變株細胞中的色胺酸濃度會增加。

Animal biology
動物學

Q19
Glucagon is secreted from pancreatic A-cells and works as a signals via receptors (GLR) on the cells of target tissues. The amount of GLR expressed on cell surfaces is important in determining the magnitude of the response to glucagon in each target tissue. Figure 1 shows the amount of GLR mRNA in different rat tissues. In the data shown here, the glucagon receptor is not detected in brain tissue, but recent reports have revealed that it is present even in a very small amount, *e.g.*, in the hypothalamus.
升糖素由胰島的A細胞所分泌並透過標的組織細胞膜上的受體(GLR)來作用。 細胞膜上 GLR 受體的表現數量決定了標的組織對升糖素的反應強度。圖一顯示 GLR 在不同大鼠組織中的表現量。數據顯示，大鼠腦組織中偵測不到升糖素受體，但近期的研究結果指出部分腦組織還是可以偵測到少量 GLR，例如下視丘。

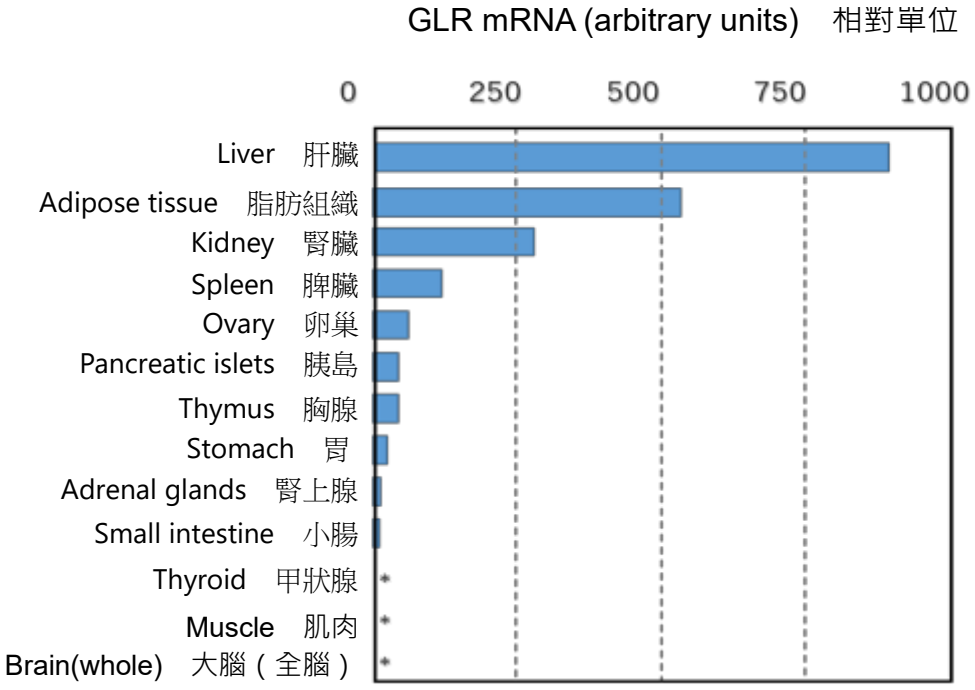


Figure 1. Relative abundance of GLR (glucagon receptor) mRNA in rat tissue. * indicates less than detectable level.
圖 1，升糖素受體(GLR) mRNA 在大鼠組織中的相對分佈量。 * 顯示低於可偵測的數值

Indicate whether the following descriptions are true or false.
指出下列的敘述是正確或是錯誤的

A. Liver expresses the largest amount of GLR because it is working as one of the major organs that uptake and storage glucose in response to glucagon. 72
因為肝臟是因應升糖素造成葡萄糖的吸收及儲存的主要器官，所以肝臟表現最大量的 GLR

B. A lack of mRNA detection in brain tissue indicates that neural tissue in the brain does not require much glucose as a nutrient. 73
實驗數據顯示腦部偵測不到 GLR 的 mRNA，顯示腦中的神經組織不需太多葡萄糖當作營養來源

C. Skeletal muscles hold stores of glucose only used in exercise. This is consistent with the absence of GLR from the results of this experiment. 74

因為骨骼肌所儲存的葡萄糖僅供運動時使用，所以與本實驗數據中骨骼肌缺乏 GLR 的結果相符合

D. Adipose tissue, which has high levels of expression of GLR, is most important energy source during starvation. 75

脂肪組織大量表現 GLR，所以飢餓時為體內葡萄糖之最重要的能量來源。

Animal biology
動物學

Q20

Metabolic substrate 代謝受質	Concentration [mM] 濃度	Output power [W] 輸出功率	Expected speed [m/s] 預期速度	Exercise duration [s] 運動持續時間
ATP	8	6400	27	2-4
CP （肌酸酐）	26	6000	25	10-17
Glycogen (肝醣)	90	1640	6.7	>6000
Fat (脂肪)	7-25	1100	4.6	

Table 1. Types of metabolic substrate and its concentration as an energy source in human muscle cells. The predicted values of output power produced by the muscle tissue, the expected speed at which the athlete ran with that power, and the duration of exercise are shown when only the respective energy sources were used. CP indicates creatine phosphate.

表一，各種用作骨骼肌能量來源的代謝受質之濃度。輸出功率為肌肉組織所產生的預期數值，預期速度指田徑選手以輸出功率奔跑之可能速度，而運動持續時間為使用相對應能量物質所能維持的時間。CP 代表肌酸酐。

Indicate whether the following descriptions are true or false. 指出下列的敘述是正確或是錯誤的

A. Athletes running a 100-meter sprint are supposed to run using ATP originally stored in muscle cells during the former half. During the last half, ATP produced by respiration is used. 76
田徑選手跑100米短跑時，前半場消耗的ATP是原來儲存在肌肉細胞中的ATP，後半場消耗的ATP則來自呼吸作用。

B. It is possible that marathon runners continue exercising using muscle tissue without ATP. 77
對馬拉松選手而言，他們可以使用沒有ATP的肌肉組織來繼續運動。

C. A crucial point for middle-distance runners of 1,500 m is switching smoothly from running with CP to that with ATP produced by aerobic breathing. 78
對1500米的中距離田徑選手而言，其關鍵所用的能量則是肌酸酐是否能有效並順利的轉換成有氧呼吸中所產生的ATP。

D. Similar to bird migration, stored fat is one of the major energy sources for long-distance runners, although it has some metabolic delay for conversion into ATP. 79
與鳥類遷徙相似，長跑選手利用原本所儲存的脂肪為主要能量來源，雖然在ATP轉換上有些許的代謝延遲

Animal biology
動物學

Q21
Huntington's disease (HD) is a genetic disorder characterized by devastating degeneration of nerve tissues that progresses with age. Huntingtin (HTT) is known to be the causative protein of HD. Near the transcriptional initiation point of **HTT** gene, there is a sequence containing repeated CAG (corresponding to glutamate), which are usually between 9 to 35 repeats in healthy individuals. These repeats are 35 to 75 in HD-population. The symptoms of HD tend to appear at a younger age and are more severe when there are an increased number of CAG repeats.
亨廷頓舞蹈症(HD)是一種遺傳疾病，其特徵是神經組織隨著年齡的增長而損傷退化。亨廷頓蛋白(HTT)是造成 HD 病變的蛋白。在 HTT 基因的轉錄起始點附近，含有一段重複的 CAG 序列(對應於麩氨酸)，正常人大概有 9-35 個重複序列，而亨廷頓舞蹈症患者大概有 35 到 75 個重複序列，重複序列的數目越多，則越早發病及症狀越嚴重。

Recently, scientists in France have revealed that HTT plays an important role in maintaining neuronal fast axonal transport (FAT, Figure 1). By careful observations with fluorescence microscopy, they first showed that HTT was co-localized with motor proteins (kinesin and dynein) that are involved in FAT. HTT was also shown to be co-localized with synaptic vesicles, as well as with glyceraldehyde-3-phosphate dehydrogenase (GAPDH). Interestingly, HTT was not found with mitochondria that were transported by FAT. Next, using cultured neurons, they investigated the effects of oligomycin, an inhibitor of ATP production in mitochondria, and iodoacetate acid, an inhibitor of GAPDH activity (Table 1). Furthermore, when HTT expression was suppressed by RNAi treatment, only the FAT of synaptic vesicles, not that of mitochondria, was significantly reduced. These results indicate that HTT was solely involved in FAT of synaptic vesicles.
近期法國的科學家發現 HTT 在維持神經元的快速軸突運輸中（FAT，圖 1）扮演著重要的角色。利用螢光顯微鏡仔細的觀察，他們首先發現 HTT 與 FAT 中的運動蛋白(驅動蛋白和動力蛋白)同時存在於細胞中。他們還發現 HTT 也和突觸小泡以及 3-磷酸甘油醛脫氫酶(GAPDH)同時存在於細胞中。 有趣的是，經由 FAT 轉運的粒線體中並未發現 HTT。接著他們培養神經細胞，利用可抑制粒線體中 ATP 生成的抑制劑寡黴素以及 GAPDH 的活性抑制劑碘乙酸的作用(表 1)。 而透過 RNAi 來處理抑制 HTT 的表現後，只有突觸小泡的 FAT(而不是粒線體的 FAT)顯著下降。 這些結果顯示 HTT 僅參與突觸小泡的 FAT。

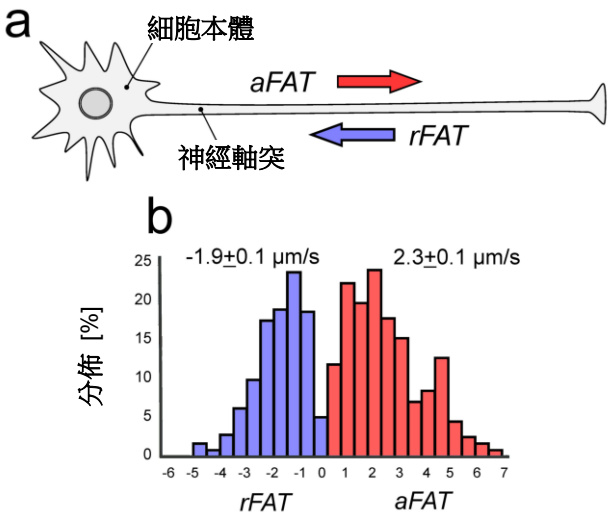


Figure 1 Fast axonal transport (FAT) in nerve cells. **a**, active transportation of synaptic vesicles and mitochondria outward to the nerve ends is called anterograde FAT (*aFAT*). Transportation in the opposite inward direction is called retrograde FAT (*rFAT*). Measured velocity and its distribution (%) is shown in **b**.

圖 1、神經細胞中的快速軸突運輸(FAT)。a. 將突觸小泡和粒線體送向神經末梢的主動轉運稱為順行性 FAT (*aFAT*)。反方向的向內運輸稱為逆行性 FAT (*rFAT*)。 測得的速度及其分佈(%)顯示於 b。

	突觸小泡			粒線體		
	控制組	寡黴素	碘乙酸	控制組	寡黴素	碘乙酸
aFAT	2.3 ± 0.1	2.2 ± 0.2	0.3 ± 0.1	0.9 ± 0.1	0.3 ± 0.1	1.0 ± 0.1
rFAT	-1.9 ± 0.1	-1.9 ± 0.2	-0.2 ± 0.1	-1.2 ± 0.1	-0.4 ± 0.2	-1.0 ± 0.1

Table 1 Effects of oligomycin and iodoacetate on the velocity [μm/s] of anterograde (*aFAT*) and retrograde (*rFAT*) transportation. In the experiments to determine FAT velocity with iodoacetate, pyruvate was included to maintain ATP production by mitochondria. Control experiments were carried out in a buffer medium without inhibitors. Under all experimental conditions, ATP/ADP ratio in axons was maintained >80%.

表 1、寡黴素和碘乙酸對順行性(aFAT)和逆行性(rFAT)轉運速度[μm/ s]的影響。 在利用碘乙酸測定 FAT 速度的實驗中，加入了丙酮酸以維持粒線體的 ATP 生成。 控制組實驗是在沒有抑制劑的緩衝液中進行。在所有的實驗條件下，軸突中的 ATP / ADP 比率均維持為 > 80%。

Indicate whether each of the following statements is true or false.

指出下列的敘述是正確或是錯誤的

A. Near the N-terminal end of HTT molecules in HD patients, there is a larger number of glutamate repeats compared to that in healthy individuals. 80

與健康個體相比，HD 患者的 HTT 分子靠近 N 端處具有較多的麩氨酸重複。

B. It is possible that HTT helps to anchor GAPDH and motor proteins to synaptic vesicles. 81

HTT 可能有助於將 GAPDH 和運動蛋白錨定在突觸小泡上。

C. ATP produced by mitochondria is not efficiently used for FAT of synaptic vesicles, even though it

can maintain a sufficiently high ATP concentration within axons. 82

粒線體生成的 ATP 即使可讓軸突內維持高濃度的 ATP，也不能有效地用於突觸小泡的 FAT。

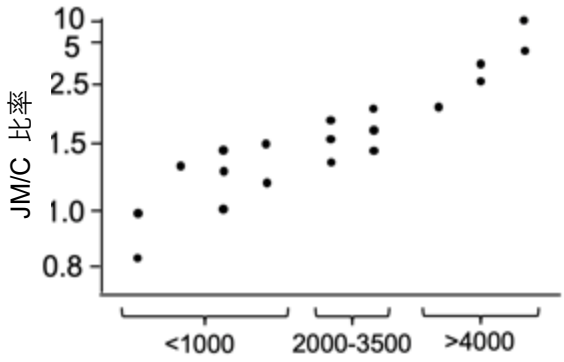
D. ATP produced by glycolysis is crucial for the FAT of mitochondria. 83

糖解作用產生的 ATP 對粒線體的 FAT 至關重要。

Animal biology
動物學

Q22
Animals living in deserts like kangaroo rats achieve the ability to sustain themselves on a limited supply of water through incredibly well adapted kidney. To remove waste without losing water, species have developed mechanisms to concentrate their urine. There are two types of nephrons that concentrate urine, a type with a short Henle loop located in the renal cortex (cortex: C) and a type with a long Henle loop located near the renal medulla (juxtamedullary: JM). The ratio of these two types of nephrons differs depending on the animal. The table shows the habitat of each animal species and the urea concentration in urine. The graph plots the juxtamedullary-cortex ratio (the number of JM type loop/the number of C type loop) in each animal species.
生活在沙漠中的動物如跳囊鼠，能在有限的水分供應下，透過高度適應的腎臟機能來維持體內水分。為了在不損失水分的情況下排除廢物，有些物種發展出濃縮尿液的機制。有兩種可濃縮尿液的腎元：一種位於腎皮質中的短 Henle 氏環(皮質 : C)，另一種位於腎髓質附近的長 Henle 氏環(近髓質 : JM)。這兩種類型腎元的比例因動物而異。 下表顯示了每種動物的棲地和尿中的尿素濃度。 該圖繪製了每種動物的近髓質-皮質比率 (JM 型環的數量/ C 型環的數量)。

Species (物種)	Habitat (棲地)	Urine concentration (尿液濃度) (mOsm/L)
Rat 大鼠	moderate 中等	2900
Domestic cat 家貓	moderate 中等	3100
Kangaroo rat 跳囊鼠	dry 乾燥	5500
Beaver 河狸	freshwater/land 淡水/陸地	520
Human 人類	moderate 中等	1400
Porpoise 鼠海豚	marine 海洋	1800
Eland 大羚羊	dry 乾燥	1880
Camel 駱駝	dry 乾燥	2800



Indicate whether each of the following statements is true or false.

