PROPOSED GUIDE FOR UACE ACEITEKA BIOLOGY PAPER 1

ITEM 1

During a marathon training camp, athletes were given a new energy supplement called "Mega-Boost". However, several athletes who consumed the supplement developed severe muscle fatigue and collapsed during long-distance races despite having normal blood glucose levels.

Sports physiologists investigated the effect of the supplement on aerobic respiration in muscle cells. Laboratory analysis showed that the supplement works by producing NADH substances directly inside the mitochondria and slows down the rate of carbohydrate break down in the body. Electron microscopy further showed that prolonged use of the supplement caused swelling of mitochondrial cristae in muscle fibers. The results obtained are shown in table 1 below.

Table 1:

Parameter	*Normal athlete*	*Athlete using "Mega- Boost"*
ATP concentration in muscle cells ($mmolkg^{-1}$ muscle)	5.2	18.6
Pyruvate concentration in cytoplasm ($mmolL^{-1}$)	3.3	1.2
Lactic acid concentration in muscle cells ($mmolL^{-1}$)	1.5	14.2
Rate of lipid breakdown	Moderate	Very high

Following the collapses, the medical team attempted the following interventions:

• Administering 100% oxygen gas to the collapsed athletes during recovery.

• Feeding the athletes with a high-glucose syrup immediately after they collapsed.

• Administering a drug that competitively inhibits fatty acid oxidation (lipid breakdown) before the race.

Tasks:

(a) Analyze the findings to explain how the Mega Boost supplement affected the various cellular parameters leading to the observed symptoms in the collapsed athletes.

(b) Evaluate the effectiveness of the interventions made by the medical team.

RESPONSES

(a) Analyse the findings to explain how the Mega-Boost supplement affected the various cellular parameters leading to the observed symptoms in the collapsed athletes.

ATP concentration in muscle cells increased from 5.2 to 18.6 mmol kg^{-1} muscle; because Mega-Boost directly supplied NADH inside the mitochondria. NADH donates electrons to the electron transport chain, increasing proton pumping across the inner mitochondrial membrane and initially stimulating oxidative phosphorylation, leading to increased ATP synthesis. However, excessive NADH drives excessive electron flow, which frequently leaks electrons that combine with oxygen to form reactive oxygen species (ROS) which cause oxidative stress in the mitochondria, damaging mitochondrial membranes and cause swelling of the mitochondrial cristae; reducing the surface area available for electron transport chain proteins and ATP synthase activity. Consequently, although ATP accumulated at rest, ATP production during prolonged exercise could not match the rapidly increasing energy demand, resulting in muscle fatigue and eventual collapse.

Pyruvate concentration in the cytoplasm decreased from 3.3 to 1.2 mmol L^{-1}; because the supplement directly supplied NADH into the mitochondria, causing an abnormal increase in ATP concentration within muscle cells; the high ATP levels created negative feedback inhibition on glycolysis, reducing the activity of key glycolytic enzymes such as phosphofructokinase and slowing the conversion of glucose to pyruvate in the cytoplasm which led to decrease in its concentration. The reduced pyruvate availability limited entry of carbon intermediates into the Krebs cycle, reducing normal aerobic respiration and causing greater dependence on anaerobic glycolysis during prolonged exercise.

Lactic acid concentration highly increased from 1.5 to 14.2 mmol L^{-1} because, although glycolysis was inhibited, prolonged exercise caused swelling of mitochondrial cristae, impairing aerobic respiration despite the high NADH concentration. The damaged mitochondria could not oxidize all the reduced coenzymes (NADH) efficiently. The limited pyruvate available was therefore increasingly converted into lactic acid through anaerobic respiration by lactate dehydrogenase using NADH to regenerate NAD^+ required for continued glycolysis, causing excessive accumulation of lactic acid, which lowered pH of muscle cells, inhibited enzymes involved in contraction and interfered with actin-myosin interactions, causing muscle pain, severe fatigue and collapse during long-distance races.

The rate of lipid breakdown increased from moderate to very high because reduced carbohydrate breakdown forced muscle cells to mobilize lipids as an alternative source of energy; where triglycerides are hydrolysed into glycerol and fatty acids and fatty acids then undergo β-oxidation to produce acetyl-CoA for aerobic respiration. Although lipid oxidation provides large amounts of ATP, it occurs more slowly and requires more oxygen than carbohydrate oxidation to generate the same amount of ATP. Therefore, lipid metabolism could not satisfy the rapid energy demand of exercising muscles, contributing to exhaustion during long distance races. Increased fat metabolism also yielded excessive reducing equivalents and electron flow through the electron transport chain, increasing production of reactive oxygen species; these free radicals damaged mitochondrial membranes and caused swelling of mitochondrial cristae, reducing the surface area available for electron transport chain complexes and ATP synthase activity; oxidative phosphorylation became less efficient, reducing sustainable ATP production during long distance exercise and contributing to muscle fatigue and collapse.

(b) Evaluate the effectiveness of the interventions made by the medical team.

