Montogue

AP Biology

15 Free-Response Questions

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Question 1: RNA and Translation. Shown below is the sequence of the 13 first nucleotide pairs in the coding region in a gene.

5′ — **A T G** A G T T G G C C T G — 3′
3′ — **T A C** T C A A C C G G A C — 5′

The first three base pairs, highlighted in blue, correspond to the amino acid methionine. The following table lists a few codons of messenger RNA and the corresponding amino acids.

RNAm codon	Amino acid
ACC	Threonine
AGU	Serine
AUG	Methionine
CCU	Proline
CUG	Leucine
GAC	Aspartic acid
GGC	Glycine
UCA	Serine
UGG	Tryptophan

A. Write the nucleobase sequence of the mRNA transcribed from the given segment of DNA.
B. Write down the three amino acids that follow methionine in the peptide coded by the RNAm segment in question.
C. Suppose a mutant version of the gene transcribes a RNA strand similar to the one you gave in part (A), but with a deleted sixth nucleobase, counting from left to right. What would be the first three amino acids of a peptide translated by this mutant RNA?

Question 2: Associating RNA with Phenotypes. Consider the following DNA sequences extracted from individuals of unknown species.

Individual	DNA segment
Individual I	ATTGGCCATATGACC
Individual II	TGAGCGAATGTTCTA
Individual III	CCGTAGATCAGTACA
Individual IV	ATATAGCTTTCACGG
Individual V	GGATCATTGGAATGC

Suppose these DNA strands were compared with specific RNAm sequences. The processes in which the RNAm sequences are involved have already been determined, and are listed below.

CCUAGUAACCUUACG	Production of lactase
GGCAUCUAGUCAUGU	Deficiency in the development of maturation of monocytes
UAUAUCGAAAGUGCC	Deficiency in the production of cholecystokinin
ACUCGCUUACAAGAU	Production of ecdysone hormone
UAACCGGUAUACUGG	Production of osteoblasts

Using this information, answer the following questions.

A. Which of the DNA samples most likely belongs to an arthropod?

B. Which individual is likely deficient in terms of its capacity to digest lipids?

C. Which individual is the most prone to suffer from infectious diseases?

Question 3: Vincristine and Microtubules. Vincristine sulfate is a substance used in the treatment of tumors. This chemotherapy agent penetrates cells and binds to tubulin, blocking the formation of microtubules.

A. Which cellular process, important for cancer treatment, is blocked when microtubules are not formed? What role do microtubules play in this process?

B. In the treatment, the chemotherapy agent can be deployed inside liposomes, small vesicles bounded by double layers of lipoprotein. Which cellular structure has a composition similar to that of a liposome and can interact with it, facilitating penetration of vincristine in the cell?

Question 4: Hemoglobin and the Buccal Mucosa. Hemoglobin, the protein responsible for the transport of oxygen from the lungs to the bodily tissues, is produced in the precursor cells of red blood cells. Sickle cell disease is a genetic disease caused by abnormal modifications in hemoglobin. The disease is caused by a mutation on the HBB gene: instead of a glutamic acid amino acid, the protein has a valine unit.

From the cells of a buccal mucosa of a person with SCD, researchers extracted:

→ Total genome DNA (genomic DNA); and

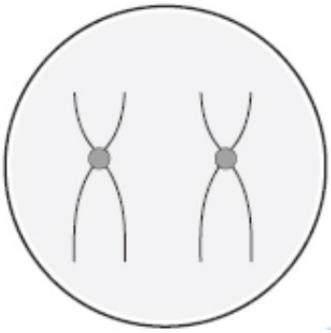
→ Messenger RNA, which was used as a mold for the synthesis of complementary DNA via reverse transcription (RNA → DNA).

A. Is it possible to detect the exchanged nucleobase (that is, the base that led to the replacement of the amino acid in hemoglobin) in the complementary DNA extracted from cells of the buccal mucosa? Explain.

B. Is it possible to detect the exchanged nucleobase in the genomic DNA extracted from cells of the buccal mucosa? Explain.

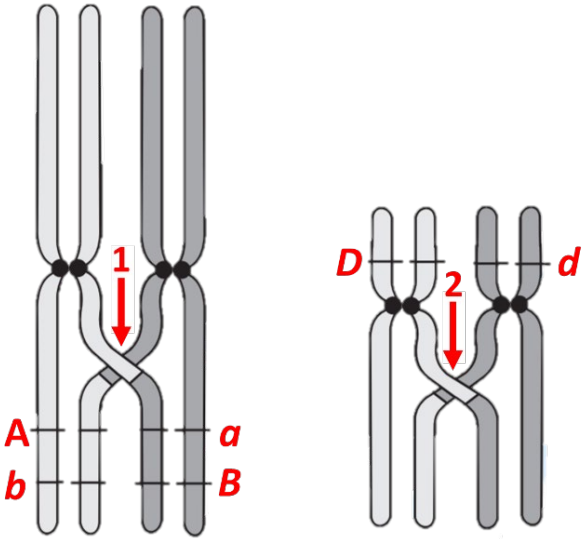
Question 5: Gametes and Crossing-Over. In an animal's somatic cells, a chromosome has alleles $M1$, $Q1$, $R1$ and $T1$, and its homologous has alleles $M2$, $Q2$, $R2$ and $T2$.