指出下列的敘述是正確或是錯誤的。

A. Beavers seem not to possess the cortex type nephron. 84

河狸似乎不具有皮質型腎元

B. The JM/C ratio of the kangaroo rat is estimated at 1.5 or more. 85

跳囊鼠的 JM / C 比率估計為 1.5 或更高

C. Longer Henle loops can efficiently reabsorb salts, resulting in urine enrichment. 86

較長的 Henle 環可以有效地再吸收鹽分，使尿液更濃。

D. Animals living in dry regions have a higher proportion of cortex type nephrons than those living in freshwater. 87

居住在乾旱地區動物的皮質型腎元比率，高於居住在淡水中的動物。

Animal biology
動物學

Q23
A researcher recorded neurotransmitter responses from a neurosecretory neuron in the hypothalamus. Gamma-aminobutyric acid (GABA) is well-known as the neurotransmitter at most inhibitory synapses in the brain. The researcher found that the application of GABA to this neuron induced more action potentials (Figure 1). Then, the researcher measured GABA-induced chloride current responses of the neuron under various experimentally controlled membrane potentials (from -50 to 0 mV at 10mV steps; Figure 2). They also plotted maximum current amplitudes (current differences before and after the GABA application) against membrane potentials (Figure 3). A downward deflection of a current trace is referred to as an inward current and reflects the movement of Cl- ions out of the cell (Figure 4). Table 1 shows the intra- and extracellular concentrations and the equilibrium potentials of sodium, potassium, and chloride ions calculated by Nernst's equation.

一位研究員記錄了位於下視丘的分泌性神經元之神經傳遞素反應。 γ-氨基丁酸（GABA）是大腦中抑制性突觸的主要神經傳遞素。 該研究員發現，向該神經元投予 GABA 可引發更多的動作電位（圖 1）。然後，研究人員測量了神經元在實驗性調控的不同膜電位下，由 GABA 所引發的氯離子電流反應；(從 -50 到 0 mV，以每 10mV 逐步遞增，圖 2）。 他們還針對膜電位繪製了最大電流幅度（施加 GABA 前後的電流差)（圖 3）。 向下偏轉的電流跡線為流向胞內電流，它反映了 Cl-離子從細胞中流出（圖 4）。表 1 顯示了藉由能斯特方程計算得出的鈉，鉀和氯離子之細胞內和細胞外濃度，以及平衡電位。

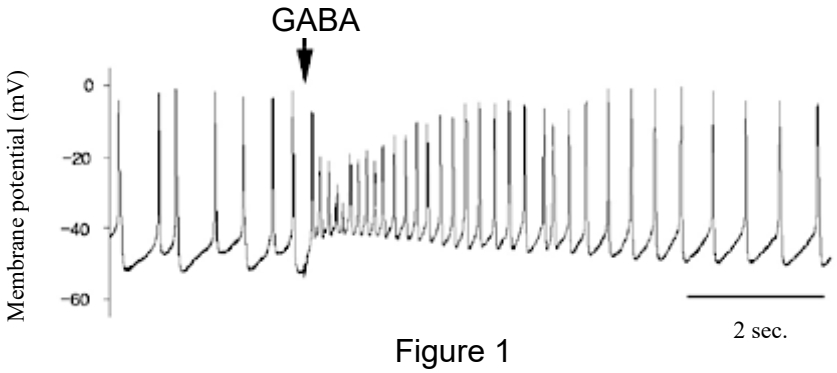


Figure 1

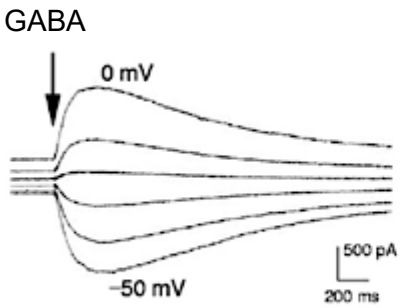


Figure 2

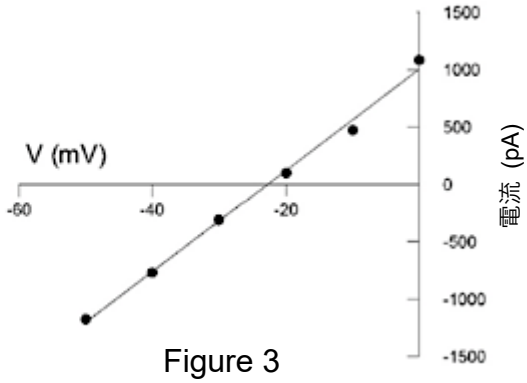


Figure 3

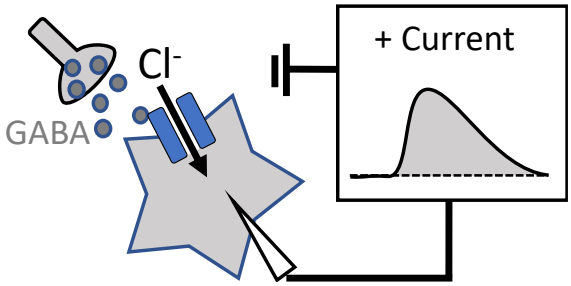


Figure 4

	濃度 (mM)		平衡電位 (mV)
	胞內	胞外	
Na^+	15	150	58
K^+	140	7	-75
Cl^-	40	120	-28

Table 1

Indicate whether each of the following statements is true or false.
指出下列的敘述是正確或是錯誤的

A. When the membrane potential was -10 mV, the application of GABA induced the depolarization of the recorded neuron. 88

當膜電位為-10 mV 時，在被記錄的神經元上投予 GABA 會引發去極化

B. The equilibrium potential of chloride ions was more positive (less negative) than the resting membrane potential of the recorded neuron. 89

氯離子的平衡電位，相較於被記錄的神經元之靜止膜電位更偏正（較為不偏負）。

C. Under the presence of tetrodotoxin (pufferfish toxin that blocks the generation of action potentials), the higher concentration of GABA depolarized the neuron more positively than 0mV. 90

在河豚毒素的存在下(河豚毒素會阻斷動作電位的產生)，較高濃度的 GABA 使神經元去極化的程度會較 0mV 更偏正。

D. The researcher recorded other neurons. The neurons hyperpolarized their membrane potentials by GABA. If the resting membrane potential of both neurons are the same, intracellular chloride ion concentration of the hyperpolarized neurons is lower than those of the neurons observed in Fig. 1~4. 91

研究人員記錄了其他神經元。 神經元的膜電位會因 GABA 而過極化。如果兩個神經元的靜止膜電位相同，則過極化神經元其細胞內氯離子濃度會低於如圖 1～4 中觀察到的神經元。

Animal biology

遺傳學

Q24

In the African clawed frog, *Xenopus laevis*, the mode of cell division shifts from cleavage to somatic cell division, which has interphase, at the 12th cleavage after fertilization. This is called the mid-blastula transition (MBT).

非洲爪蟾 *Xenopus laevis* 於受精後的第 12 次卵裂時，細胞分裂模式會從卵裂轉變為具有間期的體細胞分裂。 這稱為囊胚中期過渡(MBT)。

Microinjection of mRNA of genes that are required for nuclear membrane formation at one-cell stage results in the increase of the nuclear size, but the cell size does not change compared with a control embryo. In this experiment, MBT occurs earlier than the 12th cleavage (Figure 1, left). Conversely, when the nuclear size is artificially reduced, the cell size does not again change but MBT occurs later than the 12th cleavage (Figure 1, right). Note: These treatments do not alter the time required for each cleavage.

在單細胞階段，以顯微注射核膜形成所需基因的 mRNA 會使細胞核增大，但相對於控制組的胚胎來說細胞大小維持不變。在該實驗中，MBT 發生在第 12 次卵裂之前(圖 1，左)。 相反地，將細胞核以人工方式縮小時，細胞的大小不會再次改變，而 MBT 的發生會晚於第 12 次卵裂(圖 1，右)。 注意：這些實驗處理不會改變每次卵裂所需的時間。

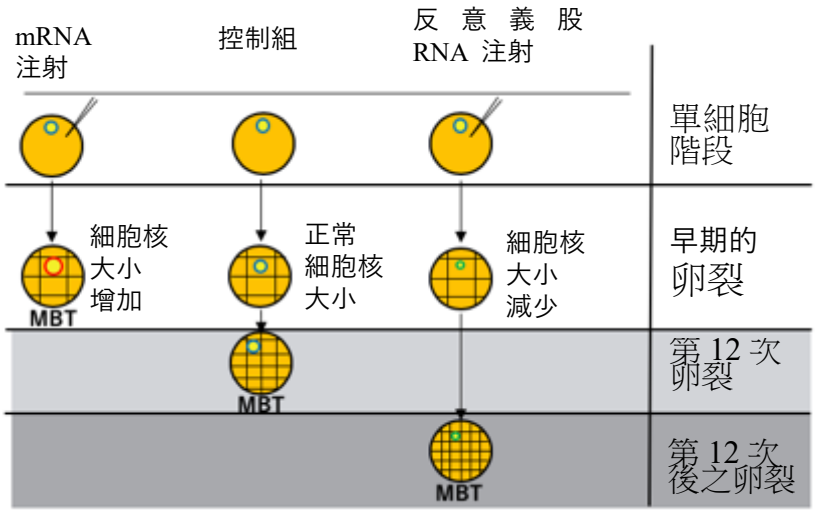


Figure 1

Indicate whether each of the following statements is true or false.

指出下列的敘述是正確或是錯誤

A. This experiment indicates that that MBT occurs when the volume ratio of nucleus/cytoplasm is high. 92

該實驗指出當細胞核/細胞質的體積比很高時，就會發生 MBT

B. When MBT occurs before the 12th cleavage stage, the duration from the fertilization to the 12th cleavage stage is reduced. 93

若 MBT 發生早於第 12 次卵裂，從受精到第 12 次卵裂的所需時間會下降

C. The timing of MBT depends on the number of divisions after fertilization. 94

MBT 的發生時間取決於受精後的分裂次數

D. These results indicate that MBT occurs when the amount of histone per nucleus is greater than a certain value (Note: No manipulations performed in this experiment affect histone). 95

這些實驗結果指出，當每個細胞核內的組蛋白量大於某定值時，就會發生 MBT(注意：本實驗中的操作不會影響到組蛋白的含量)

Animal Biology
動物學

Q25
In a *Xenopus* embryo, the dorsal-ventral axis is determined through cortical rotation after fertilization. On the dorsal side of an embryo, the Spemann-Mangold organizer is necessary to determine the body plan of the embryo. When the organizer formation is inhibited, a head defect occurs in embryos. On the other hand, the head is enlarged when the organizer region expands.
非洲爪蟾的胚胎之背腹體軸，是透過受精後的皮質轉動來確定。 在胚胎的背側，Spemann-Mangold 組織器對於胚胎身體計劃的確定是必需的。 當組織器的形成受到抑制時，胚胎會出現頭部缺損。另一方面，當組織者區域擴大時頭部會變大。

β-catenin (β-cat) and GSK3β are involved in organizer formation. The table below shows the results of phenotype of tadpoles microinjected with β-cat, GSK3β, an DN β-cat (β-catenin inhibition factor), and DN GSK3β (GSK3β inhibition factor) into the dorsal or ventral side of the embryo.
β-catenin（β-cat）和 GSK3β 參與了組織器的形成。下表顯示了於胚胎的背側或腹側用顯微注射了 β-cat，GSK3β，DNβ-cat （β-catenin 抑制因子）和 DNGSK3β（GSK3β 抑制因子）後的蝌蚪表型結果。

mRNA	Dorsal injection 背側注射	Ventral injection 腹側注射
β-cat	Large head 頭部變大	Secondary head formation 形成第二個頭部
GSK-3β	Head defect 頭部缺損	No effect 無變化
β-cat + GSK-3β	No effect 無變化	No effect 無變化
DN β-cat	Head defect 頭部缺損	No effect 無變化
DN GSK-3β	No effect 無變化	Secondary head formation 形成第二個頭部

Indicate whether each of the following statements is true or false.
指出下列的敘述是正確或是錯誤的

A. This experiment shows that GSK-3β inhibited organizer formation. 96
該實驗顯示 GSK-3β 抑制了組織器的形成

B. This experiment shows that GSK-3β inhibits β-cat activity. 97
該實驗顯示 GSK-3β 抑制了 β-cat 的活性

C. This experiment shows that β-cat is not expressed in ventral region. 98
該實驗顯示 β-cat 不會表現在腹側區域

D. This experiment shows that GSK3β works downstream of β-cat. 99
實驗顯示 GSK3β 作用在 β-cat 的下游

Animal biology

動物學

Q26

Animals possess mechanisms for maintaining their body temperature within permissible levels. For example, they show various responses to changes in room temperature. In addition, animals' body shapes are optimized to adapt to various climate changes, and their behaviors also regulate their body temperature.

動物利用多種機制來維持體溫。在可允許的範圍內，例如牠們會產生多種反應以因應室溫的改變。此外動物的身體形狀也是在不同氣候變異下所產生的最佳適應結果，動物的行為也可調解體溫

Indicate whether each of the following statements is true or false.

指出下列的敘述是正確或是錯誤的

A. In each ordinary habitat, the body temperature of endotherms is always higher than that of ectotherms. 100

一般棲地之內溫動物體溫總是高於外溫動物。

B. In humans, the body temperature is elevated when the temperature of the hypothalamus is artificially increased. 101

對人類而言，當下視丘溫度被人為升高時，體溫也會上升

C. When a female Burmese python incubates eggs, her oxygen consumption in a cold room is less than that in warm room. 102

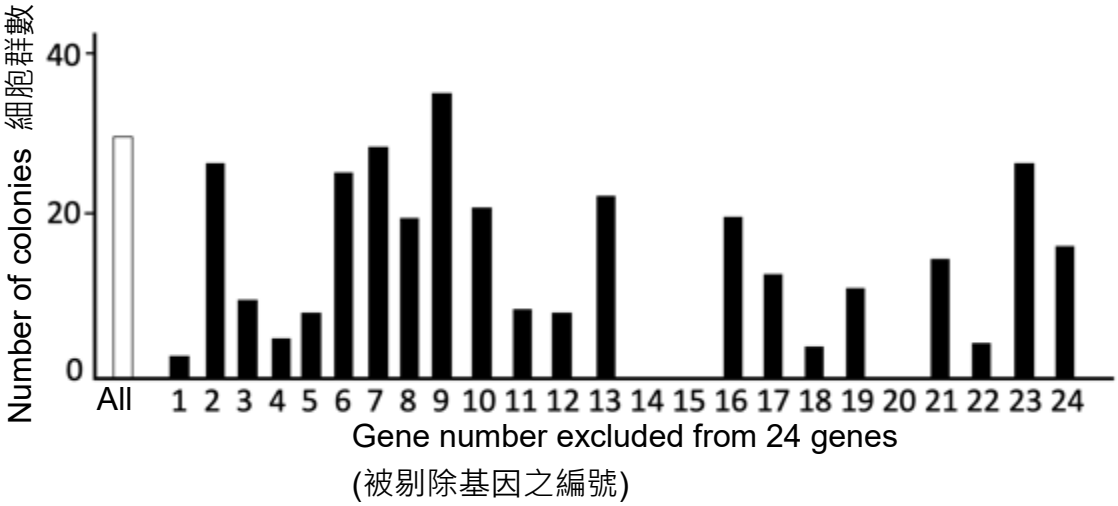
雌性緬甸蟒孵卵時，在寒冷房間的氧氣消耗量會低於在溫暖房間的消耗量

D. Ectotherms require less energy than endotherms for homeostasis. 103

相較於內溫動物，外溫動物維持恆定所需要能量較少

Animal biology
動物學

Q27
A researcher aimed to induce undifferentiated cells by expressing multiple genes in human fibroblasts. They focused on 24 genes that were identified as highly expressed in embryonic stem (ES) cells. It was found that when all 24 genes were simultaneously introduced in fibroblasts, the colony formation characteristics of undifferentiated cells occurs. Next the researchers tried to find the minimum set of genes that induce undifferentiated cells. The graph shows the colony formation when 23 genes except one were introduced into fibroblast cells.
研究者想在人類纖維母細胞當中表現多種基因以誘發細胞成為未分化的細胞。他們選定了 24 個可在胚胎幹細胞中大量表現的基因，當這 24 個基因在纖維母細胞同時表現時，可形成具有未分化細胞之特徵之細胞群。為了解哪些基因扮演決定性的角色，研究者每次單獨去除一個基因，來看具未分化細胞的特徵之細胞群之數目。 下一步這些研究者想要了解最少需要哪些基因來使細胞回到未分化狀態，下圖形顯示當剔除某一基因後，細胞群形成之結果。