Administering 100% oxygen gas during recovery

Providing 100% oxygen would be effective because it increases the oxygen concentration in alveoli, raising oxygen diffusion into the blood and improving delivery to muscle cells. This enhances aerobic respiration, promotes oxidation of accumulated lactic acid, facilitates repayment of oxygen debt and supports aerobic ATP production during recovery because oxygen acts as the final electron acceptor in the electron transport chain allowing continued aerobic respiration; promoting recovery from muscle fatigue after collapse. However, oxygen therapy does not reverse mitochondrial cristae damage or prevent excessive ATP-induced inhibition of glycolysis caused by Mega Boost and pure oxygen inhibits the carotid and aortic bodies which regulate breathing so is also fetal. Therefore, although it is effective in accelerating recovery as an emergence supportive treatment, it cannot prevent recurrence if athletes continue using the supplement. The intervention should therefore be combined with immediate discontinuation of Mega-Boost and adequate recovery time to allow restoration of mitochondrial structure and function.

Feeding the athletes with a high-glucose syrup immediately after collapse

High glucose syrup would be effective because glucose provides substrate for glycolysis, providing pyruvate that can enter mitochondria for aerobic respiration and generate ATP through the Krebs cycle and oxidative phosphorylation. However, the athletes already had excessive ATP levels and damaged mitochondria, meaning additional glucose may cause hyperglycemia, increase glycolytic activity and potentially worsen lactic acid accumulation if respiration remains impaired. Therefore, glucose syrup provides only nutritional support during recovery but it is not an effective primary intervention for the metabolic disturbance caused by the supplement. It should therefore be combined with withdrawal of the supplement and restoration of normal carbohydrate metabolism.

Administering a competitive inhibitor of fatty acid oxidation before the race

The drug would be effective because it reduces excessive lipid breakdown, decreasing the amount of fatty acids entering mitochondria for β-oxidation. This reduces excessive electron flow, reactive oxygen species formation and mitochondrial membrane damage, allowing mitochondria to maintain efficient oxidative phosphorylation during prolonged exercise. However, excessive inhibition of lipid oxidation may reduce an athlete's ability to use fats as a long-term energy source during endurance exercise. This limitation can be managed by ensuring controlled inhibition of lipid oxidation because it directly prevents the metabolic imbalance responsible for mitochondrial damage and fatigue.

ITEM 2

Diana established a peppermint (*Mentha piperita*) farm in the Eastern region of Uganda. The region experiences extreme environmental conditions. Two groups of peppermint plants A and B were formed and subjected to different conditions.

Table 2A

Peppermint Group	**Conditions**
Group A	• 8 hours of light • Moderate levels of ABA • Moderate temperature
Group B	• 6 hours of light • High levels of ABA • Moderate temperature

Agricultural scientists investigated how environmental conditions and plant hormones were affecting the plants. Their findings are shown below.

Table 2B

Measured parameters/ observation	*Peppermint plant group*	
	Group A	**Group B**
Photosynthetic rate	High	Low
Wilting	Moderate	Severe
Flowering	Flowering	No flowering

The scientists concluded that the environmental conditions in Eastern region increased stress in the peppermint plants, leading to reduced productivity which were not as intended. They therefore proposed two interventions to increase productivity of the plants:

• Routine watering of the plants especially during hot days
• Increasing the soil salinity by adding ash in the gardens.

Tasks:

(a) Analyze how the conditions subjected to the peppermint plant groups influence productivity in the plants.
(b) Evaluate the effectiveness of the interventions proposed by the scientists and give strategic guidance.

(a) Analyse how the conditions subjected to the peppermint plant groups influence productivity in the plants.

The photosynthetic rate was high in group A but low in group B; because the plants in group A received a longer photoperiod (8 hours), providing sufficient light energy for chlorophyll to absorb photons. The absorbed light stimulated photolysis of water and non-cyclic photophosphorylation, producing ATP and reduced NADP required for carbon fixation during the Calvin cycle; more glucose was synthesized, supporting respiration, growth and production of peppermint biomass, thereby increasing productivity. Also, moderate ABA caused only partial stomatal closure, allowing sufficient carbon dioxide to diffuse into the leaves while limiting excessive water loss.

In contrast, **Group B** plants received a shorter photoperiod of only six hours which supplied less light energy for the light-dependent reactions of photosynthesis; less ATP and reduced NADP were therefore produced, reducing carbon fixation during the Calvin cycle and lowering glucose production. High concentrations of ABA further reduced photosynthesis by inducing stomatal closure, limiting carbon dioxide entry into leaves; limiting carbon dioxide fixation and glucose synthesis, thereby lowering the rate of photosynthesis and reducing plant productivity.

Wilting was moderate in group A plants but severe in group B because moderate levels of abscisic acid (ABA) in group A plants caused partial closure of stomata, reducing transpiration while still allowing adequate gaseous exchange. Carbon dioxide continued to diffuse into the leaves for photosynthesis, while water loss was limited. Therefore, plant cells maintained sufficient turgor pressure to support normal physiological activities, resulting in only moderate wilting.

Wilting was severe in group B peppermint due to high ABA levels as a result of severe water stress. ABA stimulated extensive stomatal closure, reducing water loss but also restricting carbon dioxide uptake. Continued environmental stress reduced water absorption by roots and caused prolonged loss of cell turgor. Leaves became severely wilted, reducing leaf expansion and photosynthetic surface area, thereby lowering productivity

Flowering occurred in group A plants because the 8-hour light period provided a favourable photoperiod for flowering in peppermint. Light perceived by phytochrome pigments stimulated the production of florigen in leaves, which was transported to shoot apices where it initiated floral development. At the same time, the high rate of photosynthesis supplied sufficient carbohydrates to support flower formation, increasing reproductive success and productivity.

