S.5 BIOLOGY

ITEM 1

In 2020, electronic results indicate that novel toxin ***aflatoxin*** in Uganda especially Mubende and Kamwenge districts. Aflatoxins are lipophilic substances produced by a fungi, *Aspergillus flavus* and *A. parasiticus* and have been reported in maize, sorghum, sesame, beans, sunflower, millet, peanuts and cassava under warm and humid conditions. The causes and proliferation of aflatoxigenic contamination of Ugandan foods have been largely due to poor pre-, peri-, and postharvest activities, poor government legislation, lack of awareness, and low levels of education among farmers, entrepreneurs, and consumers on this plague. High levels of aflatoxin in exposed individuals increased liver cancer risk greatly in several parts of the country leading to severe vomiting, jaundice, fatigue and abdominal pain in patients. In the study, focused on two cell types: pancreatic acinar cells and liver hepatocytes. The team exposes both cell types to aflatoxins and measures various cellular parameters over a 24-hour period.

Table: Protein Synthesis and Secretion in pancreatic acinar cells, and detoxification enzyme activity in liver hepatocytes

Time (hours)	Treatment	Total Protein Synthesis (relative units)	Protein Secretion (relative units)	Detoxification enzyme activity (relative units)
0	Control	100	80	100
0	aflatoxins	100	80	100
6	Control	100	80	100
6	aflatoxins	95	50	90
12	Control	100	80	100
12	aflatoxins	80	20	70
24	Control	100	80	100
24	aflatoxins	60	5	40

Task

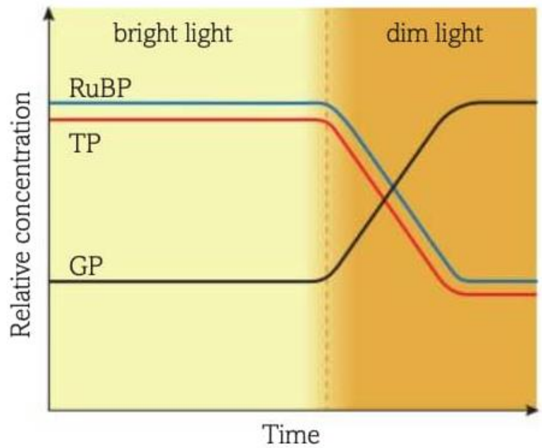
a) Describe the effect of aflatoxins on pancreatic acinar cells and detoxification enzyme liver hepatocytes over the 24-hour period.

b) (i) What specific organelle(s) are likely directly affected by aflatoxins, and how does this explain the observed accumulation of protein-filled vesicles?
(ii) What process is likely being upregulated in these acinar and liver cells, and why?

c) Explain the mechanism by which aflatoxins might be entering both cell types and how to prevent its pathways.

ITEM 2

A group of botanist at ***National Agricultural Research Laboratory (NARL) at Kawanda in Wakiso district*** are investigating the productivity of a new plant, but they are faced with the challenge of light and carbon dioxide concentration that usually regularly within few hours interval. They investigated and determined the changes in the main photosynthetic intermediates, *ribulose bisphosphate* (RuBP), *glycerate phosphate* (GP) and *triose phosphate* (TP) during the day and their findings were plotted as follows.



To eradicate famine and improve food security in different regions of the country, the team grew samples of the plant in ***Central*** and ***Northern*** Uganda. Central region is cool and has a relatively high carbon dioxide concentration due to the many established factories than north. They then compared the plant under study with the native plants in the areas and obtained the following data.

Aspect determined	***Plant under study***	***Plants in central***	***Plants in north***
Compensation period (ppm)	9	10	50
Saturation point (ppm)	350	360	450
Optimum temperature (^{O}C)	32	30	10 - 25
Growth rate (gm^{-2}d^{-1})	49	50 – 54	34-39

Task

(a) Explain how light intensity affected the photosynthetic processes in the plant that resulted in the changes in the relative concentrations of the photosynthetic intermediates.

(b) Explain physiological adaptations that enabled the plant to survive in central than in north.

(c) Which recommendations would you give to the research team so as to improve food security in northern Uganda?