("All" on the X axis shows that the 24 genes are all introduced.)
("All"代表全數 24 個基因皆被表現)

Indicate whether each of the following statements is true or false.
指出下列的敘述是正確或是錯誤的

A. These results show that colonies can be formed through the introduction of genes 14, 15, and 20 into the fibroblast together. 104
本結果顯示當纖維母細胞同時表現基因 14, 15 及 20 時，會形成細胞群

B. These results show that gene 14, gene15, and gene 20 are required for colony formation. 105
本結果顯示基因 14, 15 及 20，對於細胞群形成是必須的

C. These results show that the colony number is the highest when gene 9 is introduced into the fibroblast.
106
本結果顯示細胞表現基因 9 後所產生之細胞群數最高。

D. This experiment alone is not sufficient to find the minimum gene set needed to induce colonies. 107

本實驗成果無法證實產生細胞群所需最少基因組

E. These results show that genes 14, 15, and 20 are expressed in fibroblast cells. 108

本實驗顯示基因 14、15、20 可在纖維母細胞中表現

Animal biology

動物學

Q28

Immature lymphocyte B cells differentiate in an area of the peripheral lymph organ called the embryo center. Myeloma cells are tumor cells that produce one type of mature immunoglobulin. mRNAs for full-length or only 3 'half of the immunoglobulin light chain gene were purified from a myeloma cell and were radioisotope-labeled. Genomic DNA fragments obtained from either the embryo center or myeloma cells were digested with a restriction enzyme and size fractionated by agarose electrophoresis. These DNA were hybridized with radiolabeled mRNA, and radiation was measured after the removal of unhybridized mRNA (the experimental flow is shown in Figure 1). The results are shown in Figure 2.

未成熟的 B 淋巴球細胞在稱為胚胎中心的周圍淋巴器官中分化。骨髓瘤細胞是一種會產生成熟免疫球蛋白的腫瘤細胞。可自骨髓瘤細胞(myeloma)中純化出免疫球蛋白輕鏈基因全長或僅有 3'端的 mRNA，並進行了放射性同位素標記。用限制性內切酶切割從胚胎中心或骨髓瘤細胞獲得的基因組 DNA 片段，並通過瓊脂糖電泳將其大小分級。將這些 DNA 與放射性標記的 mRNA 雜交，並在去除未雜交的 mRNA 後測量其放射性(實驗流程如圖 1 所示)，結果如圖 2 所示。

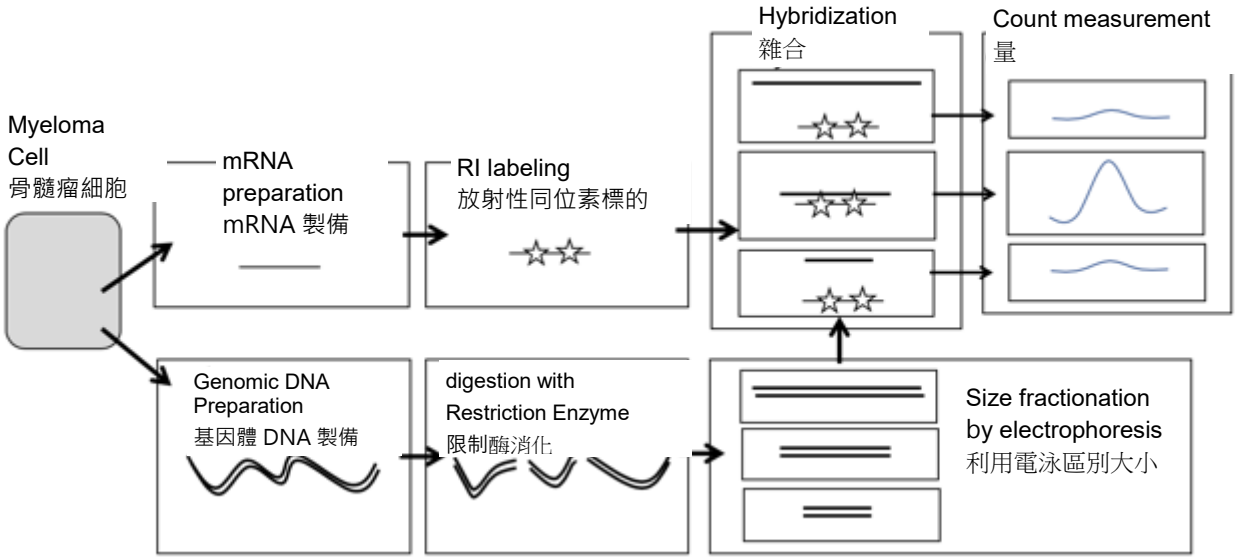


Figure 1

	DNA	mRNA
———	myeloma	Full length
- - - -	myeloma	3'end half
———	embryo	Full length
- - - -	embryo	3'end half

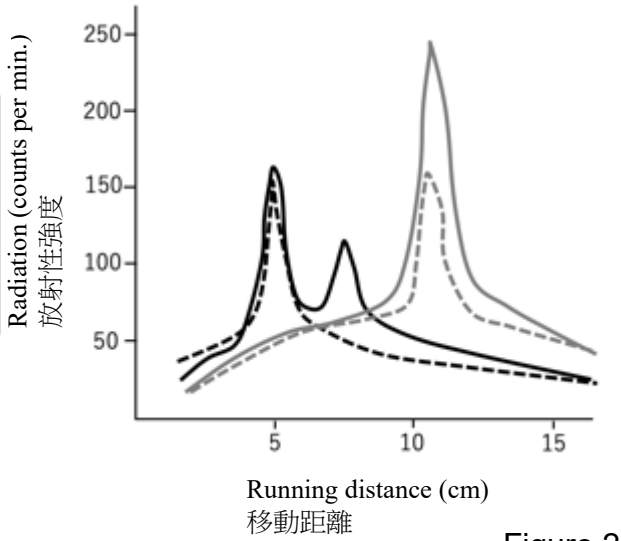


Figure 2

Indicate whether the sentences below are correct or incorrect.

指出下列的敘述是正確或是錯誤的

A. The immunoglobulin light chain gene contained in the embryo center cells is shorter than that in the myeloma cells. 109

從胚胎中心細胞所得的輕鍊免疫球蛋白基因比骨髓瘤取出的輕鍊免疫球蛋白基因短

B. The running distance depends on the length of DNA hybridized with mRNA. 110

電泳移動的距離取決於與 mRNA 雜交後的 DNA 長度

C. The nucleotide sequence of DNA region hybridized with 3'-end mRNA is different between the myeloma-derived DNA and the embryo center-derived DNA. 111

從骨髓瘤和胚胎中心取出與 3 端 mRNA 雜交的 DNA 核酸序列兩者不同

D. The full-length immunoglobulin light chain mRNA isolated from myeloma cells contains sequences from two different parts of the DNA genome of the embryo center cells. 112

從骨髓瘤分離出的輕鍊免疫球蛋白全長 mRNA 含有從胚胎中心細胞而來的兩部分基因組 DNA

Plant biology
植物學

Q29
In order to prevent an excess water loss, stomata respond rapidly to changes in humidity. Transpiration rate per unit leaf area represents the speed of water loss from the plant body. It is proportional to the diffusion rate of water vapor (d_{water}), the water vapor concentration difference across the leaf epidermis (Δw), and the relative stomatal aperture. Figure 1 shows relative stomatal apertures in normal air and in Helox air (79:21 mixture of He and O_2 with the appropriate concentrations of water vapor and CO_2 added). Relative stomatal apertures were measured in normal air (Air) and in Helox air under three different Δw conditions: the same Δw as that in normal air (Helox), 2/3 of the normal air Δw (Helox$^{2/3}$), and 1/2.33 of the normal air Δw (Helox$^{1/2.33}$). d_{water} in Helox air is 2.33 times higher than that in normal air, while Helox air does not affect any other factors of transpiration. Note that water vapor diffuses only though the stomata and that the water vapor concentration inside the leaf is always saturated.
為避免過度喪失水分，當濕度改變時，氣孔會快速反應。單位葉面積下的蒸散速率即代表從植物體喪失水分的速度。蒸散速率與水蒸氣的擴散速率(d_{water})、水蒸氣通過葉表皮的濃度差(Δw)、以及氣孔的相對大小有關。圖 1 顯示正常空氣以及氦氧氣體 (Helox；以氦氣：氧氣比例為 79:21 並加入適當濃度的水蒸氣與 CO_2 混合而成的氣體) 之下的氣孔相對大小。分別測量在正常空氣(Air)下，以及氦氧氣體在三種不同 Δw 情況之氣孔相對大小，圖中 Helox 即是其 Δw 與正常空氣情況相同；Helox$^{2/3}$ 即是其 Δw 為正常空氣情況的 2/3；Helox$^{1/2.33}$ 即是其 Δw 為正常空氣情況的 1/2.33。氦氧氣體下的 d_{water} 比在正常空氣下高出 2.33 倍，而氦氧氣體不會影響蒸散作用的任何因子。請注意水蒸氣只會從氣孔擴散，且葉內的水蒸氣濃度維持飽和狀態。

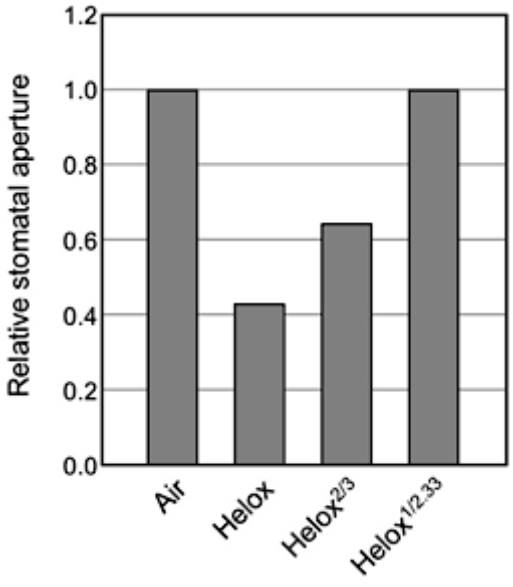


Figure 1 Relative stomatal apertures in various conditions
圖 1 不同情況下的相對氣孔大小。縱軸：相對氣孔大小

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. Stomata respond to the absolute humidity of the air. 113
氣孔是對空氣中的絕對濕度而反應。

B. Transpiration is higher in Helox air than that in normal air at the same humidity. 114
在相同的濕度下，蒸散作用在氦氧氣體下比在正常空氣下者高。

C. Stomatal response to low humidity decreases the photosynthetic assimilation rate. 115
氣孔因低濕度的反應會導致光合作用的速率降低。

D. Stomatal response to low humidity keeps the water loss constant. 116
氣孔因低濕度的反應會使水分喪失維持恆定。

Plant biology
植物學

Q30
When tomato leaves are wounded, the expression of protease inhibitor genes is induced and protease inhibitor proteins accumulate in the leaves. This response contributes to defense against insect herbivory as the protease inhibitor proteins suppress the digestive function of insects. Since this response occurs not only in damaged leaves but also in undamaged leaves, it is assumed that some mobile molecules transmit wound signals over long distances.
當番茄葉片受傷時，蛋白酶抑制因子的基因之表現會被誘導，且蛋白酶的抑制蛋白會在葉片中累積。這樣的反應可以抵抗昆蟲取食，因為蛋白酶的抑制蛋白會減低昆蟲的消化功能。由於這樣的反應不僅發生在受傷的葉片，也會發生在未受傷的葉片中，所以假設有某些可移動的分子會釋出長距離傳遞的受傷訊息。

Jasmonate and systemin, a signaling peptide composed of 18 amino acids, are involved in wound-induced expression of protease inhibitor genes. Indeed, neither systemin-insensitive mutant (*spr1*), jasmonate biosynthesis-deficient mutant (*spr2*), nor jasmonate-insensitive mutant (*jai1*) show expression of protease inhibitor genes after wounding.
茉莉酸與系統素 (其是一種由 18 個胺基酸組成的訊號胜肽) 涉及受傷所誘導的蛋白酶抑制因子基因之表現。對系統素不敏感的突變株(*spr1*)、茉莉酸生合成有缺失的突變株(*spr2*)、以及對茉莉酸不敏感的突變株(*jai1*) 確實都不會在受傷之後有蛋白酶抑制因子的基因之表現。

To investigate the roles of jasmonate and systemin in the long-distance signaling, experiments with grafts between wild-type and mutant plants were conducted. Leaves of the stock were subjected to wounding and then the expression of protease inhibitor genes were assayed, both in damaged leaves of the stock and in undamaged leaves of the scion (Figure 1). The results are summarized in Table 1.
為了探討茉莉酸與系統素在長距離訊息傳遞的角色，利用野生型和突變株間的嫁接(graft)來進行實驗。由砧木(stock)的葉片受傷與否，然後分析砧木的受傷葉片以及接穗(scion)的未受傷葉片中的蛋白酶抑制因子基因之表現，如圖 1。結果摘錄在表 1。

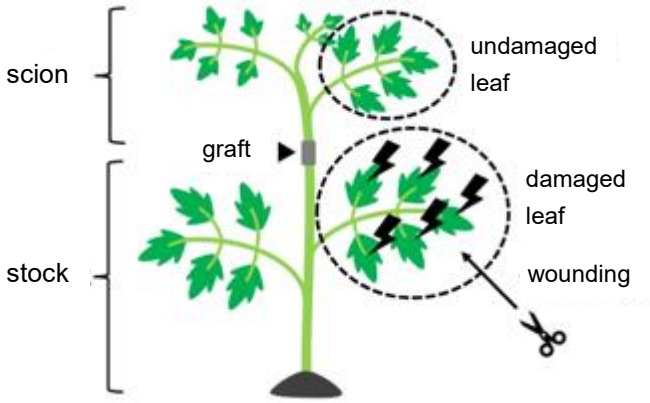


Figure 1. Schematic illustration of graft experiments

圖 1 嫁接實驗的示意圖

Table 1 表 1

Genotype 基因型		Expression of protease inhibitor genes 蛋白酶抑制因子基因之表現	
stock 砧木	scion 接穗	stock 砧木	scion 接穗
wild type	*spr1*	+	+
spr1	wild type	–	–
wild type	*spr2*	+	+
spr2	wild type	–	–
wild type	*jai1*	+	–
jai1	wild type	–	+

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. Perception of systemin in the proximity of the wound site is required for the expression of protease inhibitor genes in leaves distant from the wound site. 117