However, no flowering occurred in group B; because the shorter 6-hour photoperiod failed to provide the appropriate light stimulus required for flowering. Reduced photosynthesis also produced insufficient carbohydrates to support reproductive development. High ABA also suppresses growth processes and diverts resources toward survival rather than reproduction. Flowering was therefore inhibited, reducing seed production and crop productivity.

(b) Evaluate the effectiveness of the interventions proposed by the scientists and give strategic guidance.

Routine watering of the plants, especially during hot days

Routine watering replaces soil moisture and increases water uptake by roots through osmosis. Adequate water maintains cell turgidity, supports stomatal opening, enhances carbon dioxide uptake and promotes photosynthesis. Water also serves as a raw material for photolysis during the light-dependent stage of photosynthesis. Therefore, routine watering reduces wilting, increases carbohydrate production and improves peppermint growth and essential oil yield.

However, excessive watering may lead to waterlogging, reducing oxygen availability around roots. Poor aeration limits aerobic respiration in root cells, reducing ATP production needed for active mineral ion uptake. Waterlogged conditions may also promote root diseases caused by fungi. This limitation can be overcome by applying irrigation only according to crop water requirements and ensuring proper drainage systems that prevent waterlogging while maintaining adequate soil moisture.

Increasing soil salinity by adding ash

Adding ash increases the concentration of dissolved salts in the soil, lowering the soil water potential. As a result, water moves less readily from the soil into root hairs by osmosis. In severe cases, water may even move out of root cells into the soil, causing plasmolysis and further wilting. High soil salinity also interferes with mineral ion uptake and may cause ionic toxicity, reducing enzyme activity, chlorophyll formation and photosynthesis leading to decline in plant growth, and flowering.

Although ash may supply useful mineral nutrients such as potassium, excessive application is generally unsuitable under already stressful environmental conditions because it increases osmotic stress. Instead of increasing soil salinity, soil fertility should be improved using well-decomposed organic manure or balanced inorganic fertilizers. Organic matter improves soil structure, increases water-holding capacity and supplies nutrients without creating excessive osmotic stress.

Strategic guidance

The most effective long-term strategy is to implement routine watering together with proper irrigation management and soil moisture conservation practices such as mulching. Mulching reduces evaporation, moderates soil temperature and maintains favourable soil moisture for root function. The proposal to increase soil salinity by adding ash should not be adopted as a primary intervention because it worsens water stress and reduces productivity. Where ash is used, it should only be applied in carefully controlled quantities to supply minerals and should be accompanied by regular monitoring of soil pH and salinity.

ITEM 3

After attending a 6-hour outdoor music festival featuring extreme noise levels, dancing and consuming large quantities of alcohol, an 18-year-old student, David, was admitted to the school's sickbay. He presented with inability to walk in a straight line, profound dehydration, and complaints of a constant "ringing" in his ears.

The university nurse assessed David and compared his vitals to a healthy, sober student who did not attend the concert.

Table 3

Table	**David (Post-concert & Alcohol)**	**Healthy Student**
ADH concentration in blood (pg/mL)	0.8	4.5
Cardiac output (L/min)	3.2	5.1
Sensory Hair Cell Integrity in Cochlea	35% damaged	0% damaged
Endolymph fluid dynamics in Semicircular Canals	Highly turbulent/ Altered viscosity	Normal flow

Following his admission, the medical team proposed to give him isotonic saline solution intravenously, oral rehydration salts or plain distilled water and place him in a quiet rehabilitation environment. The attending doctor however later advised that David should quit alcohol to avoid long term complications.

Tasks:

(a) Explain how David's parameters varied from those of a healthy student and how this led to the David's presentation.

(b) Evaluate the medical team's proposal in helping David and support the attending Doctor's advice.

(a) Explain how David's parameters varied from those of a healthy student and how this led to David's presentation.

Antidiuretic Hormone (ADH) concentration decreased from 4.5 pg/mL to 0.8 pg/mL because he consumed large quantities of alcohol, which inhibited the release of antidiuretic hormone (ADH) from the posterior pituitary gland. ADH normally binds to receptors on kidney collecting duct cells and distal convoluted tubules, increasing their permeability by promoting insertion of aquaporin water channels, allowing more water to be reabsorbed into the blood. Reduced ADH lowered aquaporin insertion, decreasing the permeability of the distal convoluted tubules and collecting ducts to water, reducing water reabsorption into the blood stream and causing water to remain in urine. Therefore, large volumes of dilute urine were produced, causing dehydration, reduced blood volume and increased plasma osmolarity. Dehydration reduced efficient circulation and oxygen delivery to brain cells, reducing neuronal metabolism and neurotransmission. The resulting disturbance in brain function contributed to severe disorientation, poor coordination and impaired judgement.

Cardiac output decreased from 5.1 L/min to 3.2 L/min because dehydration reduced blood volume and circulating blood returning to the heart (venous return). Reduced venous return lowered ventricular filling during diastole, decreasing stroke volume according to the Frank-Starling mechanism. Since cardiac output equals stroke volume × heart rate, cardiac output fell. Reduced cardiac output decreased the delivery of oxygen and glucose to the brain and skeletal muscles while slowing removal of metabolic wastes such as carbon dioxide. Consequently, muscle performance declined, causing weakness, fatigue and difficulty maintaining posture and balance.

