Biology Model Paper 3 2025

Essay Questions

Time Allowed: 1 hour 30 minutes

Total Marks: 60

You must bring a soft pencil (preferably type B or HB), a clean eraser, and a dark blue or black pen.

Before attempting the paper, write your name, candidate number, centre name, and centre number clearly in the designated spaces.

Instructions for Candidates

- **Section A** consists of a comprehension passage followed by questions. All questions must be attempted.
- **Section B** consists of two essay-type questions, both carrying equal marks. You should attempt only **one** question.
- You may use a simple calculator if needed.
- You should show all your working and use appropriate units.
- Do not use an erasable pen or correction fluid.
- Avoid writing over any barcodes printed on the paper.

Information for Candidates

- This paper consists of a total of **60 marks**.
- **Section A** carries a total of **30 marks**.
- **Section B** carries a total of **30 marks**.
- The number of marks for each question or part question is shown in Brackets [ ].

Please read all questions carefully and follow the instructions exactly to ensure your responses are properly evaluated.

SECTION A

Comprehension Paragraph I [20 Marks]

Respiration is a vital biological process in which organic molecules act as fuel. These molecules are broken down in a series of steps to release chemical potential energy, which is used to produce ATP—the energy currency of the cell. Glucose, a carbohydrate, is the primary respiratory substrate for most cells. While some cells rely solely on glucose, others can also metabolise fatty acids, glycerol, and amino acids to generate energy through respiration. **5**

Glucose breakdown can be divided into four stages:
glycolysis, the link reaction, the Krebs cycle and oxidative phosphorylation

Glycolysis is the splitting, or lysis, of glucose. It is a multi-step process in which a glucose molecule with six carbon atoms is eventually split into two molecules of pyruvate, each with three carbon atoms.Energy from ATP is required in the initial steps of respiration, but energy is released in the later stages, which can then be used to synthesise more ATP. Overall, there is a net gain of two ATP molecules for each glucose molecule broken down. Glycolysis occurs in the cytoplasm of the cell. In its first stage, known as phosphorylation, glucose is phosphorylated using ATP. Although glucose is energy-rich, it does not react easily. To access the bond energy of glucose, an input of energy is needed to make the reaction more feasible. **15**

Two ATP molecules are used for each molecule of glucose to make first glucose phosphate, then fructose phosphate, then fructose bisphosphate, which breaks down to produce two molecules of triose phosphate. Hydrogen is then removed from triose phosphate and transferred to the carrier molecule NAD (nicotinamide adenine dinucleotide). Two molecules of reduced NAD are produced for each molecule of glucose entering glycolysis.The hydrogens carried by reduced NAD can easily be transferred to other molecules and are used in oxidative phosphorylation to generate ATP.The end-product of glycolysis, pyruvate, still contains a great deal of chemical potential energy. When free oxygen is available, some of this energy can be released via the Krebs cycle and oxidative phosphorylation. However, the pyruvate first enters the link reaction, which takes place in the mitochondria. **25**

Pyruvate is transported actively from the cytoplasm through the outer and inner membranes of a mitochondrion into the mitochondrial matrix. In this location, it undergoes decarboxylation (removal of carbon dioxide), dehydrogenation (removal of hydrogen), and combines with coenzyme A (CoA) to form acetyl coenzyme A. This process is known as the **link reaction.** Coenzyme A is a complex molecule consisting of a nucleoside (adenine plus ribose) and a vitamin (pantothenic acid), and it functions as a carrier of acetyl groups to the Krebs cycle. The hydrogen removed from pyruvate is transferred to NAD. Fatty acids from fat metabolism may also be used to produce acetyl coenzyme A. Fatty acids are broken down in the mitochondrion in

a cycle of reactions in which each turn of the cycle shortens the fatty acid chain by a two-carbon acetyl unit.Each of these can react with coenzyme A to produce acetyl coenzyme A. **35**