在靠近受傷處必須感知到系統素，才能使遠離受傷處的葉片中有蛋白酶抑制因子基因之表現。

B. Jasmonate synthesis required for protease inhibitor gene expression takes place in the proximity of the wound site. 118

必須有茉莉酸生合成，才會在靠近受傷處有蛋白酶抑制因子基因之表現。

C. Perception of jasmonate in the proximity of the wound site is required for the expression of protease inhibitor genes in leaves distant from the wound site. 119

在靠近受傷處必須感知到茉莉酸，才能使遠離受傷處的葉片中有蛋白酶抑制因子基因之表現。

D. Systemin is likely to be the mobile signaling molecule responsible for long-distance wound signaling. 120

系統素可能是負責長距離傳遞受傷訊息的可移動分子。

Plant biology
植物學

Q31
Strigolactone (SL) is a plant hormone that controls shoot branching. In *Arabidopsis thaliana*, several SL-related mutants, such as *max1, max2*, and *max4*, which have loss-of-function mutations in the genes *MAX1*, *MAX2*, and *MAX4*, respectively, have been isolated. While *MAX2* encodes a key component of the SL receptor complex, *MAX1* and *MAX4* each encode an enzyme for SL biosynthesis (Figure 1); *MAX4* for the production of the SL precursor carlactone (CL), and *MAX1* for the conversion of CL into SL. Grafting experiments using these mutants and the wild type (WT) were conducted, and the number of shoot branches were counted (Figure 2 & 3). In this experiment, neither mRNAs nor proteins of the *MAX* genes were found to move across the grafting junction.
獨腳金萌發素內脂 (SL)是一種控制莖分枝的植物荷爾蒙。在阿拉伯芥中，有多種與 SL 相關的突變株，被分離出來的包括 *max1, max2*, 和 *max4*，其分別在 *MAX1*, *MAX2*, 和 *MAX4* 基因處發生喪失功能的突變。其中 *MAX2* 負責 SL 受體組(SL receptor complex)的重要組成之編碼，而 *MAX1* 和 *MAX4* 分別負責 SL 生合成過程中的一種酵素之編碼 (圖 1)；*MAX4* 與產生 SL 的前驅物 carlactone (CL) 有關，*MAX1* 則與將 CL 轉換為 SL 有關。利用這些突變株和野生株(WT)進行嫁接實驗，以計算所產生的分枝數目 (圖 2 和圖 3)。實驗中，*MAX* 基因的 mRNAs 和其蛋白質都不會在嫁接交接處移動。

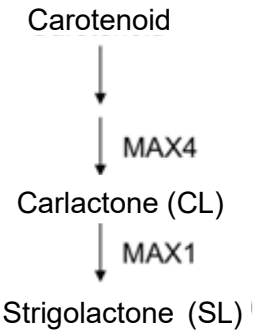


Figure 1.
Biosynthetic pathway of strigolactone

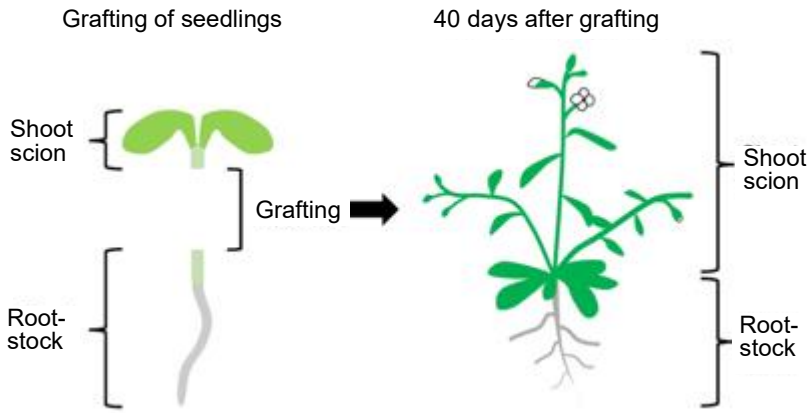


Figure 2.
Schematic illustration of grafting experiments

圖 1 獨腳金萌發素內脂的生合成過程

圖 2 嫁接實驗示意圖

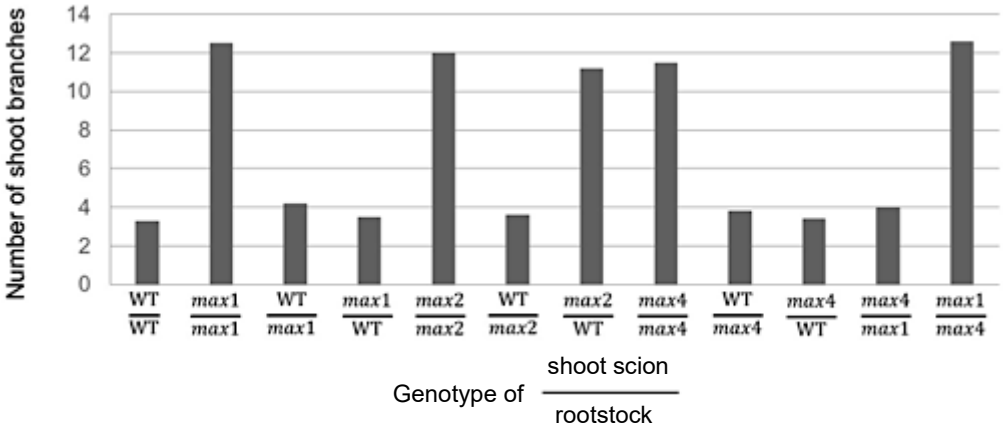


Figure 3. Number of shoot branches in the grafted plants

圖 3 嫁接植物產生的分枝數目

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. The *MAX2* gene mainly functions in the root. 121
MAX2 基因的功能主要發生在根部。

B. SL is synthesized both in the root and shoot. 122
在根和莖中，SL 皆會生成。

C. CL, the substrate of MAX1, is transported between the root and shoot in either direction. 123
CL (MAX1 的反應物)可以任一方向在根與莖間被運送。

D. If a shoot scion of *max4* is grafted on a rootstock of *max2*, shoot branching will be normal. 124
倘若 *max4* 的接穗嫁接在 *max2* 砧木上，莖的分枝將會是正常的。

Plant biology
植物學

Q32
Zinc (Zn) and iron (Fe) are both micronutrients for plants. Plants obtain Zn and Fe ions from soil through the root system, and transport them to the shoot. Plant culture media usually contains low concentrations of these micronutrients. Half-strength MS medium, a typical plant culture medium, contains 15 μM Zn^{2+} and 50 μM Fe^{2+}.
鋅(Zn)和鐵(Fe)皆是植物的微量營養素。植物藉由根系從土壤中獲得鋅和鐵離子，並運送至莖中。植物的培養基通常也添加少量的這些微量營養素。中強度的 MS 培養基(常見的植物培養基) 含有 15 μM Zn^{2+} and 50 μM Fe^{2+}.

Although micronutrients are essential for plant growth, at excess concentrations they inhibit plant growth. To examine the inhibitory effects of excess micronutrients, *Arabidopsis thaliana* plants were grown on half-strength MS media, supplemented with additional Zn^{2+} and/or Fe^{2+}.。
雖然微量營養素是植物生長所必需的，濃度過高則會抑制植物生長。為了測試微量營養素濃度過高的抑制作用，讓阿拉伯芥在添加了不同組合情況的 Zn^{2+} 和 Fe^{2+}的中強度 MS 培養基中生長。

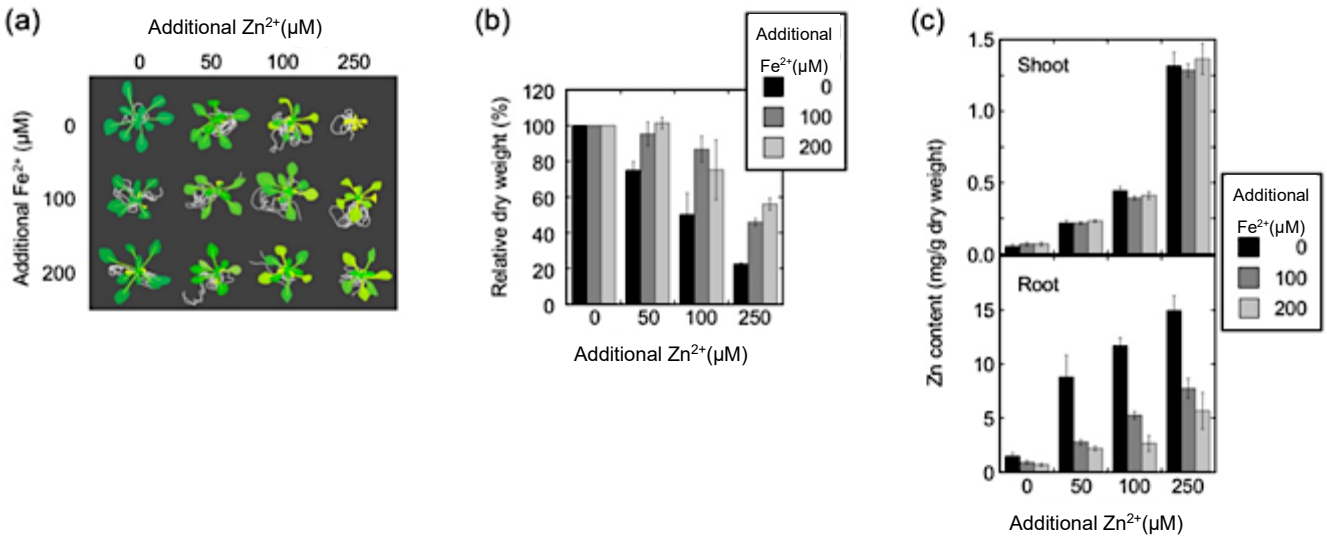


Figure 1. Effects of additional Zn and Fe ions on plant growth. Plants that had been grown on half-strength MS media, supplemented with additional Zn^{2+} and/or Fe^{2+} at the indicated concentrations, were pictured from above (**a**), measured for the dry weight of the shoot (**b**), and analyzed for the Zn contents in the shoot and root (**c**).
圖 1 添加鋅和鐵離子對植物生長的影響。(**a**) 植物在中強度 MS 培養基並添加不同 Zn^{2+} 和 Fe^{2+}濃度的生長情形(橫軸：添加 Zn^{2+}；縱軸：添加 Fe^{2+})；(**b**) 莖的乾重(橫軸：添加 Zn^{2+}；縱軸：相對乾重)；(**c**) 根與莖中的鋅含量分析(橫軸：添加 Zn^{2+}；縱軸：鋅含量)。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. Zn accumulation in the shoot shows a stronger correlation to growth defects than the correlation shown by Zn accumulation in the root. 125

莖累積在莖中，顯示其與生長缺陷的相關性比鋅累積在根中者高。

B. The growth defect caused by excess Zn^{2+} in the culture medium is mitigated by the addition of Fe^{2+}. 126

培養基中添加過量的 Zn^{2+}所造成的生長缺陷可因添加 Fe^{2+}而被減緩。

C. High concentrations of Fe^{2+} in the culture medium suppresses Zn^{2+} uptake by the root. 127

培養基中高濃度的 Fe^{2+}會抑制根中 Zn^{2+}的吸收。

D. Total Zn amount in the shoot is not affected by the addition of Fe^{2+} in the medium. 128

莖中的鋅總量不會受到培養基中添加 Fe^{2+}的影響。

Plant biology
植物學

Q33
While snapdragon normally has bilateral flowers, flowers of its mutant defective in gene ***G*** lose bilateral symmetry and have radial symmetry, thereby indicating that gene ***G*** confers bilateral symmetry to the flower.
相較於正常的金魚草具有兩側對稱的花，基因 ***G*** 缺陷的突變株則喪失兩側對稱而轉為輻射對稱，因此顯示基因 ***G*** 導致花呈現兩側對稱。

In the inflorescence of wild-type sunflower, the outer region has ligulate florets, whereas the inner region has tubular florets (Figure 1). Variants ***x***, ***y***, and ***z*** of sunflower have DNA insertions in gene ***G'***, a sunflower orthologue of the gene ***G*** from snapdragon (Figure 2). As a result of these insertions, variant ***x*** has only ligulate florets over the entire inflorescence, and variants ***y*** and ***z*** have only tubular florets over the entire inflorescence.
野生型的向日葵花序中，外圍有舌狀花、中間有管狀花(圖 1)。將某段 DNA 序列 插入向日葵的基因 ***G'*** (為金魚草 ***G*** 的同源基因)中，形成 ***x***, ***y***, and ***z*** 三個變種(圖 2)，這些插入的結果，***x*** 變種的整個花序只有舌狀花，***y*** 和 ***z*** 變種的整個花序則只有管狀花。

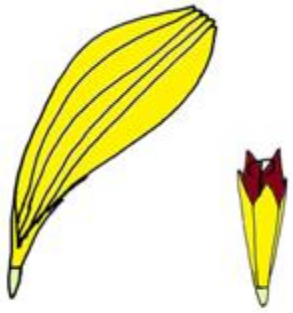


Figure 1 Ligulate and tubular florets of sunflower
圖 1 向日葵的舌狀花和管狀花。

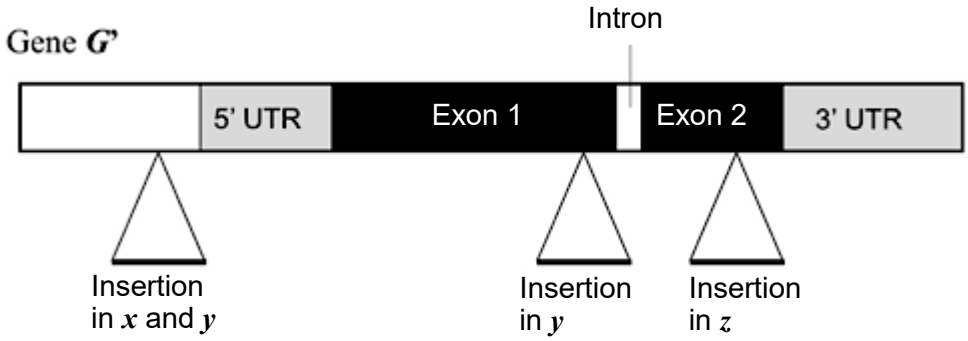


Figure 2 DNA insertions in gene ***G'*** in the sunflower variants
Variant ***y*** has two DNA insertions, while variants ***x*** and ***z*** have one insertion.
圖 2 向日葵變種中，基因 ***G'***的 DNA 插入情形。變種 ***y*** 有兩個 DNA 插入，而變種 ***x*** 和 ***z*** 則有一個插入。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. In the wild-type sunflower, gene ***G'*** is not expressed in the florets that form early during inflorescence development, but is expressed in the florets that form later. 129

在野生型向日葵花序發育的早期所形成的小花中，基因 ***G'***沒有被表現，但在後期形成者則有。

B. In variant ***x***, expression of gene ***G'*** is decreased due to the DNA insertion. 130

在變種 ***x*** 中，基因 ***G'***的表現量因 DNA 插入而減少。

C. Variant ***y*** is a loss-of-function mutant of gene ***G'***. 131

變種 ***y*** 是基因 ***G'***喪失功能的突變株。

D. Variant ***y*** is more closely related to variant ***x*** than to variant ***z*** in the lineage of sunflower variants. 132