Sensory hair cell integrity in the cochlea showed 35% damage instead of 0% because prolonged exposure to extremely loud music damaged the sensory hair cells within the organ of Corti in the cochlea. Normally, sound vibrations cause these hair cells to bend, generating nerve impulses that are transmitted through the auditory nerve to the brain. Excessive sound intensity caused over-bending of stereocilia, calcium ion overload and production of reactive oxygen species, leading to cellular damage and abnormal spontaneous activity of auditory nerves even in absence of sound. The damaged hair cells sent inappropriate electrical signals through the auditory nerve even in absence of external sound. The brain interpreted these abnormal signals as sound, producing the sensation of continuous ringing/ tinnitus;

Endolymph fluid dynamics in the semicircular canals became highly turbulent instead of normal because the loud music exposure and alcohol consumption disrupted normal functioning of the vestibular system located in the semi- circular canals. Alcohol diffused into the endolymph of semicircular canals altering its viscosity and density; Altered viscosity and turbulent movement of endolymph changed the stimulation of sensory hair cells. Normally the movement of endolymph bends stereocilia on hair cells, generating receptor potentials that are converted into nerve impulses informing the brain about head movement and balance.

During head movements, the altered endolymph flowed abnormally, causing excessive or inappropriate bending of the cupula and sensory hair cells. These abnormal/ inaccurate impulses were transmitted from vestibular receptors through the vestibular branch of the auditory nerve to the cerebellum and brainstem. The brain therefore received conflicting information about body position and movement, reducing coordination between visual, vestibular and proprioceptive systems. David therefore experienced impaired balance control, causing disorientation, vertigo/spinning sensation and was unable to walk in a straight line.

(b) Evaluate the medical team's proposal in helping David and support the attending doctor's advice.

Intravenous administration of isotonic saline solution

Intravenous administration of isotonic saline solution would be effective because saline has approximately the same osmotic concentration as blood plasma; when infused intravenously, it rapidly restores plasma volume without causing red blood cells to swell or shrink. Increased blood volume improves venous return, stroke volume and cardiac output, enhancing delivery of oxygen and nutrients to tissues. This intervention is highly effective because it rapidly corrects dehydration and restores circulatory function. However, excessive infusion may overload the circulation, especially in individuals with cardiac or renal disease, causing oedema/swelling. The intervention should therefore be administered under careful medical supervision with continuous monitoring of fluid balance and blood pressure.

Oral Rehydration Salts (ORS)

ORS contains water together with sodium and glucose. Sodium and glucose are absorbed simultaneously through sodium-glucose co-transporters in the small intestine, promoting efficient water absorption into the bloodstream. This effectively replaces both water and electrolytes lost through excessive urination, correcting dehydration while restoring normal cellular function. However, ORS acts more slowly than intravenous saline and may not be suitable for severely dehydrated or unconscious patients who cannot drink safely. It is therefore most effective after initial stabilization with intravenous fluids or in cases of mild to moderate dehydration.

Plain distilled water

Providing water would be effective because it restores fluid balance, increases blood volume and reduces dehydration caused by reduced ADH activity and excessive water loss. Restored hydration improves circulation and oxygen delivery to brain cells, helping in recovery from dizziness and confusion. However, plain distilled water contains no electrolytes such as potassium and sodium which are important for maintaining osmotic balance and normal nerve and muscular function. Excessive intake of plain water may also dilute plasma sodium concentration, leading to hyponatraemia/low blood sodium ion level. Therefore, distilled water alone is the least effective option for treating severe dehydration caused by alcohol consumption. It should only be used after electrolyte balance has been restored or alongside electrolyte-containing fluids.

Quiet rehabilitation environment

A quiet environment minimizes further stimulation of the damaged cochlear hair cells, allowing the auditory system to recover from temporary threshold shifts. It also reduces vestibular stimulation, making dizziness and balance disturbances less severe. Reduced sensory also allows the nervous system to recover from alcohol-induced impairment and improves patient comfort. However, permanent damage to cochlear hair cells cannot be reversed simply by resting in a quiet environment. Therefore, quiet rehabilitation should be combined with hearing assessment and follow-up if symptoms persist.

Supporting the doctor's advice to quit alcohol

The doctor's advice is scientifically justified because continued alcohol consumption repeatedly suppresses ADH secretion, leading to recurrent dehydration and electrolyte imbalance. Chronic alcohol use may also damage the liver, brain, heart and peripheral nerves while increasing the risk of addiction. Repeated alcohol exposure can permanently impair cerebellar function, worsen balance disorders and contribute to long-term hearing problems. Abstaining from alcohol allows normal ADH secretion to resume, reduces dehydration episodes and protects the nervous, circulatory and excretory systems from progressive damage though he may miss the social benefits associated with drinking.

ITEM 4

During a high-stakes football tournament in Kampala, three players used different strategies to manage performance and injury:

• Player 1: First time player, who completed a structured warm-up before play.

• Player 2: Seasoned player, given a local anesthetic injection after sustaining a muscle injury and continued playing.

• Player 3: Seasoned player, applied ice-cold treatment immediately after injury and returned to play shortly after.

After the match, the team physiologist raised concerns that some of these interventions may have improved short-term performance but increased the risk of body physiological damage and impaired body temperature regulation. Important homeostatic, nervous and circulatory parameters were therefore assessed in the three players.

Data Provided:

Table 4:

Parameter	**Player 1**	**Player 2**	**Player 3**
Synaptic transmission efficiency	High	Reduced	Moderate
Reaction time (ms)	160	260	210
Heartrate after play (bpm)	150	138	132
Skin temperature (^oC)	38.2	36.4	32.5

Tasks:

(a) Analyze the data and account for the differences in the physiological parameters assessed in the three players.