The Krebs Cycle: Acetyl coenzyme A combines with a four-carbon compound (oxaloacetate) to form a six-carbon compound (citrate).The citrate is decarboxylated and dehydrogenated in a series of steps, to yield carbon dioxide, which is given off as a waste gas, and hydrogens which are accepted by the carriers NAD and FAD. Oxaloacetate is regenerated to combine with another acetyl coenzyme A. For each turn of the cycle, two carbon dioxide molecules are produced, FAD and NAD molecules are reduced, and one ATP molecule is generated via an intermediate compound. In addition to ATP Kreb's cycle produces several other products, one is regenerated oxaloacetate that keeps the cycle going. The most important contribution of the Krebs cycle to the cell's energetics is the release of hydrogens, which can be used in oxidative phosphorylation to provide energy to make ATP. **45**

Oxidative phosphorylation and the electron transport chain: In the final stage of aerobic respiration, oxidative phosphorylation, the energy for the phosphorylation of ADP to ATP comes from the activity of the electron transport chain. Oxidative phosphorylation takes place in the inner mitochondrial membrane.Reduced NAD and reduced FAD are passed to the electron transport chain. Here, the hydrogens are removed from the two hydrogen carriers and each is split into its constituent proton (H+) and electron (e−). The energetic electron is transferred to the first of a series of electron carriers. Most of the carriers are associated with membrane proteins, of which there are four types. A functional unit, called a respiratory complex, consists of one of each of these proteins, arranged in such a way that electrons can be passed from one to another down an energy gradient. **55**

As an electron moves from one carrier at a higher energy level to another one at a lower level, energy is released. Some of this energy is used to move protons from the matrix of the mitochondrion into the space between the inner and outer membranes of the mitochondrial envelope. This produces a higher concentration of protons in the intermembrane space than in the matrix, setting up a concentration gradient. Now, protons pass back into the mitochondrial matrix through protein channels in the inner membrane, moving down their concentration gradient. Associated with each channel is the enzyme ATP synthase. As the protons pass through the channel, their electrical potential energy is used to synthesise ATP in the process called

chemiosmosis. Finally, oxygen has a role to play as the final electron acceptor. In the mitochondrial matrix,an electron and a proton are transferred to oxygen, reducing it to water. **65**

Theoretically, three molecules of ATP can be produced from each molecule of reduced NAD, and two molecules from each molecule of reduced FAD. However, this maximum yield is only achievable if ADP and inorganic phosphate (Pi) are available within the mitochondrion. as these molecules are essential substrates for ATP synthesis during oxidative phosphorylation. Approximately 25% of the total energy generated during electron transfer is used to transport ADP into the mitochondrion and ATP out into the cytoplasm. As a result, each reduced NAD molecule entering the electron transport chain produces, on average, 2.5 molecules of ATP, while each reduced FAD yields about 1.5 molecules. The actual number of ATP molecules produced varies across different tissues and under different conditions, depending largely on the energy required to move substances into and out of the mitochondria. **75**

Mitochondrial structure and function: In eukaryotic organisms, the mitochondrion is the site of the Krebs cycle and the electron transport chain. Mitochondria are rod-shaped or filamentous organelles about 0.5–1.0 μm in diameter, they are not rigid, but can change their shape. The number of mitochondria in a cell depends on its activity.For example, highly active mammalian liver cells contain between 1000 and 2000 mitochondria, occupying 20% of the cell volume.The structure of a mitochondrion is more or less like a chloroplast, each mitochondrion is surrounded by an envelope of two phospholipid membranes. The outer membrane is smooth, but the inner is much folded inwards to form cristae(singular: crista). These cristae significantly increase the total surface area of the inner membrane, providing more space for the attachment of enzymes and proteins involved in the electron transport chain and ATP synthesis. **85**

Cristae in mitochondria from different types of cell show considerable variation, but, in general, mitochondria from active cells have longer, more densely packed cristae than mitochondria from less active cells.The two membranes have different compositions and properties. The outer membrane is relatively permeable to small molecules, whereas the inner membrane is less permeable.The inner membrane is studded with tiny spheres, about 9 nm in diameter, which are attached to the inner membrane by stalks. The spheres are the enzyme ATP synthase. The inner membrane is the site of the electron transport chain and contains the proteins necessary for this. The space between the two membranes of the envelope usually has a lower pH than the matrix of the mitochondrion as a result of the protons that are released into the intermembrane space by the activity of the electron transport chain. **95**

1 State the word equation for a biochemical reaction involving Co Enzyme A.
(lines 27-29)

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2 Describe the method to investigate the effect of temperature on the rate of respiration in yeast. Include all practical details.