向日葵變種的族系關係中，變種 ***y*** 與變種 ***x*** 的親緣比與變種 ***z*** 者較近。

Plant biology
植物學

Q34
Fragaria chiloensis is a stolon*-bearing perennial herb that grows on coastal sand dunes. In coastal sand dunes, nitrogen-fixing shrubs often create small patches of lower photon flux density (PFD) but higher soil nitrogen availability. The presence of such patches frequently makes a difference in the resource availability between stolon-connected ramets**. To examine effects of stolon connection, researchers compared the growth of connected ramets and severed ramets; one ramet in each pair was provided with high PFD but a low level of soil nitrogen, and the other ramet was provided with low PFD but a high level of soil nitrogen (Figure 1). As a result, combined dry biomass of connected ramets was 54% higher than that of severed ramets.
草莓屬植物(*Fragaria chiloensis*)是一種具走莖*的多年生草本植物，生長在海邊沙丘上。海邊沙丘中，具固氮功能的灌木通常會形成一些小區塊，其具有較低的光子通量密度(photon flux density , PFD)，但具有較高的土壤氮素之可用量。此類區塊的存在會頻繁地對走莖相連的兩個分株**間之資源可用性造成改變。為了測試走莖連結的影響，研究人員比較相連分株以及切斷連結後的生長情形；其中一個分株給予高 PFD 但低含量的土壤氮素，而另一個分株給予低 PFD 但高含量的土壤氮素(圖 1)。結果顯示：相連分株的總乾重比切斷連結者高出 54%。

*Stolon: a stem that grows along the soil surface and forms buds and roots at the nodes for clonal propagation.
走莖：沿著土壤表面生長的莖，並在莖節處形成芽和根，以利無性繁殖。
**Ramet: an individual unit of a clonal colony.
分株：在一無性繁殖群落的單一個體。

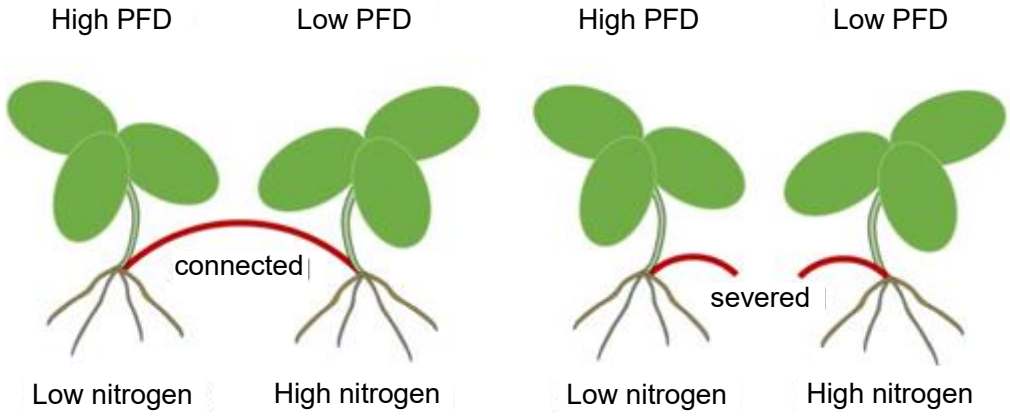


Figure 1 Schematic cartoon of experimental setup
圖 1 實驗設置的示意圖

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. Shoot/root ratio of the connected ramet provided with high PFD and low nitrogen was higher than that of the severed ramet provided with high PFD and low nitrogen. 133

在莖/根比值上，給予高 PFD-低土壤氮素的相連分株較低 PFD-高土壤氮素的切斷連結者高。

B. In the severed ramet provided with low PFD and high nitrogen, PFD was not a limiting factor for plant growth. 134

在給予低 PFD-高土壤氮素的切斷連結分株中，PFD 不是植物生長的限制因子。

C. Severing of stolons does not affect the combined dry mass of ramets when resources (i.e. PFD and nitrogen) are distributed uniformly. 135

當資源(如 PFD 和氮素)分布不均時，切斷連結的走莖不會影響兩分株的總乾重。

D. Assimilation products and nitrogen can be translocated via stolons in *Fragaria chiloensis*. 136

在草莓屬植物(*Fragaria chiloensis*)中，同化作用的產物和氮素可以經由走莖轉運。

Plant biology
植物學

Q35
Soil salinity (NaCl) affects the growth of plants. As the increase of osmotic pressure induced by soil salinity reduces the ability of plants to take up water and minerals, soil salinity elicits osmotic stress. Additionally, because cytosolic Na^+ interferes with the activities of metabolic enzymes, soil salinity also elicits ionic stress. Thus, NaCl elicits two primary effects on plant cells, which both trigger a signaling cascade that start with the elevation of the intracellular Ca^{2+} concentration ($[Ca^{2+}]i$). In contrast, sorbitol, a sugar alcohol often used as an osmoticum, elicits only osmotic stress because sorbitol is non-ionic. *x* and *y* are mutants of Arabidopsis isolated as defective in NaCl-induced increases in $[Ca^{2+}]i$. Figure 1 illustrated below shows the dose-dependent $[Ca^{2+}]i$ increases induced by NaCl or sorbitol in the seedlings of the wild type (WT) and mutants *x* and *y*.
土壤鹽度(NaCl)會影響植物的生長。由於土壤鹽度降低引起的滲透壓升高，會降低植物吸收水分和礦物質的能力，所以土壤鹽度導致滲透逆境。此外，因為細胞質的 Na^+會干擾代謝酵素的活性，土壤鹽度也會導致離子逆境。因此，NaCl 會對植物細胞引發兩種主要影響，此兩者會啟動一條訊息傳遞路徑，起始於細胞內 Ca^{2+}濃度($[Ca^{2+}]i$)的提升。相反地，山梨糖醇(Sobitol)(一種常作為滲透調節劑的糖醇)只會在滲透逆境時增加，因為它屬於非離子性。*x* 和 *y* 是阿拉伯芥中分離出來的兩種突變株，它們在 NaCl 誘發$[Ca^{2+}]i$ 增加的過程中有缺陷。以下圖 1 顯示在野生型以及突變株的小苗中，受劑量控制的$[Ca^{2+}]i$ 會被 NaCl 或山梨糖醇誘發而增加。

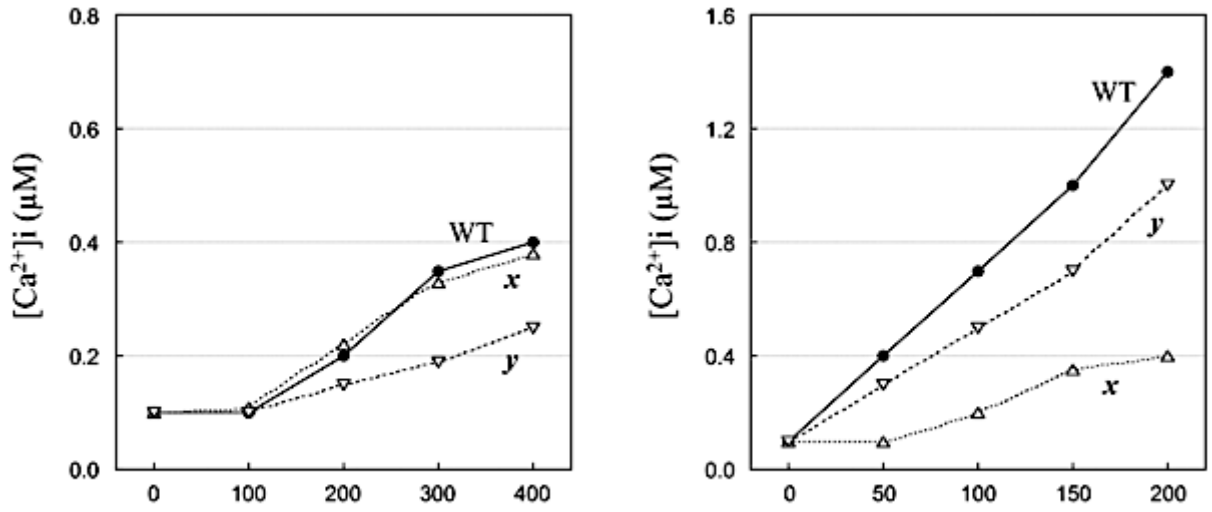


Figure 1

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. Mutant *x* is defective in sensing osmotic stress. 137
突變株 *x* 是在感受滲透逆境上有缺陷。

B. Mutant *y* can sense ionic stress. 138
突變株 *y* 能感受離子逆境。

C. The dose-dependent $[Ca^{2+}]i$ increases induced by NaCl of the *x y* double mutant are expected to be equivalent to those of the *x* single mutant. 139
在 *x y* 雙突變株中，受劑量控制的$[Ca^{2+}]i$ 會被 NaCl 誘發而增加的情況，與其在 *x* 單突變株者大致相同。

D. The dose-dependent $[Ca^{2+}]i$ increases induced by sorbitol of the *x y* double mutant are expected to be equivalent to those of the *y* single mutant. 140
在 *x y* 雙突變株中，受劑量控制的$[Ca^{2+}]i$ 會被山梨糖醇誘發而增加的情況，與其在 *y* 單突變株者大致相同。

Evolution

演化生物學

Q36

Following is a description regarding a population of a diploid organism, species A, with a special focus on the locus *C* that is involved in body color.

下列是一個雙倍體生物(物種 A)針對其體色之基因座 *C* 的相關描述。

Based on the given information, indicate whether each of the following statement is true or false.

根據所提供的資訊，指出下列各敘述是正確或錯誤。

A. Information: Species A consists of two color morphs, black and yellow, controlled by a single locus C: the allele C^B for the black type and the allele C^Y for the yellow type.
Statement: If the allele C^B is completely dominant to the allele C^Y and the frequency of the yellow type individuals is 9%, the genotype frequency of C^BC^B is about 70%. Note that the population is assumed to be under Hardy-Weinberg equilibrium. 141

背景資訊：物種 A 有兩種體色，黑和黃色，受單基因座 *C* 的控制：等位基因 C^B 控制黑色型、等位基因 C^Y 控制黃色型。

說明：倘若等位基因 C^B 對 C^Y 是完全顯性，且黃色型個體的頻率是 9%，C^BC^B 基因型的頻率則約為 70%。注意：假設此族群符合哈溫平衡定律。

B. When the body colors of ten species belonging to the same genus with species A were examined, they were all yellow.
Statement: In this case, the body color of the ancestral species A just after splitting from these closely related species must have been yellow under a parsimony principle. 142

檢視與物種 A 同屬的 10 個物種的體色，結果都是黃色。

說明：因此，根據簡約原理(parsimony principle)，剛從這些親緣相近的物種中分歧出來的物種 A 祖先，其體色應該是黃色的。

C. A small portion of individuals in the population of species A was isolated due to diastrophism (large-scale deformation of Earth's crust) and formed a new population A'.
Statement: The drastic inter-generation changes of allele frequency of locus *C* in population A' can be best explained by natural selection. 143

物種 A 族群中的一小部分個體因大規模的地殼變動(diastrophism)而形成新族群 A'。

說明：在族群 A'中，基因座 *C* 的等位基因頻率在世代之間發生急遽改變的情形，天擇可以是最好的解釋。

D. A slightly deleterious mutation with exactly the same effect on the fitness of an individual independently occurred in both the small population A' and the larger parental population A.
Statement: The fixation probability of this mutation is the same in both populations. 144

在小的族群 A'以及較大的母族群 A 中，有一個輕微有害的突變，分別獨立地發生在兩族群的一個個體上，且對其適應性具有相同的作用。

說明：此突變在兩族群的固定下來的機率相同。

Evolution
演化生物學

Q37
The following figure is a phylogenetic tree of *ECP* and *EDN* genes in primates. EDN shows strong ribonuclease activity. By contrast, ECP shows strong anti-bacterial function, although its ribonuclease activity is weak.
下圖是靈長類 *ECP* 和 *EDN* 基因的親緣關係樹。EDN 顯示強的核糖核酸酶活性，相反地，ECP 顯示強的抗菌功能，然而其核糖核酸酶活性較弱。

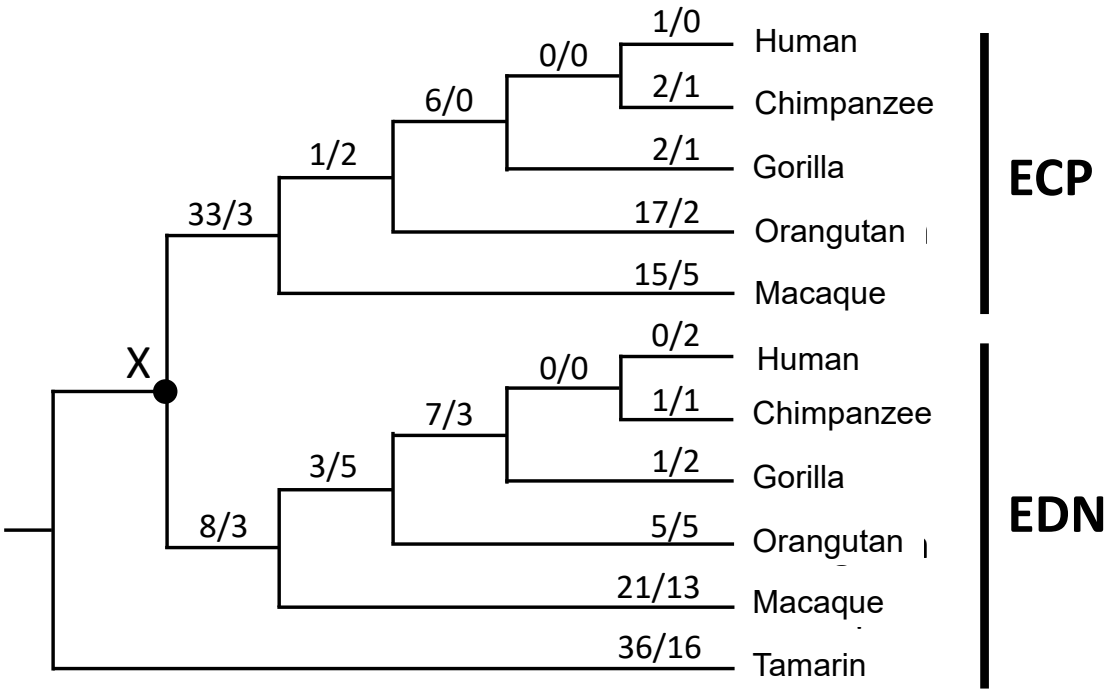


Figure 1. A molecular phylogenetic tree of *ECP* and *EDN* genes in primates based on amino-acid sequences. The numerator and denominator along each branch show the numbers of nonsynonymous and synonymous nucleotide substitutions (substitutions that cause and do not cause amino-acid changes), respectively. Branch length is not proportional to sequence divergence nor time.
圖 1 靈長類的 *ECP* 和 *EDN* 基因之親緣關係樹，其基於分析胺基酸序列而得。在每個分支上的分子和分母分別代表非同義核苷酸取代(會造成胺基酸改變)以及同義核苷酸取代(不會造成胺基酸改變)。分支長度和序列分歧與時間皆無關。

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. The most recent common ancestor of these primate species only had the *EDN* gene. 145
這些靈長類物種的最近共同祖先只有 *EDN* 基因。

B. It is likely that the Human, Chimpanzee, Gorilla, Orangutan, and Macaque independently obtained the *ECP* gene by gene duplication. 146
人類、黑猩猩(Chimpanzee)、大猩猩(Gorilla)、紅毛猩猩(Orangutan)和獼猴(Macaque)可能會個別獨立地藉由基因複製而取得 *ECP* 基因。