(b) Evaluate each player's strategy and assess which one balances performance and physiological safety.

(a) Analyse the data and account for the differences in the physiological parameters assessed in the three players.

Synaptic transmission efficiency

Player 1 had the highest synaptic transmission efficiency, because they performed a structured warm-up before play. Warming up increased muscle temperature, improved blood circulation and enhanced enzyme activity involved in neurotransmitter synthesis and release. Higher temperatures also increased the rate of diffusion of neurotransmitters across synaptic clefts and accelerated depolarization of nerve membranes. Consequently, nerve impulses were transmitted rapidly between neurones and muscles, improving coordination and muscular performance.

Player 2 had reduced synaptic transmission efficiency because they received a local anaesthetic after sustaining a muscle injury. Local anaesthetics block voltage-gated sodium channels in neurone membranes, preventing depolarization and generation of action potentials. As a result, fewer nerve impulses reached the central nervous system and skeletal muscles; therefore, synaptic transmission efficiency was reduced despite the player continuing to participate in the match.

Player 3 had moderate synaptic transmission efficiency because application of ice lowered tissue temperature around the injured area. Low temperature slowed enzyme-controlled reactions, reduced neurotransmitter release and decreased the rate of nerve impulse conduction. However, unlike the anaesthetic, cold treatment did not completely block impulse transmission; thus, synaptic transmission remained moderate.

Reaction time

Player 1 had the shortest reaction time (160 ms), Player 2 had the longest reaction time (260ms) while Player 3 had a moderate reaction time of 210 ms.
In player 1, warm-up increased nerve conduction velocity and muscle enzyme activity while improving flexibility and joint mobility; impulses travelled rapidly from sensory receptors to the central nervous system and back to muscles, producing the shortest reaction time.
In player 2, the local anaesthetic reduced sensory nerve conduction by blocking action potential generation. As a result, impulses from pain receptors and other sensory receptors reached the brain more slowly, while motor responses were also delayed. Consequently, Player 2 exhibited the longest reaction time despite feeling less pain.

In player 3, cold treatment slowed metabolic activity and reduced the speed of nerve impulse conduction; reaction time became longer than Player 1's but remained shorter than Player 2's because nerve conduction was slowed rather than completely inhibited.

Heart rate after play

Player 1 had the highest heart rate after play, 150bpm because the structured warm-up increased sympathetic nervous activity before exercise. During play, muscles required greater amounts of oxygen and glucose for aerobic respiration; the heart beat faster to increase cardiac output, delivering oxygen and nutrients while removing carbon dioxide and metabolic wastes.
In Player 2, pain relief produced by the anaesthetic reduced sympathetic stimulation arising from pain perception; heart rate was thus lower than Player 1's despite continued physical activity. However, because the injury remained, the player risked worsening tissue damage without experiencing protective pain.

In Player 3, ice treatment caused vasoconstriction of superficial blood vessels and reduced metabolic activity within the injured tissues; oxygen demand therefore declined and heart rate remained the lowest (132bpm) among the three players.

Skin temperature

Player 1 had the highest skin temperature of 38.2°C. This is because warm-up increased muscle metabolism and ATP hydrolysis, generating large amounts of heat. Increased blood flow to the skin transported this heat to the body surface; skin temperature therefore became highest, promoting heat loss through sweating and radiation, thereby maintaining normal body temperature.
In Player 2, the local anaesthetic itself had little direct effect on heat production. Although muscular activity continued, reduced pain perception slightly lowered sympathetic responses and therefore skin temperature remained close to normal (36.4°C)

However, in Player 3, application of ice removed heat from the injured tissues by conduction. Cold also caused vasoconstriction, reducing blood flow to the skin and limiting heat transfer from deeper tissues. Player 3 therefore recorded the lowest skin temperature.

(b) Evaluate each player strategy and assess which one balances performance and physiological safety.

Player 1 carried out a structured warm-up before play. A structured warm-up gradually increases muscle temperature, heart rate and blood circulation before vigorous activity. Increased blood flow supplies muscles with oxygen and glucose while removing carbon dioxide. Warm muscles also become more elastic, reducing the risk of strains and ligament injuries. Improved enzyme activity accelerates ATP production, enhancing muscle contraction and coordination.
This strategy is highly effective because it improves athletic performance while protecting muscles, tendons and joints from injury. However, an excessively long or intense warm-up may cause early

fatigue and depletion of glycogen stores before competition begins. This limitation can be overcome by using sport-specific warm-up programmes of appropriate intensity and duration under professional supervision.

Player 2 used a local anaesthetic after injury and continued play. The local anaesthetics block transmission of pain impulses by preventing sodium ion influx into sensory neurones. This temporarily relieves pain, allowing continued participation. However, pain is an important protective mechanism. By eliminating pain sensation, the player may continue stressing already damaged muscles, tendons or ligaments without realizing the severity of the injury. Continued activity may worsen tissue damage, increase bleeding and delay healing. Therefore, this strategy is unsuitable for injured athletes who intend to continue competing. A better alternative is to stop play immediately, assess the injury medically and begin appropriate rehabilitation before returning to sport.