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3 Evaluate the suitability of carbon dioxide as an indicator of respiration rate in yeast.

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4 State the net yield of ATP and NADH produced during glycolysis from one glucose molecule. (lines 16 and 20)

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……...**[3]**

5 Is glycolysis classified as an aerobic or anaerobic process? Briefly describe your answer.

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6 Calculate the total yield of reduced NAD and FAD molecules from one glucose molecule under aerobic conditions.

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7 Explain how the nucleotide linkage in NAD differs from that in a typical polynucleotide chain.

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8 Assess how the proton concentration gradient is sustained as protons are transported from the mitochondrial matrix to the intermembrane space.
(lines 57 to 60)

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Comprehension Passage II [10 Marks]

In a resting axon the potential difference across the membrane is around -70 mV This is the resting potential. When a neurone is stimulated the membrane potential changes; if a stimulus is large enough this can lead to an action potential

Action potentials can be transmitted along neurones; this is a nerve impulse.An action potential consists of several stages:

Depolarisation, Repolarisation, Hyperpolarisation, or the refractory period

Depolarisation : When a neurone is stimulated, the following process occurs:

sodium ion channels in the axon membrane open, sodium ions pass into the axon down an electrochemical gradient, the inside of the axon becomes less negative; this is depolarisation.This initial depolarisation is sometimes known as a generator potential, if the membrane potential reaches around -50 mV, voltage gated sodium ion channels open and more sodium ions enter the cell, -50 mV is known as a threshold potential,enough sodium ions enter the axon for the membrane potential to reach around +30 mV; this is an action potential.

Repolarisation:Once membrane potential reaches around +30 mV, the following sequence of events occurs:

all the voltage-gated sodium channels close, stopping any further sodium ion influx, voltage-gated potassium ion channels open, allowing the diffusion of potassium ions out of the axon, down their concentration gradient, the inside of the membrane becomes more negative.

Hyperpolarisation: The outward movement of potassium ions during repolarisation continues until the inside of the membrane becomes more negative than resting potential; this is known as hyperpolarisation.The hyperpolarised membrane is said to be in a refractory period. Eventually the voltage-gated potassium ion channels close, and the action of sodium-potassium pumps restores the membrane to resting potential.

The all-or-nothing principle

If a stimulus is too weak then threshold potential will not be reached and there will be no action potential, while a stimulus that is strong enough for threshold potential to be reached will always result in an action potential. This is the all-or-nothing principle.

The all-or-nothing principle means that action potentials are always the same size, at around +30 mV; there is no such thing as a large or small action potential.A strong, or long-lasting, stimulus will result in the generation of multiple action potentials in quick

succession; this allows the brain to distinguish between large and smaller stimuli

A stronger stimulus = a high frequency of action potentials
A weaker stimulus = a lower frequency of action potentials

<u>The refractory period:</u>

During repolarisation the voltage-gated potassium ion channels remain open for longer than needed to restore resting potential, and the axon membrane becomes hyperpolarised. The time during which the membrane is hyperpolarised is known as the refractory period The refractory period is very important as it ensures that new action potentials are generated ahead, rather than behind, the original action potential, so nerve impulses are only ever transmitted in one direction, nerve impulses are separate events, rather than merging together.

1 Evaluate the importance of the refractory period in ensuring unidirectional nerve impulse transmission.

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2 A neuron is stimulated but the membrane potential only reaches -55 mV. Predict what will happen and explain why.

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3 (a) State the typical resting potential of a neurone?

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(b) Define the term "action potential."

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(c) Name the ion responsible for depolarisation in a neurone.

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(d) What is the threshold potential required to trigger an action potential?