C. The number of synonymous substitutions in branches between common ancestor X and human *ECP* is smaller than that between X and human *EDN*. 147
共同祖先 X 和人類 *ECP* 之間的分支上，其同義取代的數目比 X 和人類 *EDN* 者小。

D. During the early evolution of the *ECP* gene, positive selection likely operated on mutations that enhance anti-bacterial activity. 148
在 *ECP* 基因的早期演化時，正選擇可能會作用在促進抗菌功能的突變上。

Evolution
演化生物學

Q38
Following is the phylogenetic tree based on the amino-acid sequences of all opsin genes in the human and zebrafish genomes.
下圖是基於在人類和斑馬魚(zebrafish)基因體的所有視蛋白(opsin)基因之胺基酸序列分析所得的親緣關係樹。

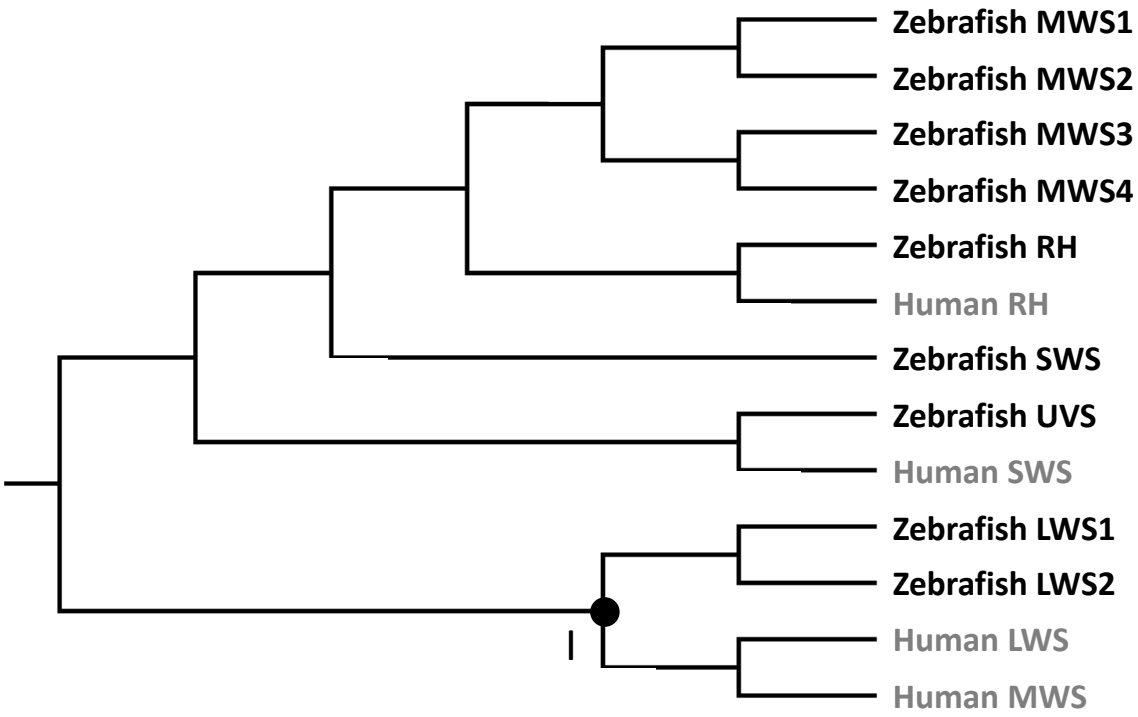


Figure 1. A phylogenetic tree based on the amino-acid sequences of all opsin genes in the human and zebrafish genomes. LWS: Long Wavelength Sensitive opsin, MWS: Middle Wavelength Sensitive opsin, SWS: Short Wavelength Sensitive opsin, UVS: Ultra Violet Sensitive opsin, RH: Rhodopsin type opsin. Branch length is not proportional to sequence divergence nor time.
圖 1 一種基於以所有視蛋白(opsin)基因之胺基酸序列分析，所得的人類和斑馬魚基因體的親緣關係樹。

圖中 LWS : 對長波敏感的視蛋白 ; MWS : 對中長波敏感的視蛋白 ; SWS : 對短波敏感的視蛋白 ; UVS : 對紫外光敏感的視蛋白；RH：視紫質型的視蛋白。分支長度和序列分歧與時間皆無關。

Indicate whether each of the following statements is true or false under a parsimony principle.
根據簡約原則，指出下列各敘述是正確或錯誤。

A. In the phylogenetic tree, zebrafish SWS is most closely related to RH. 149
在親緣關係樹中，斑馬魚 SWS 和 RH 關係最近。

B. The common ancestor of the human and zebrafish had four opsin genes in the genome. 150
在人類和斑馬魚的共同祖先之基因體中，有 4 個視蛋白基因。

C. The opsin gene at node I was supposed to encode an LWS. 151
在節 I 的視蛋白基因應該會編碼 LWS。

D. The zebrafish has acquired five opsin genes after splitting from the human. 152
斑馬魚在從人類分歧出來之後，已得到 5 個視蛋白基因。

E. The human has lost two opsin genes after splitting from the zebrafish. 153
人類在從斑馬魚分歧出來之後，已喪失 2 個視蛋白基因。

F. The common ancestor of the human and zebrafish did not have any SWS in the genome. 154
在人類和斑馬魚的共同祖先之基因體中，沒有任何 SWS。

Evolution
演化生物學

Q39

The *Peromyscus polionotus* inhabits the mainland of the Florida peninsula (Figure 1 ④) and has a dark-colored coat (Figure 1). In contrast, *P. polionotus,* inhabiting the light-colored sandy coastal dunes (Figure 1 ①-③), which are estimated to be 6,000 years old, has a lighter-colored coat (Figure 1). These mice show obvious differences in color patterns according to their habitat. The researchers compared the melanocortin 1 receptor gene (*MC1R*), a key gene for melanogenesis, and revealed the existence of two alleles, of which 65th amino acid residue is R or C, among these mice populations.
東南白足鼠(*Peromyscus polionotus*)棲息在佛羅里達半島的內陸(圖 1 ④)，且具深色毛(圖 1)。相反地，棲息在淺色海邊沙丘(圖 1①-③，估計其地質年代約有 6,000 年)的東南白足鼠則具有淺色毛(圖 1)。這些老鼠顯示出依其棲地而有毛色上的明顯差異。研究人員比較黑皮質素 1 受體基因(*MC1R*；黑色素生成的關鍵基因)，發現有兩個等位基因，在這些老鼠族群中，第 65 個胺基酸側基是 R 或 C。

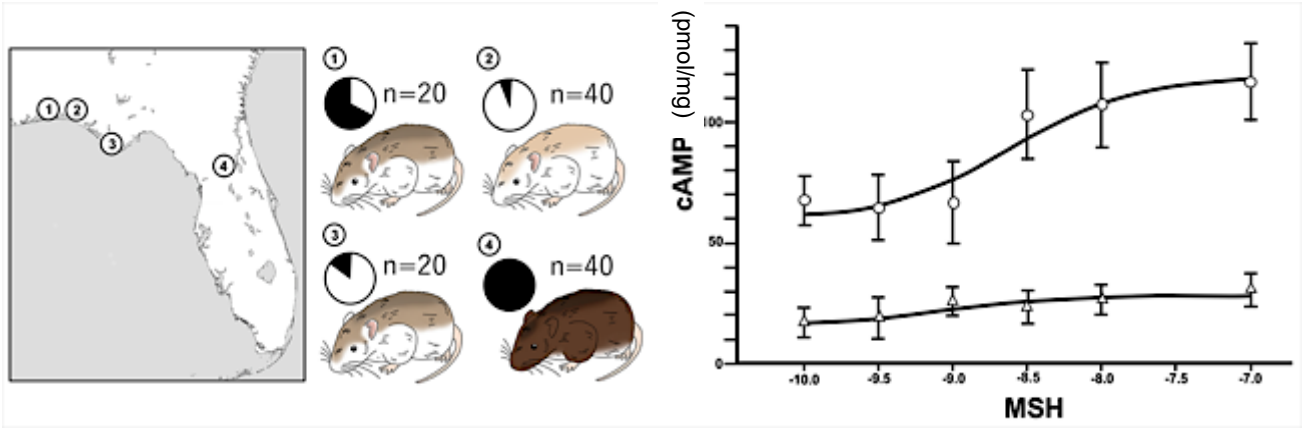


Figure 1　　Figure 2

Figure 1. (left) Four localities of habitat of *P. polionotus* in the Florida peninsula. (right) Cartoons represent the color patterns of the mice in each locality. Pie charts indicate the frequencies of the R allele (black) and C allele (white). n indicates the number of individuals surveyed.
圖 1 (左圖) 東南白足鼠在佛羅里達半島的 4 個棲地；(右圖)每個地點的老鼠毛色類型，圓形圖中顯示 R 等位基因(黑色)和 C 等位基因(白色)的頻率。n 是調查的個體數目。

Figure 2. Plot of the cAMP response to the MSH (melanocyte stimulating hormone) stimulation for MC1R expressing cultured cells. The X and Y axis indicate the concentration of the MSH and cAMP, respectively. The MC1R proteins encoded by R or C alleles were examined in this experiment.
圖 2　cAMP 對黑色素細胞刺激素(MSH)刺激培養細胞的 MC1R 表現作圖，X 和 Y 軸分別指出 MSH 和 cAMP 的濃度。本實驗檢視由 R 或 C 等位基因編碼之 MC1R 蛋白質。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. In addition to the *MC1R* gene, other genes are likely to be involved in the body color of these subspecies. 155

除了 *MC1R* 基因，其他基因可能涉及這些亞種的毛色表徵。

B. The dark color coat population is likely to have emerged from the light color coat population. 156

深色毛的族群可能是從淺色毛的族群分歧出來的。

C. It is likely that the C alleles (65th amino acid residue is C) of each population ① to ③ results from an independent mutation. 157

族群①-③中，每個族群的 C 等位基因(第 65 個胺基酸側基是 C)都是來自獨立的突變。

D. In Figure 2, the white circle and white triangle represent R and C alleles, respectively. 158

圖 2 中，白色圓圈和白色三角形分別代表 R 和 C 等位基因。

Evolution
演化生物學

Q40

Pundamilia pundamilia and *P. nyererei* are a closely related sister species pair of cichlids in Lake Victoria. These two species are distinct in male nuptial body colors, in that the former and latter are blue and red, respectively. By contrast, the females of the two species are not distinct, both possessing cryptic body coloration. *P. pundamilia* and *P. nyererei* inhabit shallow and deep environments, respectively. The light component in Lake Victoria is oriented to be blue (short wavelength) in shallow and red (long wavelength) in deep environments. The opsin proteins of the two species are shifted to the same wavelength of their habitat light components. In addition, inter-species hybridization occurs under the specific light condition, where red and blue lights cannot be distinguished.

在維多利亞湖中，*Pundamilia pundamilia* 和 *P. nyererei* 是慈鯛科中親緣關係相近的一對姊妹物種。這兩種的雄性個體之婚姻色明顯不同，前者是藍色、後者是紅色。相反地，這兩種的雌性個體則沒有明顯差別，皆屬隱藏色。*P. pundamilia* 和 *P. nyererei* 分別棲息在淺水和深水環境中。維多利亞湖的光組成，在淺水處偏藍(短波長)、在深水處偏紅(長波長)。兩物種的視蛋白會被轉移至與其棲息地的光組成相同波長者。此外，在紅和藍光不能明顯區別的特殊環境下，就會發生種間的雜交。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. The speciation of the two species is considered to have been caused by mating preference of males to females. 159

兩物種的種化是由雄性對雌性的交配偏好所造成。

B. During evolution, each of the two species is considered to have adapted their visual cues to their habitat light environment. 160

在演化期間，兩物種皆已適應其棲地環境的視覺提示。

C. The consistency between the male nuptial colorations and the light components of their habitats are explained by natural selection for camouflage. 161

雄性婚姻色與其棲地光組成之間的一致性可用偽裝色的天擇來解釋。

D. The sequences of the opsin gene differ between males and females in each species. 162

每個物種的雄性和雌性個體間的視蛋白基因之序列不同。

Evolution
演化生物學

Q41
Molecular phylogenetics is a powerful tool for inferring phylogenetic relationships among extant species. The following are methodological statements on molecular phylogenetics.
分子系統發生學是用來探討現存物種間親緣關係之強力工具。下列是有關分子系統發生學方法的敘述。

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. We must choose gene(s) with faster evolutionary rate(s) when inferring a phylogenetic tree of species with older divergence. 163
欲探討具有分歧較早的物種之間親緣關係樹，應選擇演化速率較快的基因。

B. In order to infer phylogenetic relationships between species, paralogous gene(s) that were duplicated during the evolution of the subject group should not be analyzed. 164
為了探討物種間的親緣關係，所研究類群在演化期間被複製的旁系同源基因(paralogous gene)不應被列入分析。

C. To root a phylogenetic tree with an outgroup, we should choose a species, which is as distantly related to the subject species as possible. 165
欲使用外群來找出親緣關係樹的根，應儘可能選擇與研究類群親緣較遠者。

D. Two species (sp. **X** and sp. **Y**) are described based on morphological characteristics. Here, we sequenced a gene from five individuals of each species. As a result, we found that the gene sequence of an individual of sp. **Y** is more similar to those of five individuals of sp. **X** than those of other four individuals of sp. **Y**. This result contradicts the biological species concept. 166
根據形態特徵而分出的兩個物種(sp. **X** 和 sp. **Y**)。在此，從每種 5 個個體分析某基因之序列，結果發現 sp. **Y** 的 1 個個體的基因序列和 sp. **X** 的 5 個個體，比起 sp. **Y** 的其他 4 個個體，較為相似。此結果和生物種的概念相衝突。

Evolution
演化生物學

Q42
Figure 1 shows the evolution of cetaceans. Studies using stable isotopes indicate that *Pakicetus* and *Amburocetus* ate freshwater fish, while *Remingtonocetus*, *Miacetus* and *Basirosaurus* ate seawater fish. *Indhyus* was, like most extant artiodactyls, a terrestrial herbivorous animal.
圖 1 為鯨類(Cetacea)的演化。利用穩定同位素的研究指出，巴基鯨(*Pakicetus*)和游走鯨(*Ambulocetus*)吃淡水魚，而雷明頓鯨(*Remingtonocetus*)、慈母鯨(*Maiacetus*)和龍王鯨(*Basilosaurus*)則吃鹹水魚，印原豬(*Indoyus*)，如同大部分現存的偶蹄類(artiodactyls)，是陸生的食草動物。