Player 3 applied ice treatment followed by immediate return to play. Ice treatment reduces tissue temperature, causing vasoconstriction that limits bleeding, inflammation and swelling. It also decreases metabolic rate and reduces pain by slowing nerve impulse conduction. This makes ice highly effective as an immediate first-aid measure after acute injuries. However, returning to play immediately while tissues remain cold increases the risk of muscle stiffness, reduced flexibility and delayed reaction time. Cold muscles generate less force and are more susceptible to further injury. The strategy should therefore be modified by allowing gradual rewarming and reassessment before resuming activity.

Assessment

Among the three strategies, Player 1's structured warm-up provides the best balance between performance and physiological safety. It enhances cardiovascular function, nervous coordination and muscle flexibility while reducing injury risk. Player 2's strategy offers temporary pain relief but significantly increases the risk of worsening tissue damage because protective pain sensations are removed. Player 3's strategy is appropriate for immediate injury management but is unsafe if followed by an immediate return to play without adequate recovery and medical reassessment.

Therefore, the most sustainable approach is to perform a structured warm-up before competition, immediately manage injuries using appropriate first aid such as ice treatment, and avoid masking pain with local anaesthetics to continue playing. This combination maximizes athletic performance while maintaining normal homeostasis, protecting the nervous and circulatory systems and minimizing long-term physiological damage.

ITEM 5

Lake Kyoga has recently been heavily invaded by the Water hyacinth, an invasive weed that forms thick mats on the water surface, drastically altering light penetration and the types of fish-food available.

A native cichlid fish species, which originally had a uniform intermediate jaw size, has begun to show distinct physical changes. Researchers sampled the fish population over 15 years and recorded the distribution of jaw sizes, alongside the weed coverage.

Table 5

Year	***Hyacinth coverage (%)***	***Small-jawed fish (%)***	***Intermediate-jawed Fish (%)***	***Large-jawed Fish (%)***
2009	5	10	80	10
2014	35	25	50	25
2019	65	42	16	42
2024	85	48	4	48

In addition to the above changes, the researchers noticed that the population of the African eagles around the lake decreased whereas that of the moorhen birds increased.

In an attempt to restore the ecosystem stability, researchers are proposing Introduction of the *Neochetina bruchi* weevils that feed on the hyacinth.

Tasks:

(a) Analyze the data to explain how the water hyacinth affected the available fish foods and how the distinct physical changes in fish jaw size came about over the 15-year period.

(b) Propose two more ways to restore the ecosystem and compare them to the effectiveness of that proposed by the researcher and give strategic guidance.

RESPONSES

(a) Analyse the data to explain how the water hyacinth affected the available fish foods and how the distinct physical changes in fish jaw size came about over the 15-year period.

Changes in water hyacinth coverage

Water hyacinth coverage increased steadily from 5% in 2009 to 85% in 2024. As the weed spread, it formed dense floating mats over the lake surface, reducing the amount of sunlight penetrating into the water; which lowered the rate of photosynthesis by submerged aquatic plants and phytoplankton, decreasing primary productivity. Therefore, the abundance of organisms that depended on these producers, such as zooplankton and aquatic invertebrates, also declined. The dense root systems of water hyacinth, however, created new habitats that supported insect larvae, snails and other small organisms. Therefore, the type and distribution of fish food changed considerably.

Evolution of jaw size in the cichlid fish population

Initially, the fish population consisted mainly of intermediate-jawed individuals (80%), while small-jawed and large-jawed fish each accounted for only 10%. As water hyacinth altered the available food resources, fish possessing extreme jaw sizes became better adapted to exploit the new feeding niches; fish with small jaws efficiently fed on small invertebrates, algae and organisms attached to hyacinth roots. Fish with large jaws effectively captured larger prey organisms that remained in open-water habitats or beneath the vegetation while fish with intermediate jaws became less efficient because they could not specialize on either food resource. Consequently, individuals with small and large jaws survived better, reproduced more successfully and passed the advantageous alleles to their offspring.

Over successive generations, the frequency of small-jawed fish increased from 10% to 48%, while that of large-jawed fish also increased from 10% to 48%. Meanwhile, intermediate-jawed fish declined drastically from 80% to only 4%. This pattern demonstrates disruptive selection, where individuals possessing the two extreme phenotypes are favoured while the intermediate phenotype is selected against because the environment provides two distinct ecological niches

The population of African eagles decreased because water hyacinth reduced open-water areas where they normally hunt fish. The decline in fish availability further reduced their food supply, lowering survival and reproduction. However, moorhen populations increased because these birds thrive in dense aquatic vegetation, thus water hyacinth provided nesting sites, shelter and abundant invertebrate food associated with the floating mats, hence enabling their population to increase.

(b) Propose two more ways to restore the ecosystem and compare them to the effectiveness of that proposed by the researcher and give strategic guidance.

The proposed strategy for restoring the ecosystem is introduction of *Neochetina bruchi* weevils; which is a biological control method. Both the adults and larval forms of *Neochetina bruchi* weevils feed on water hyacinth leaves, petioles and crowns, reducing photosynthesis, growth and reproduction of the weed. This strategy is effective because it specifically targets water hyacinth without causing widespread damage to other aquatic organisms. Once established, the weevil population can maintain long-term suppression of the weed with minimal recurrent costs.
However, biological control acts slowly and may require several years before significant reductions in hyacinth coverage occur. During this period, ecosystem degradation may continue. The strategy can be strengthened by integrating it with other control methods that rapidly reduce existing weed mats such as mechanical removal of the weed and pollution control.