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SECTION B [30 Marks]

ESSAY

Write an essay on any one of the following topic:

a. **PCR in Biotechnology.**

or

b. **Evolution and Genetic Diversity.**

Note: Your essay will be marked for:

- **Its scientific accuracy,**
- **The selection of relevant materials,**
- **Your knowledge,**
- **The quality of your written communication**

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Ziauddin University Examination Board

Ziauddin University Examination

Biology **HSSC**
Model Paper 3 **2025**

Essay Questions

Mark Scheme

Maximum Marks 120

Section A Comprehension Passage [30 Marks]

Section B Essay Writing [30 Marks]

Biology Model Paper 3 – Mark Scheme 2025

Section A

Comprehension Passage [30 Marks]

Question # Passage I	Answers	Marks
1	Pyruvate + Coenzyme A + NAD^+ ⟶ Acetyl-CoA + CO_2 + NADH + H^+	2
2	**Mix yeast suspension with glucose solution in a conical flask. Seal the flask with a bung and then connect it with a respirometer or a gas syringe. Place the flask in a water bath set to a specific temperature and leave the apparatus for five minutes at that temperature so yeast suspension and glucose solution adapted to the required temperature. Measure volume of a gas produced which is CO2 after every 5 minutes at different set temperatures for example; 20^0C, 30^0 C, 40^0 C, 50^0C. Glucose concentration and volume of yeast suspension must be constant.**	4
3	**CO2 is direct by product of aerobic respiration and can be measured easily with gas syringe or respirometer.**	2
4	**In glycolysis, 2 ATP molecules are consumed, producing 4 ATP, 2 NADH, and 2 pyruvates per glucose molecule. The pyruvate**	3

	can be used in the citric acid cycle or serve as a precursor for other reactions.	
5	**Glycolysis itself is an anaerobic process as it does not require oxygen. It is the first step in cellular respiration which can occur aerobically or anaerobically. The products of glycolysis are used for aerobic respiration when oxygen present or also used in an anaerobic respiration when oxygen is absent**	**2**
6	**During glycolysis, 2 molecules of reduced NAD (NADH) are produced per glucose molecule.** **In the link reaction, 2 molecules of reduced NAD (NADH) are produced per glucose molecule.** **In the Krebs cycle, 6 molecules of reduced NAD (NADH) and 2 molecules of reduced FAD (FADH2) are produced per glucose molecule.** **Summing these, for each molecule of glucose, 10 molecules of reduced NAD (NADH) and 2 molecules of reduced FAD (FADH2) are produced.** **Each NADH molecule can produce 3 ATP molecules in oxidative phosphorylation, and each FADH2 molecule can produce 2 ATP molecules.** **Thus, 10 NADH molecules produce 10 * 3 = 30 ATP molecules, and 2 FADH2 molecules produce 2 * 2 = 4 ATP molecules.** **Summing these, 30 + 4 = 34 ATP molecules are produced in oxidative phosphorylation per glucose molecule.**	**4**
7	**In NAD two nucleotide are joined via their phosphate group** **In polynuleotide (DNA) nucleotides are linked by repeating sugar phosphate backbone**	**1**

8	**The inner membrane is impermeable to small molecules or ions due to which protons pump from mitochondrial matrix accumulate in the intermembrane space creating high concentration of protons outside the matrix. This build up of proton creates a proton concentration gradient outside the matrix.**	**2**
Question # **Passage II**	**Answers**	**Marks**
1	**no new action potential can be initiated regardless of stimulus strength, A stronger-than-normal stimulus is required to trigger another action potential, as the membrane is hyperpolarised**	**2**
2	**The threshold potential required to trigger an action potential is typically around -50 mV. At -55 mV, the stimulus is too weak to open the voltage-gated sodium ion channels.Without these channels opening, no rapid influx of sodium ions occurs, and the membrane potential does not reach +30 mV, which is the peak of an action potential.**	**4**
3 a	**The typical resting potential of a neurone is –70 millivolts (mV).**	**1**
3b	**An action potential is a rapid, temporary change in the electrical potential across a neurone's membrane that occurs when a stimulus exceeds the threshold level**	**1**
3c	**The ion responsible for depolarisation in a neurone is the sodium ion (Na^+)**	**1**
3d	**The threshold potential required to trigger an action potential is approximately –50 millivolts (mV). When the membrane potential reaches this level, voltage-gated sodium ion channels**	**1**

	open, allowing a rapid influx of sodium ions and initiating the full action potential.	