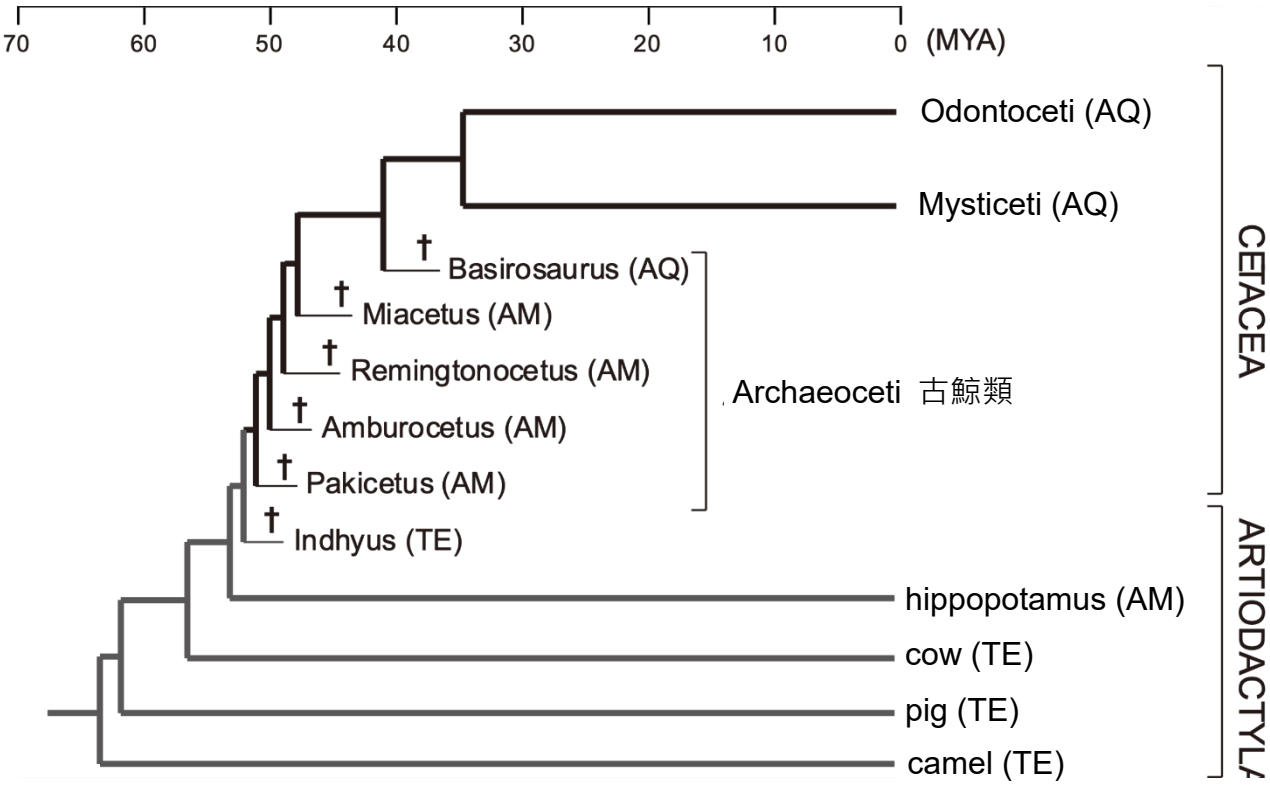


Figure 1. A phylogenetic tree of cetaceans and artiodactyls. Extinct fossil species are shown with†. All extant cetaceans are classified into two subfamilies: Mysticeti (baleen whales, which do not possess enamel-based teeth but possess baleen plates) and Odontoceti (toothed whales, which possess teeth). The lifestyle (AQ: aquatic, AM: amphibious, TE: terrestrial) of each group is also shown. Lifestyles of fossil species are inferred based on morphological characteristics. MYA: million years ago
圖 1 為鯨類和偶蹄類的親緣關係樹。已滅絕的化石物種有加 † 標示。所有現存的鯨類被分為 2 個亞科：鬚鯨 (Mysticeti；鬚鯨不具有琺瑯質牙齒，但具有鯨鬚板) 和齒鯨(Odontoceti；齒鯨具有牙齒)。圖中也顯示其生活型式 (AQ：水生；AM：兩棲；TE：陸生)，化石物種的生活型式則是根據形態特徵來推衍。MYA：百萬年前。

Judging ONLY from this phylogenetic tree, indicate whether each of the following statements is true or false.

僅根據此親緣關係樹，指出下列各敘述是正確或錯誤。

A. Under the maximum-parsimony criterion, the most recent common ancestor of the hippopotamus and modern cetaceans is amphibious. 167

依據最大簡約法原則，河馬和現生鯨類的最近共同祖先是兩棲的。

B. There were no fully-aquatic cetaceans 50 MYA. 168

在 50 MYA，還沒有完全水生的鯨類。

C. Based on these studies, the evolutionary scenario of cetaceans is speculated as follows: 1. becoming carnivorous, 2. becoming fully aquatic, 3. invasion to oceanic environments, 4. divergence into baleen whales and toothed whales. 169

根據這些研究，推測鯨類的演化情境可能如下：1.成為食肉的；2.成為完全水生的；3.侵入海洋環境棲息；4.分歧惟鬚鯨和齒鯨。

D. The *enamelin* gene, which encodes an essential protein for the formation of teeth enamel, was lost during the evolution of cetaceans before 35 MYA. 170

琺瑯質基因(*enamelin*)，其負責編碼一種與形成牙齒琺瑯質有關的重要蛋白質，早在 35 MYA 鯨類演化期間喪失了。

Evolution
演化生物學

Q43
Proteins encoded by *Hox* genes share a 60-amino-acid DNA-binding motif, the homeodomain. In the fruit fly *Drosophila melanogaster* genome, eight *Hox* genes are assembled in one cluster on the same chromosome (Figure 1A). The segmental expression pattern of *Hox* genes along the anterior-posterior axis of the fruit fly embryo shows collinearity with the gene order on the chromosome (Figure 1B). Fruit flies normally possess a pair of wings that develop from the second thoracic segment (T2) of the embryo, and a pair of balance organs (halteres) that develop from the third thoracic segment (T3). When the gene expression of *Ubx* gene is lost by mutations, T3 transform into T2 and two pairs of wings are formed. Beetles and grasshoppers have two pairs of wings although the most anterior segment of the UBX protein expression of their embryos is found in T3, the same as that of the wild fruit fly (Figure 1C).
由 *Hox* 基因所編碼的蛋白質，同樣都有一段由 60 個胺基酸所構成之 DNA 鍵結膜體(DNA-binding motif)，稱為同源異型域(homeodomain)。果蠅(*Drosophila melanogaster*)的基因體中，8 個 *Hox* 基因組成一團，接在相同染色體上(圖 1A)。*Hox* 基因在體節上的表現模式，沿著果蠅胚胎的前後軸，依照基因在染色體上的順序，以平行弧線來呈現(圖 1B)。果蠅通常具有一對從胚胎的第二胸節(T2)長出之翅膀，以及一對從第三胸節(T3)長出之平衡棍。當 *Ubx* 基因的表現因突變而喪失，T3 會轉變為 T2 而形成兩對翅膀。甲蟲和蝗蟲有兩對翅膀，雖然在其胚胎的 T3 體節中發現 UBX 蛋白表現的最前段；在野生的果蠅中也有相同情況。

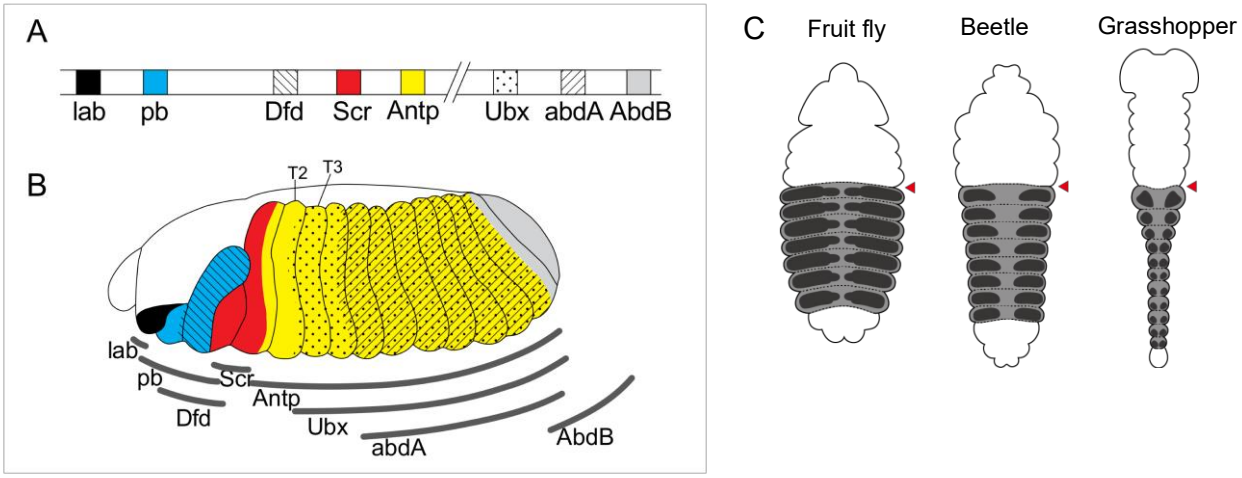


Figure 1. (A) Eight *Hox* genes on the fruit fly genome: *lab*, *pb*, *Dfd*, *Scr*, *Antp*, *Ubx*, *abd-A*, and *Abd-B*. (B) Segmental expression pattern of the *Hox* genes in the fruit fly embryo. Anterior is the left. The expression patterns for each gene are illustrated by labels that correspond to (A). Arced bars shown below indicate the range of the expression of each gene. (C) Schematic drawings for UBX protein expression in three species of embryos. Anterior is up. Red arrows indicate the boundary between T2 and T3. Area with gene expression is painted dark.
圖 1 (A)果蠅基因體上的 8 個 *Hox* 基因：*lab*, *pb*, *Dfd*, *Scr*, *Antp*, *Ubx*, *abd-A*, and *Abd-B*； (B) 果蠅胚胎中，*Hox* 基因在體節上的表現模式，圖的左側是胚胎前端。每個基因的表現模式弧線的編號與(A)相同。弧線代表每個基因的表現範圍；(C)手繪圖呈現三種昆蟲胚胎的 UBX 蛋白表現，圖的上方是胚胎前端。紅色箭頭指出 T2、T3 間的界限，深色區塊則是基因表現的區域。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. Proteins encoded by *Hox* genes act as transcription factors that regulate gene expression. 171

Hox 基因編碼的蛋白質可當作調節基因表現的轉譯因子。

B. The segmental expression pattern of the *Hox* genes determines the identities of each segment in fruit fly embryos. 172

Hox 基因在體節上的表現模式，決定在果蠅胚胎中每個體節的形成。

C. In the *Ubx* gene mutants, the extension of the *abd-A* expression to the anterior region leads to the transformation of thoracic segment. 173

在 *Ubx* 基因突變體中，*abd-A* 表現延伸至前端，導致胸節的轉型。

D. Beetles and grasshoppers have two pairs of wings because their *Ubx* genes control a different set of genes in T3 from that of fruit flies. 174

甲蟲和蝗蟲有兩對翅膀，因為牠們的 *Ubx* 基因控制在 T3 的基因組合和果蠅的不相同。

Evolution
演化生物學

Q44
Three-spined stickleback *Gasterosteus aculeatus* are widely distributed in both marine and freshwater areas across the world. Adaptive radiation has led to morphological differences between marine and freshwater populations. Of such differences, all of the marine populations have a pair of pelvic spines that evolved from the pelvic skeleton, while some freshwater populations of various localities have lost their spines (Figure 1). Genetic analyses revealed that the causative genomic region for this pelvic difference is located around the *Pitx1* gene. This *Pitx1* plays an important role in the development of the ventral spine, thymus, and neuromast. Although the amino acid sequences of *Pitx1* transcripts are identical in both populations, the expression patterns of *Pitx1* in the pelvic fin buds of embryos are different: *Pitx1* is expressed in the marine population (purple), while it is not in the freshwater population (Figure 1 insets).

三刺魚(*Gasterosteus aculeatus*)廣泛分布在全世界的海洋和淡水水域中。輻射適應導致海洋和淡水族群間的形態差異。在這些差異中，所有海洋族群有一對從骨盆(pelvic skeleton)衍生而成的骨盆刺(pelvic spines)，而不同地區的部分淡水族群則已喪失了刺(Figure 1)。遺傳分析結果顯示，造成此骨盆差異的基因體區域位在 *Pitx1* 基因周圍。此 *Pitx1* 在腹刺、胸腺和神經丘的發育上扮演重要角色。雖然在兩水域的族群中，*Pitx1* 轉譯的胺基酸序列相同，其胚胎骨盆鰭芽的表現模式則不相同：*Pitx1* 在海洋族群被表現 (紫色)，但在淡水族群則否(圖 1 的方框)。

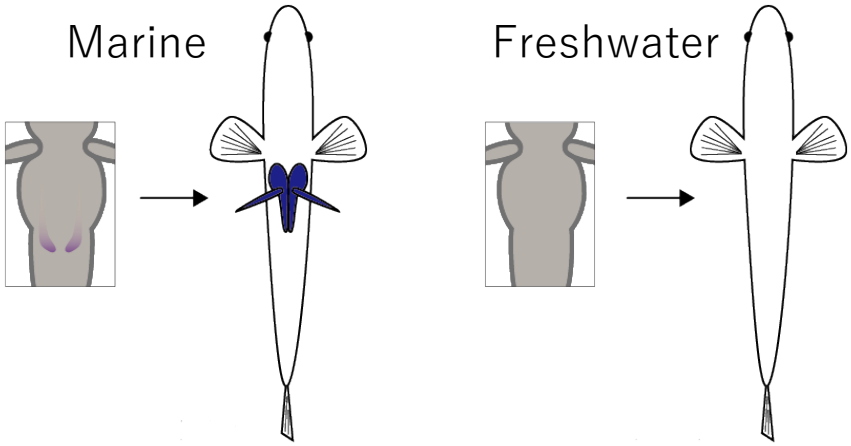


Figure 1. Ventral view of marine (left) and freshwater (right) sticklebacks, showing the presence/absence of pelvic spines (shown by dark blue). Anterior is to up. (Boxes) Magnified ventral view of stickleback embryos showing *Pitx1* expressions in the pelvic fin buds.

圖 1 海洋(左側)和淡水(右側)的三刺魚腹面，顯示其是否具有骨盆刺(深藍色)。圖上方是前端。(方框)三刺魚胚胎的腹面放大，顯示在骨盆鰭芽的 *Pitx1* 表現。

Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. The freshwater population without pelvic spines independently have likely evolved from the marine population with pelvic spines. 175

沒有骨盆刺的淡水族群，可能各自獨立地從具有骨盆刺的海洋族群演化而來。

B. Pelvic spines can function to protect the marine population against predators. 176

海洋族群中，骨盆刺可當作抵抗獵食者的防禦功能。

C. The *Pitx1*-knockout individual of the marine population are likely to show similar phenotypes to those of the freshwater population. 177

海洋族群中，*Pitx1*-剔除的個體可能會顯現出淡水族群相似的表徵。

D. The presence/absence of *Pitx1* expression in the pelvic fin buds of embryos may result from the difference of enhancer sequences that control the gene expression. 178

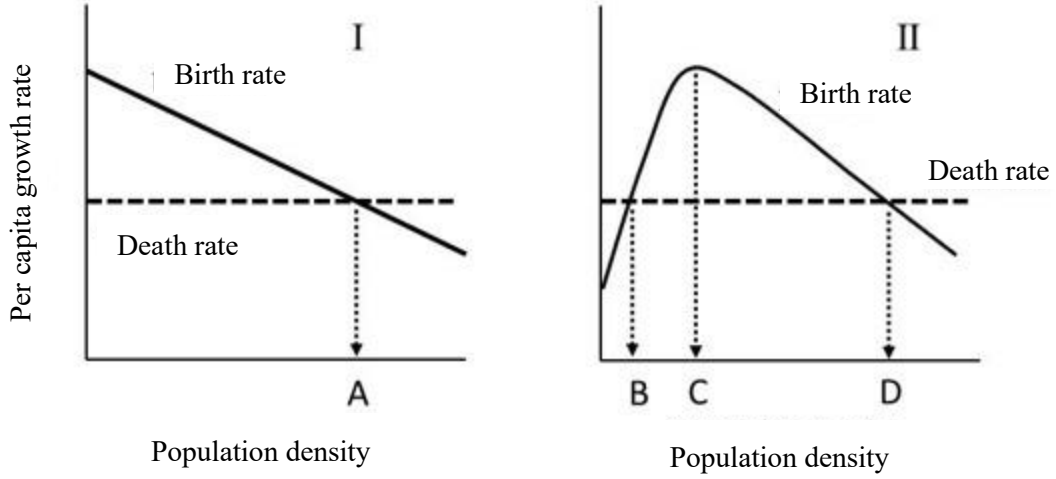
胚胎中，骨盆鰭芽的 *Pitx1* 是否表現可以是來自控制基因表現的增強子之序列差異。

Ecology
生態學

Q45
Density dependence is the fundamental process governing the population dynamics of organisms. The graph below describes per capita (per-individual) birth rate and death rate as a function of population density in two types of species (I and II).