More strategies;

Mechanical removal of water hyacinth; Mechanical removal involves harvesting or manually removing floating mats from the lake. This method immediately restores open-water habitats, improves light penetration and increases dissolved oxygen levels. Consequently, submerged plants recover, phytoplankton productivity increases and fish habitats improve rapidly. However, mechanical removal is labour-intensive, expensive and often incomplete because small plant fragments remaining in the water regenerate into new infestations. Compared with biological control, mechanical removal produces much faster results but is less sustainable if used alone because repeated removal is required.

Reducing nutrient pollution entering the lake; This strategy involves controlling fertilizer runoff, sewage discharge and industrial wastes entering Lake Kyoga. Reducing nitrogen and phosphorus decreases nutrient availability required for rapid water hyacinth growth; future infestations are thus minimized while water quality improves, promoting recovery of phytoplankton, aquatic plants and fish populations. However, improvements occur gradually and require cooperation among farmers, industries and local communities. Effective enforcement of environmental regulations is also necessary.
Compared with biological control, nutrient management addresses the root cause of excessive weed growth rather than simply reducing the existing weed population.

Strategic guidance

The most sustainable restoration programme should combine the three methods rather than relying on one approach. Initially, mechanical removal should be used to rapidly clear dense hyacinth mats and restore open water. At the same time, *Neochetina bruchi* should be introduced to provide long-term biological suppression and reduce future weed growth. Finally, nutrient pollution control should be implemented to eliminate the environmental conditions that favour hyacinth proliferation. This integrated approach restores fish habitats, increases biodiversity, improves water quality and provides the most sustainable long-term recovery of Lake Kyoga's ecosystem.

ITEM 6

In the semi-arid rangelands of Kotido District, pastoralists keep indigenous Zebu cattle adapted to harsh environmental conditions. Heat tolerance and water-retention ability in these cattle are controlled by a multiple allele system (T^H, T^M, T^S), where T^H (extreme tolerance) is dominant over T^M (moderate tolerance), and both are dominant over T^S (sensitivity).

However, increasing herd sizes have led to severe overgrazing, causing a shift in vegetation from nutritious perennial grasses (*Themeda triandra*) to invasive, unpalatable weeds (*Sporobolus pyramidalis*). Ecologists have carried out several investigations on the cattle genetics and survival features and comparisons have been done on the land affected by overgrazing. The findings are summarized in tables 6A and 6B below.

Table 6A: Cattle Genotype Frequencies and Survival Metrics during Extreme Drought

Cattle genotype	***Population frequency***	***Mean Daily Water Intake (L)***	***Body Mass Loss (%)***
T^HT^H	0.05	12	4
$T^H T^S$	0.15	14	6
T^MT^M	0.30	25	15
T^MT^S	0.40	28	19
T^ST^S	0.10	45	35

Table 6B: Rangeland Ecological Succession Metrics across Grazing Gradients

Grazing Pressure zone	Dominant Plant Species	Net Primary Productivity ($g/m^2/yr$)	Soil Erosion Rate (tons/ha/yr)
Light grazing	*Themeda triandra* (Perennial)	500	0.5
Moderate grazing	Mixed grasses & herbs	200	4.2
Heavy overgrazing	*Sporobolus pyramidalis* (weed)	110	38.0

As part of the ecologists' implementation strategies, they intend to roll out mass culling program targeting to remove any cattle showing traits of the T^ST^S genotype, dividing the grazing land into paddocks for rotational grazing and clearing the *Sporobolus pyramidalis* weed using broad-spectrum herbicides to allow native grasses to grow back.

(a) Using Table 6A, explain the inheritance pattern of heat tolerance in cattle and the selective pressures acting on each genotype. Predict how the frequencies of T^H, T^M and T^S alleles would change under prolonged drought conditions, and explain why the T^S allele remains in the population despite strong selection against it.

Using table 6B, describe how varying grazing pressure affected the ecosystem.

RESPONSES

Inheritance pattern of heat tolerance

Heat tolerance is controlled by a multiple allele system involving three alleles on a gene loci controlling a single character; T^H, T^M, and T^S for extreme heat tolerance, moderate heat tolerance and heat sensitivity respectively and the dominance relationship is $T^H > T^M > T^S$; implying that any genotype containing T^H expresses extreme heat tolerance **because** T^H masks both T^M and T^S. Genotypes containing T^M but lacking T^H express moderate heat tolerance since T^M is dominant over T^S. Only T^ST^S individuals express heat sensitivity **because** T^S is recessive to both T^H and T^M.

Selective pressures acting on each genotype

The frequency of T^HT^H is 0.05 and these cattle consumed the least amount of water (12 L/day) and lost the smallest proportion of body mass (4%). This indicates that they possessed the highest drought tolerance. Efficient thermoregulation and water conservation enabled them to survive prolonged drought with minimal physiological stress. Consequently, they had the highest survival and reproductive success and were strongly favoured by natural selection.

The T^HT^S cattle had a frequency of 0.15; they required slightly more water (14 L/day) and lost only 6% body mass. Although they carry one T^S allele, the dominant T^H allele conferred extreme heat tolerance. Therefore, these cattle also survived drought successfully and contributed the T^H allele to future generations.

The T^MT^M animals had a frequency of 0.30 and they consumed 25 L/day and lost moderate body mass of 15% because they possessed moderate heat tolerance and therefore survived reasonably well under drought conditions. However, compared with T^H genotypes, they experienced greater dehydration and energy loss, giving them lower reproductive success.