Biology Model Paper 3 – Mark Scheme 2025

Section B

Essay Writing [30 Marks]

a. PCR in Biotechnology

Polymerase Chain Reaction (PCR) is an essential technique in biotechnology that amplifies a targeted DNA segment, producing millions of copies.This powerful method allows for precise genetic analysis and is widely used in fields such as genetic engineering, medical diagnostics, and forensic investigations.

Polymerase Chain Reaction (PCR) is a widely used laboratory method for amplifying nucleic acids. It employs Taq polymerase—a heat-resistant DNA polymerase derived from *Thermus aquaticus*—to replicate DNA after the strands have been separated by heat and primers have bound to the target sequences.

This method selectively amplifies particular DNA fragments from a sample by cycling through denaturation, annealing, and extension phases. Taq polymerase is commonly used due to its heat resistance, allowing it to maintain enzymatic activity despite repeated exposure to high temperatures. PCR is widely regarded as the benchmark technique for detecting bacterial and viral infections and for identifying genetic disorders, owing to its exceptional sensitivity.

PCR begins with the extraction of a small nucleic acid sample, typically DNA or RNA, into a reaction tube. The process consists of three major phases: denaturation, annealing, and extension. During denaturation, DNA is heated to 95°C to disrupt hydrogen bonds between complementary base pairs of the double-stranded molecule. Annealing follows immediately, cooling the denatured DNA to a temperature typically ranging from 55°C to 72°C, allowing primers to bind to their complementary sequences. Annealing is most effective at 55°C to 72°C.

The optimal annealing temperature depends on the physical and chemical properties of the primers in solution. Primers are typically 20 to 25 nucleotides long. During annealing, primers bind to complementary sequences on single-stranded DNA by pairing their 3′ ends to the template strand, providing a starting point for DNA synthesis. This interaction enables the subsequent synthesis of double-stranded DNA during the extension phase. The

final phase uses a temperature of 75°C to 80°C to optimize DNA polymerase activity and promote strand elongation.

PCR is a widely adopted technique in both basic and biomedical research due to its rapidity, sensitivity, and dependability. It has become the preferred method for many applications, often delivering results within hours, though more complex procedures may extend to three days. The reaction requires only a small amount of nucleic acid—typically between 1 and 100 nanograms of DNA or RNA—with some highly sensitive protocols functioning with even less. PCR can generate between one million and one billion copies of DNA in a short time. Additionally, the addition of restriction sites at the ends of amplified fragments facilitates efficient cloning and gene expression in downstream processes.

Real-Time PCR (qPCR) is a refined version of conventional PCR that enables the monitoring of DNA amplification as it occurs. This technique eliminates the need for post-PCR processing by using fluorescent dyes or sequence-specific probes that emit signals in proportion to the accumulation of DNA. The key distinction between real-time and standard PCR is that qPCR allows immediate detection of amplified products during the reaction itself, enhancing precision and efficiency in DNA analysis.

PCR is a highly sensitive technique, but this sensitivity can also lead to challenges—such as detecting even trace amounts of contamination in DNA or RNA samples, which may result in misleading outcomes. During the amplification process, DNA can be tracked using fluorescent dyes that bind to double-stranded DNA or through sequence-specific probes. A key measurement in this process is the quantification cycle (Cq), which represents the number of cycles needed for the fluorescence signal to cross a detectable threshold. When PCR efficiency is low, more cycles are required, leading to a higher Cq value. These values, when interpreted alongside a patient's clinical symptoms and history, can help determine the stage and severity of disease.

Due to its speed, specificity, and sensitivity, PCR is widely used in both research and clinical settings. It plays a vital role in detecting a broad range of viral pathogens, including human papillomavirus, HIV, herpes simplex virus, SARS-CoV-2, varicella-zoster virus, enterovirus, cytomegalovirus, and hepatitis viruses B through E. Additionally, PCR is instrumental in identifying bacterial, fungal, and parasitic infections, as well as diagnosing various immunodeficiencies.

Real-time PCR enhances diagnostic precision by enabling the rapid detection of microbial pathogens. This allows healthcare providers to deliver timely, targeted treatments, helping to reduce hospital stays and prevent the misuse of antibiotics—ultimately contributing to the fight against antibiotic resistance.

b. Evolution and Genetic Diversity

Evolution is the cornerstone of biological science, describing the gradual change in heritable traits within populations across successive generations. This process is driven by several mechanisms—mutation, gene flow, genetic drift, and natural selection—all of which contribute to shifts in allele frequencies within a gene pool. These changes enable populations to adapt to their environments, survive challenges, and diversify over time.