族群的密度依存性是影響生物族群動態最基本的機制。

下圖描述兩類型物種(I and II)，平均每隻個體的出生率與死亡率與族群密度的關係。縱軸：個體平均成長率，橫軸：族群密度。



Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

1. Asexually reproducing species are more likely to be type I than sexually reproducing ones. 179

無性生殖的物種比有性生殖的物種更接近第一類型(type I)。

2. Population density is kept constant around all points of A, B, and D with a density-dependent manner.

180

在密度依存的狀況下，族群密度於 A、B、D 三點處都會維持定值。

3. The aggregation of individuals is advantageous, rather than detrimental, below the density threshold of C.

181

在族群密度閥值在 C 點以下時，個體聚集是有利的而非有害的。

4. Type I species are more likely to go extinct when the population is severely decreased, than type II species.

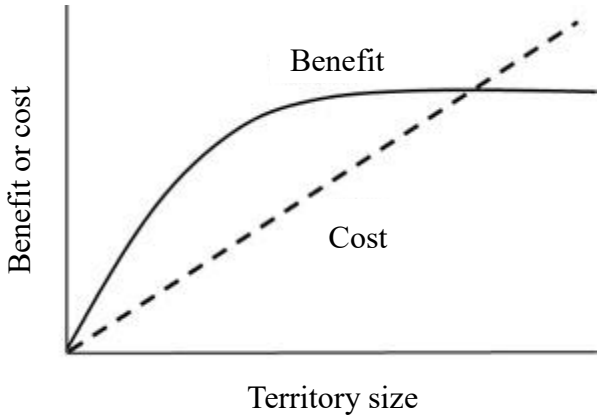
182

當族群數量大量減少時，第一類型(Type I)的物種較第二類型(type II)的物種更有可能滅絕。

Ecology
生態學

Q46
An animal's territory is an exclusive area defended by an individual to keep resources, such as food, and mates. Territory is different from home range, because home range simply represents an area over which an animal regularly moves and may overlap with those of neighboring animals of the same species. The size of the territory is determined by the cost and benefit obtained from the area, in a way that maximizes the net benefit gain of individual animals. The graph below shows how cost and benefit change with the size of the territory.
一隻動物的領域是一塊完全不允許其他個體入侵的範圍，在其內牠可以獲得資源，如食物及配偶。領域不同於家域，家域為動物經常活動的範圍，並且可能與同一物種的相鄰動物的活動範圍重疊。領域的大小取決於牠由此區域獲得的好處及代價平衡後的最大淨收益。

下圖顯示隨著領域大小的改變，其好處及代價的變化。縱軸為好處或代價、橫軸為領域大小。



Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. The benefit curve shows saturation at a large territory size due to the depletion of resources. 183
在領域範圍大時，好處曲線會出現飽和是由於資源耗損的結果。

B. The optimal territory size is the intersection point between the cost line and the benefit curve. 184
最理想的領域範圍是在代價曲線與好處曲線的交界處。

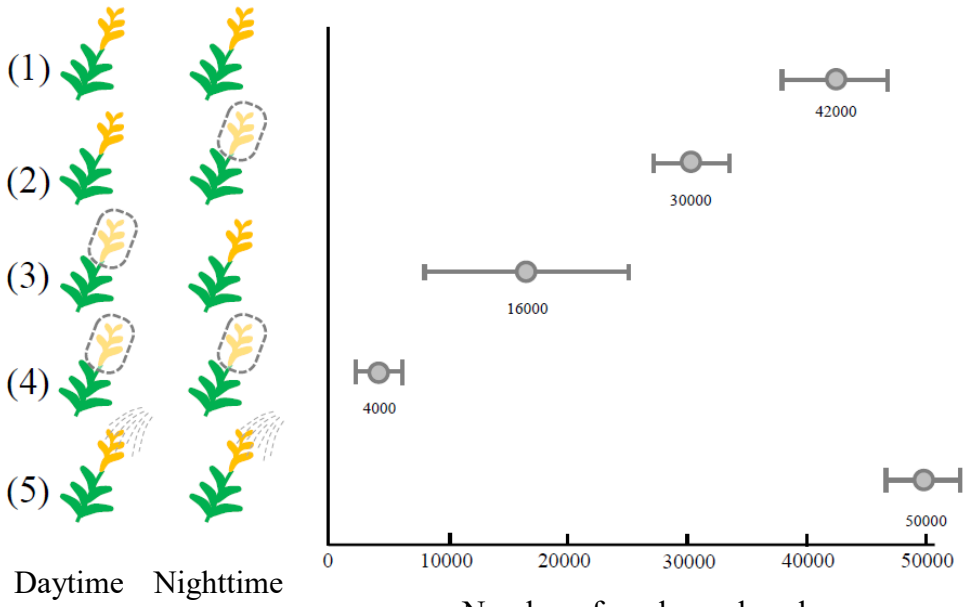
C. When resources become scarce while the cost line is unchanged, the optimal territory size becomes larger. 185
當資源變稀少而代價曲線不變，則最佳領域範圍會變大。

D. When the population density increases and intraspecific competition becomes intense, territorial behavior could disappear. 186
當族群密度增加以及種內競爭變強時，領域行為有可能會消失。

Ecology
生態學

Q47
An experiment was conducted to examine the relative effect of pollinators during the night and in the daytime on the reproductive success of golden rod flowers. Pollinators cannot visit the bagged flowers. The figure shows the number of viable seeds produced (mean ± standard deviation) by flowers that were not bagged (1), those bagged during the night (2), those bagged in the daytime (3), those bagged during both day and night (4), and those that underwent enforced pollination by an experimenter (5).

一項研究欲了解授粉者在白天與晚上對某種菊科植物的授粉成功率的影響。授粉者不能尋訪套袋的花朵。下圖顯示各實驗組的花所產生的已授粉種子數(平均±標準差)：(1)非套袋，(2)夜間套袋，(3)日間套袋，(4)日夜皆套袋，(5)以及由研究人員執行的授粉。



Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. Nighttime pollinators contribute to about 60% of the total seed production. 187
夜間授粉者貢獻整體 60%的種子生產量。

B. The flowers may be capable of self-pollination. 188
此植物的花或許可行自花授粉。

C. The contribution of daytime pollinators has a greater variability than nighttime pollinators. 189
日間授粉者的貢獻比夜間的授粉者有更大的變異性。

D. There are no limitations to pollination under natural conditions. 190
在自然的情況下，授粉沒有任何的限制。

Ecology
生態學

Q48
Mosquitos are vectors for transmitting human diseases, and the application of insecticides to water bodies is occasionally conducted to control mosquito populations. In a mosquito population, there are two alleles of a locus that affect susceptibility to pesticides, (s): susceptible, and (r): resistant. The resistance is completely recessive. The table below shows the change in the number of individuals with different genotypes before (Pre-1990), during (1990-2000; shown by an arrow), and after (2005-2015) pesticide application.

蚊子是傳染人類疾病的媒介，人偶爾會在水域環境中噴灑殺蟲劑來控制蚊子的族群。蚊子的族群中有一組等位基因會影響蚊子對殺蟲劑的耐受性，(s)為敏感型、與(r)為具抗性。具抗性的等位基因是完全隱性。下表顯示在殺蟲劑施作的前期(1990 之前)、施作期(1990~2000;箭頭指示處)、後期(2005~2015)，不同基因型個體數量的改變。

	s/s	s/r	r/r
Pre-1990	222	3	0
1990	31	12	4
1995	26	35	41
2000	2	12	126
2005	74	64	44
2010	165	45	20
2015	210	12	1

Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. No resistance allele was present before insecticide application. 191
施作殺蟲劑之前，具抗性的等位基因沒有出現。

B. During pesticide application, natural selection favored the resistance allele. 192
在殺蟲劑的施作期，天擇有利於具抗性的等位基因。

C. Resistant individuals (r/r) are likely to have lower fitness than others (s/r, s/s) in the absence of pesticide application. 193
具抗性的個體(r/r)在沒有殺蟲劑施作的情況下，與其他基因型的個體(s/r, s/s)相比，有較低的存活度。

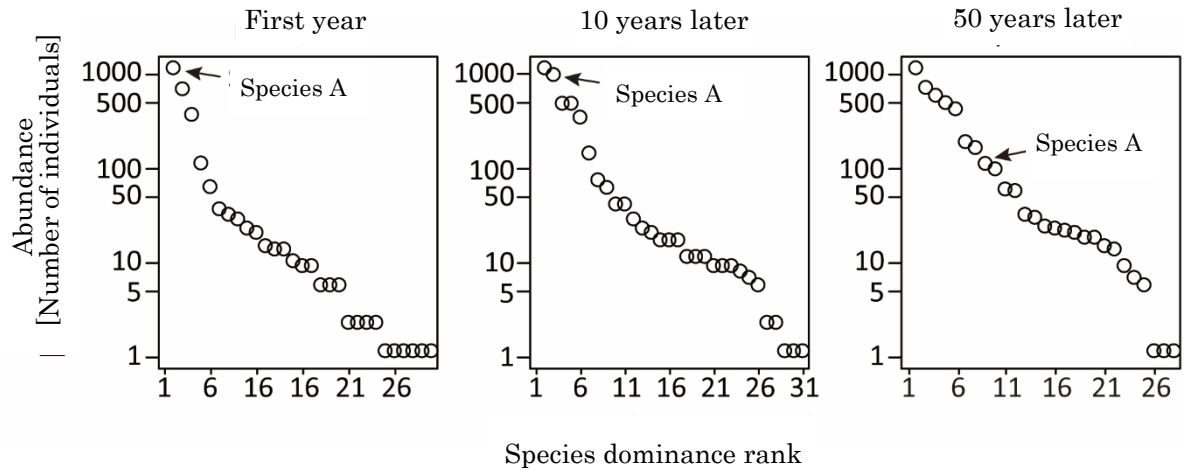
D. From 1990 to 1995, the frequency of the resistant allele increased more than 10 times. 194
從 1990 到 1995 年間，具抗性的等位基因頻率增加了十倍。

Ecology
生態學

Q49

Scientists monitored the number of individuals for ant species in a 5 hectare plot of land for 50 years. The below figures represent the dominance rank of observed species in terms of their abundance, that is, the number of individuals for each species. Each open circle represents the value for each species. Note that the most abundant species is given rank 1.

科學家在一個 5 公頃的地上監測螞蟻的數量，持續了 50 年。下圖是不同種的螞蟻，依序照其數量的相對多寡呈現的優勢序位變化圖。每個圓圈代表一種螞蟻的數量及優勢序位，數量最多的螞蟻排序在第一。縱軸：豐富度 (各物種的數量)、橫軸：物種優勢序位。



Indicate whether each of the following statements is true or false.

指出下列各敘述是正確或錯誤。

A. The total number of species does not change in the three periods observed. 195

在三個不同的觀察期間，物種數沒有改變。

B. Species A has gradually outcompeted other species over time. 196

物種 A 在此段期間，優勢排序逐漸超越一些物種。

C. The top three species account for more than 75% of the total number of individuals in the first year. 197

在第一年排名前三的物種占所有螞蟻數量的 75%以上。

D. During the 50 years, evenness among species has decreased. 198

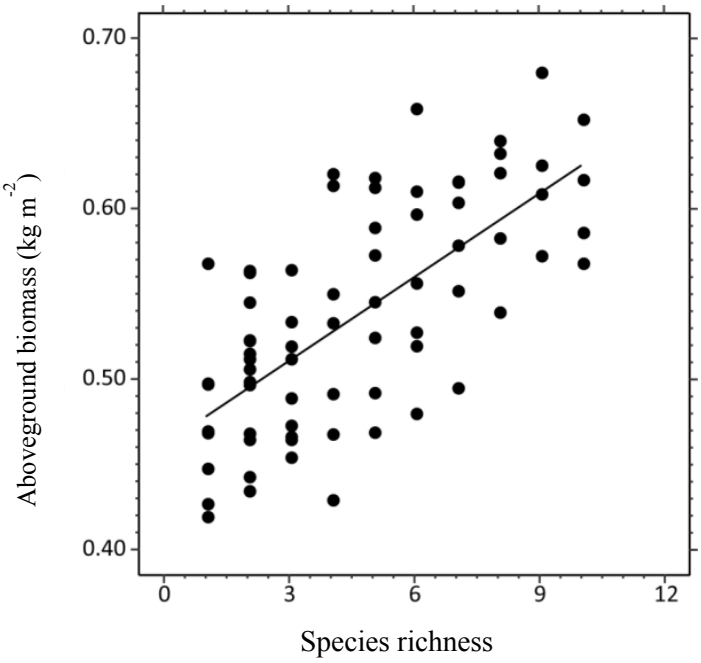
在此五十年內，物種的均勻度下降。

Ecology
生態學

Q50
Understanding how plant species richness affects community biomass production is important for biodiversity and ecosystem conservation. In a grassland, scientists created 72 experimental plots (1 m^2 each) with different numbers of vascular plant species (from 1 to 10 species), with species combinations assembled randomly. Both local light and soil conditions were similar among the plots before establishing vegetation. After three years of this experiment, they harvested aboveground vegetation to measure aboveground biomass in each plot. The figure shows the relationship between species richness (number of species) and the dry weight of aboveground biomass (kg m^{-2}) of plant communities in each plot. The line indicates the linear relationship obtained from the least square regression.

了解植物物種的豐富度如何影響群集的生物量的生產，對於生物多樣性及生態系的保育是很重要的。科學家在草原上設置了 72 個一公尺見方的實驗區，裡面種了隨機組合、不同數量種類的維管束植物(從 1~10 種)。各區的光線與土壤狀況在設置之前都是類似的。經過三年的實驗，他們收割了各區植物的地上部分，並且測量其生物量。下圖顯示各區物種豐富度(物種的數量)、與植物群集的地上乾重的生物量(kg m^{-2})之關係圖。圖中的直線指示了由最小平方迴歸獲得的線性關係。

縱軸：地上生物量、橫軸：物種豐富度。



Indicate whether each of the following statements is true or false.
指出下列各敘述是正確或錯誤。

A. Niche difference among species is one reason for producing a positive association between species richness and aboveground biomass. 199
物種間的生態棲位的差異是造成物種豐富度與地上生物量呈正相關的原因之一。

B. The plot showing the largest aboveground biomass also has the highest species richness. 200
實驗區中地上生物量最大者，其物種豐富度也最多。

C. On average, increasing aboveground biomass of 0.1 kg m^{-2} in a plot requires an additional eight species. 201

平均來說，一個實驗區中，地上生物量每增加 0.1 kg m^{-2}，要增加 8 個物種。

D. The greater chance of including more productive species in species-rich plots is one reason for producing the positive association between species richness and aboveground biomass. 202

造成物種豐富度與地上生物量之間產生正相關的原因之一，是物種數量越多的實驗區中有越大的機會包含了較具生產力的物種。