The frequency of T^MT^S cattle was 0.40 and they required 28 L/day and lost 19% body mass. The dominant T^M allele provided only moderate tolerance. They experienced greater physiological stress than T^H-containing genotypes and were less likely to survive prolonged drought.

T^ST^S cattle had a frequency of 0.10 and consumed the largest amount of water (45 L/day) and lost 35% of their body mass. Because they lacked both T^H and T^M alleles, they were unable to conserve water efficiently during drought. Severe dehydration greatly reduced survival and reproductive success. Therefore, natural selection acted most strongly against this genotype.

Prediction of the changes in allele frequencies during prolonged drought

Under prolonged drought, natural selection would favour cattle possessing alleles that improve survival under hot, dry conditions. The frequency of the T^H allele would increase because T^H-containing cattle survive better, require less water and produce more offspring. The T^M allele would probably decline slowly because although moderately tolerant cattle survive, they are less successful than T^H genotypes. The T^S allele would decrease because individuals expressing heat sensitivity experience high mortality and poor reproductive success. Therefore, the cattle population would gradually become dominated by heat-tolerant genotypes.

Why the T^S allele remains in the population

Despite selection against T^ST^S cattle, the T^S allele is unlikely to disappear completely. Many T^S alleles occur in heterozygous individuals; T^HT^S and T^MT^S, where the dominant T^H or T^M allele masks the harmful effects of T^S. These heterozygous animals survive and reproduce successfully, transmitting the T^S allele to their offspring. Therefore, natural selection cannot eliminate the T^S allele completely because it remains hidden in carriers that do not express the sensitive phenotype.

Effects of grazing pressure on the ecosystem (Table 6B)

Light grazing

Under light grazing, *Themeda triandra* remained the dominant grass species because grazing pressure was low enough to allow the grass to regenerate continuously. The dense vegetation provided extensive ground cover, protecting the soil from the direct impact of raindrops and reducing surface runoff. Therefore, soil erosion remains low at 0.5 tons ha^{-1} yr^{-1} and organic matter accumulated in the soil through decomposition of plant litter, improving soil fertility and water retention. The favourable soil conditions supported vigorous plant growth, resulting in the highest net primary productivity and providing abundant forage for livestock as well as habitat for other organisms. The ecosystem therefore remained stable, productive and biologically diverse.

Moderate grazing

Under moderate grazing, grazing intensity exceeded the rat at which the dominant perennial grasses could fully regenerate; the vegetation thus shifted from *Themeda triandra* to a mixture of grasses and herbs that are more tolerant to repeated grazing. The reduction in plant cover exposed portions of the soil to rainfall and wind, increasing run off and erosion to 4.2 tons ha^{-1} yr^{-1}. Loss of nutrient-rich topsoil reduced soil fertility and water holding capacity, thereby lowering the rate of pant growth and reducing net primary productivity to 200 $g/m^2/yr$; although the posture still supported livestock, its carrying capacity and ecological stability were lower than under light grazing.

Heavy overgrazing

Heavy overgrazing removed vegetation faster than it could regenerate, leading to severe depletion of the desirable perennial grasses. The loss of protective ground cover exposed the soil directly to erosion by rain and wind, causing soil erosion to increase sharply to 38tons ha^{-1} yr^{-1}. Continuous removal of vegetation also depleted soil organic matter and nutrients, reducing soil fertility and limiting establishment of productive forage species, which greatly lowers the ecosystem productivity, biodiversity and stability.

(b) Evaluate the long-term sustainability and effectiveness of the ecologists' implementation strategies.

Mass culling of T^ST^S cattle

This strategy removes cattle expressing the heat-sensitive genotype before they reproduce. It is effective because it reduces the frequency of the undesirable genotype, reducing competition for resources and increases the proportion of drought-tolerant animals in future generations. Therefore, the herd becomes more resilient to prolonged drought. However, culling alone may reduce genetic diversity and accidentally remove animals possessing other valuable traits such as disease resistance or high fertility. Since the T^S allele is hidden in heterozygous animals, culling T^ST^S cattle alone cannot eliminate the allele completely. The strategy should therefore be improved through selective breeding supported by genetic screening so that breeding animals carrying favourable alleles are selected while maintaining adequate genetic diversity.

Rotational grazing

Rotational grazing divides pasture into paddocks, allowing grazed areas to recover before livestock return. This strategy is highly effective because resting paddocks permits perennial grasses to regenerate, increases ground cover, improves soil fertility and reduces soil erosion. It also distributes grazing pressure more evenly across the rangeland. However, rotational grazing requires fencing, water points and proper management, which may be expensive for pastoral communities. The strategy can be strengthened through community grazing schemes, farmer training and provision of infrastructure that supports effective paddock management.

Broad-spectrum herbicides against *Sporobolus pyramidalis*

Broad-spectrum herbicides rapidly reduce populations of invasive weeds, allowing native grasses to re-establish. This provides quick improvement in pasture quality and increases forage availability for livestock. However, broad-spectrum herbicides may also kill desirable native grasses and other non-target plants, reducing biodiversity. Chemical residues may contaminate soil and water leading to death soil living organisms and aquatic organisms respectively while repeated use can promote herbicide resistance. The strategy should therefore be modified by combining weed removal, reseeding with native grasses and integrated weed management to minimize environmental damage.

END