At the heart of evolution lies genetic diversity, the variation in genes among individuals within a species. This diversity provides the raw material upon which evolutionary forces act. Without it, populations would lack the flexibility to respond to environmental pressures such as climate change, disease, or competition. For example, mutations introduce new alleles, while gene flow allows genetic material to move between populations, increasing variability. Natural selection then favors traits that enhance survival and reproduction, gradually shaping the genetic makeup of future generations.

A large gene pool—rich in allelic variation—offers a population greater resilience. It increases the likelihood that some individuals will possess traits suited to changing conditions, ensuring the survival of the species. In contrast, low genetic diversity can be detrimental. Populations with limited variation are more vulnerable to extinction, as they may lack the necessary traits to cope with new threats. A striking example is the wild cheetah, whose genetic uniformity has made it susceptible to disease and reproductive challenges, threatening its long-term survival.

Genetic diversity is the total number of genetic characteristics in the genetic makeup of a species. It ranges widely, from the number of species to differences within species, and can be correlated to the span of survival for a species.

Genetic diversity refers to the variation in genes among individuals within a population. This diversity is fundamental to the survival and adaptability of species, as it gives rise to differences in physical traits and biological responses. These variations enable individuals to cope with stress, resist diseases, and endure unfavorable environmental conditions.

Environmental changes—whether natural or caused by human activities—create selective pressures that drive evolution through the principle of "survival of the fittest." In genetically diverse populations, individuals with traits suited to new conditions are more likely to survive and reproduce, while those lacking adaptive traits may perish. This process ensures that resilient genetic variants are passed on to future generations.

A healthy population relies on a wide range of genetic traits, including those that confer resistance to pests, pathogens, and environmental stressors. In agriculture, genetic diversity is harnessed through cross-breeding, allowing the development of plant varieties with desirable characteristics such as improved yield, disease resistance, and drought tolerance.

Moreover, genetic diversity plays a crucial role in reducing the recurrence of harmful inherited traits. By maintaining a broad gene pool, the likelihood of expressing deleterious mutations is minimized. This diversity also acts as a safeguard for species survival—ensuring that even in the face of catastrophic events, some individuals may possess the genetic makeup necessary to endure and repopulate.

Genetic variation plays a crucial role in enabling populations to adapt to changing environments. Within any given population, individuals possess different genetic traits, which manifest as variations in their physical characteristics, or phenotypes. Natural selection acts directly on these phenotypes, favoring traits that enhance survival and reproductive success.

When new alleles arise through mutation, they can have varying effects on an organism. Some alleles may confer advantages—such as improved resistance to disease or better adaptation to environmental conditions—thereby increasing the organism's chances of survival and reproduction. As these beneficial traits are passed on to future generations, the advantageous alleles become more common within the population.

Conversely, some mutations may produce harmful alleles, such as those that result in defective proteins essential for survival. Organisms carrying these detrimental mutations are less likely to survive and reproduce, leading to the eventual elimination of these alleles from the gene pool. In contrast, neutral alleles—those that neither benefit nor harm the organism—often persist in the population without being influenced by natural selection.

Ultimately, genetic diversity within a population enhances its resilience. A wide range of genetic traits increases the likelihood that some individuals will possess characteristics suited to new or changing environmental conditions. This adaptability ensures the continued survival of the population, even in the face of challenges and uncertainty.

In conclusion, genetic diversity is not just a biological asset; it is a vital mechanism for resilience, adaptation, and long-term survival. Protecting and promoting genetic variation is essential for sustaining ecosystems, improving agriculture, and preserving biodiversity in an ever-changing world. Evolution and genetic diversity are deeply interconnected. Evolution depends on the presence of genetic variation, while genetic diversity ensures that populations can adapt and thrive in dynamic environments. Preserving genetic diversity is not only essential for understanding evolutionary processes but also for safeguarding biodiversity and the health of ecosystems worldwide.