ITEM 3

A study was conducted to compare biochemical activities related to the endomembrane system and material movement in human liver cells and Ugandan maize leaf cells. The researchers measured:

- The rate of protein secretion by the endoplasmic reticulum (ER) and Golgi apparatus (nmol protein/hour/10^6 cells)
- The rate of endocytosis measured by vesicle formation counts per hour per cell.
- The rate of water movement across cell membranes under different osmotic conditions (µl water/min/10^6 cells)
- The permeability of membranes to potassium ions (K^+) measured in moles per hour per gram of tissue

The data is shown below:

Cell Type	Protein Secretion Rate	Endocytosis Rate	Water Movement Rate	K^+ Membrane Permeability
Human Liver	400	250	30	1.2×10^{-5}
Maize Leaf	220	150	50	4.5×10^{-6}

Task

a) Compare the protein secretion rates in liver and maize leaf cells, explaining the role of the endomembrane system in these differences and how endocytosis rates reflect the cellular activity related to material uptake in these cell types.

b) Explain the differences in the water movement rate and potassium ion membrane permeability across cell membranes these cells and suggest the implications for cellular physiology in plants versus animals.

c) Based on the data, propose how understanding these cellular processes could help Ugandan agricultural or medical research.

ITEM 4

Since 1990, scientists at the **Namulonge Agricultural and Animal Production Research Institute** have developed nine varieties of cassava that are both resistant to the cassava mosaic virus and produce much higher yields than older varieties. In one of their investigations on the inheritance of a novel disease resistance trait in local Ugandan varieties of cassava (*Manihot esculenta*), a staple food crop. It was suggested that the trait, tentatively named "CMD-Res," confers resistance to Cassava Mosaic Disease (CMD), a viral disease-causing significant yield loss. Initial studies suggested that CMD-Res is controlled by a single gene with two alleles: *R* (dominant, conferring resistance) and *r* (recessive, conferring susceptibility).

The research team conducted controlled crosses between a homozygous resistant variety (RR) and a susceptible variety (rr). The F1 generation was then self-crossed to produce the F2 generation. A field trial was conducted with 500 F2 plants. The plants were genotyped using a PCR-based marker linked to the CMD-Res gene, and their CMD resistance was assessed based on a visual scoring system (1 = highly susceptible, 5 = highly resistant).

Data:

Genotype	Number of Plants	Average CMD Resistance Score
RR	120	4.8
Rr	250	4.2
rr	130	1.5

Task

a) Based on the data, does the inheritance of CMD-Res in cassava follow Mendelian principles? Show your calculations and state your conclusion.
b) Describe the structure of the genetic material that carries the CMD-Res gene and explain how the sequence of nucleotides in the *R* allele might differ from the *r* allele, leading to the observed difference in CMD resistance. Discuss the roles of transcription and translation in expressing the CMD-Res trait.
c) A local agricultural company wants to develop and market CMD-Res cassava varieties to Ugandan farmers.
   (i) Describe two different breeding strategies that the company could use to efficiently incorporate the *R* allele into popular but susceptible cassava varieties.
   (ii) Discuss potential benefit and risk associated with the widespread adoption of CMD-Res cassava in Uganda.

ITEM 5

The Uganda National Council for science and technology has considered and approved more than 17 confined field experiments of genetically modified crop events following technical recommendations from the National Biosafety Committee (NBC). A research team of the council is investigating the biochemical adaptations of two common crop plants, maize and cassava, that grow in regions with varying soil salinity levels. Soil salinity affects enzyme activity and cell membrane integrity, which in turn influences plant growth and yield. Researchers collected root samples from maize and cassava plants grown in low-salinity (control) and high-salinity soils from different Ugandan agricultural zones. They measured:

- The activity level of the enzyme catalase (which breaks down hydrogen peroxide, a harmful reactive oxygen species)
- The membrane permeability of root cells (using electrolyte leakage percentage)
- The concentration of proline (an amino acid that accumulates under stress and protects cell membranes)

The data obtained are as follows:

Plant	**Soil Condition**	**Catalase Activity (µmol H_2O_2 / min /g tissue)**	**Membrane Permeability (% electrolyte leakage)**	**Proline Concentration (µmol/g tissue)**
Maize	Low Salinity	120	15	4.2
Maize	High Salinity	65	42	11.5
Cassava	Low Salinity	135	12	3.8
Cassava	High Salinity	85	35	9.0

Task

a) Analyze how salinity affects catalase activity in maize and cassava and what does the observed change imply about the oxidative stress experienced by the plants, stating which of the two crops shows better biochemical adaptation to salinity stress? Justify your answer.
b) Explain the significance of proline accumulation in plants under high salinity, relating it to enzyme activity and membrane stability.
c) Propose biochemical or physiological strategies Ugandan farmers could use to improve crop tolerance to salinity based on the enzyme and membrane data.