A. Shown below is a germ cell of this animal in which the two chromosomes in question are duplicated. Arrange the alleles of loci M, Q, R, and T in these chromosomes.



B. Supposing a single permutation occurred between loci Q and R as the germ cell divided, draw up the four resulting gametes with the pertaining alleles in loci M, Q, R, and T.

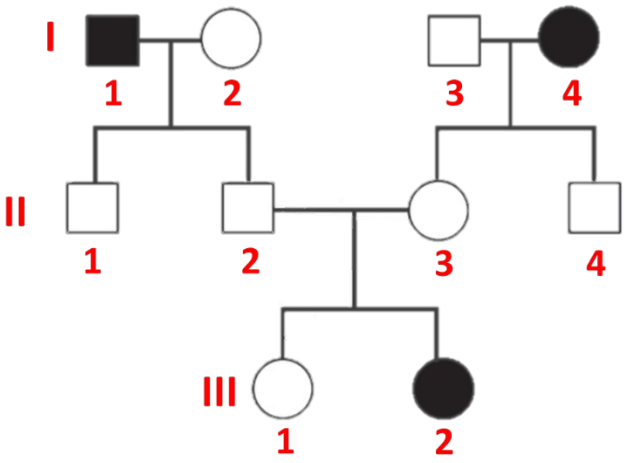
Question 6: Gametes and Independent Segregation. The following diagram shows, in a cell undergoing meiosis, two pairs of chromosomes with three heterozygous genes: A/a, B/b, and D/d. Over the course of meiosis, the chromosomes recombined in the regions indicated by 1 and 2.



A. Relatively to the allele pairs mentioned, how many types of gamete will the cell form?
B. Which pairs of gametes have independent segregation?

Question 7: Inbreeding and Phenylketonuria. In families constituted of unions between first cousins, there is a higher incidence of genetic disorders than in the offspring of couples with no consanguinity.
A. Why is the incidence of genetic disorders greater in inbreeding?
B. Phenylketonuria (PKU) is a genetic disorder that affects an enzyme responsible for the metabolism of the amino acid phenylalanine. In the absence of this enzyme, phenylalanine may accumulate in the body and affect a child's neurologic development. If the condition is found in a newborn, their diet must be controlled. Which type of nutrient should a child with PKU avoid: carbohydrates, lipids, or proteins? Why?

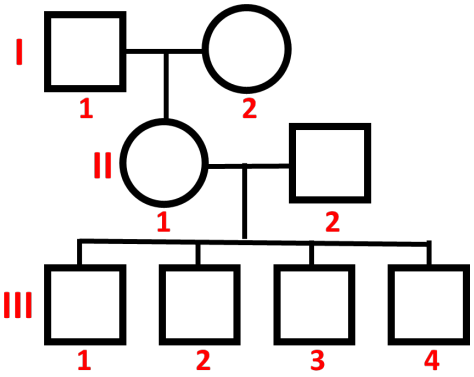
Question 8: Simple Mendelian Genetics. The following pedigree shows three generations of a family. Individuals represented by dark shapes are affected by a recessive disorder; individuals represented by clear shapes are normal.



A. Which individuals in the pedigree are certainly heterozygous?
B. What is the probability that couple II.2-II.3 will have two more children, both male and affected by the disorder?

Question 9: Sex Linkage. The genes that determine color sight and synthesis of G6PD (glucose-6-phosphate dehydrogenase) are located in the human X chromosome. Recessive allele d determines color blindness and recessive allele g determines deficient G6PD synthesis.

In the following pedigree, man I-1 is both color blind and G6PD-deficient, whereas his wife I-2 is homozygous and normal for both traits. The daughter II-1 of this couple married man II-2, who had normal sight and no G6PD deficiency. The four children of this couple, III-1, 2, 3 and 4, each had a different combination of phenotypes relatively to color sight and G6PD synthesis.



A. What are the genotypes of I-1 and I-2?
B. What are the genotypes of II-1 and II-2?
C. What genotypes and respective phenotypes can the children of II-1 and II-2 have?
D. Using the term “permutation” in your answer, explain how III-1, 2, 3 and 4 inherited different genotypes.

Question 10: Cloning. Upon being questioned about the possibility of cloning animal populations to prevent their extinction, a scientist proposed two techniques, I and II, that may be used with this purpose. The two techniques are detailed below.

Technique I	Technique II
1. A female (animal X) is stimulated with hormones to produce egg cells. 2. The female is artificially inseminated. 3. After a few days, a fertilized cell is extracted from the female. 4. The cell is implanted in the uterus of another female of the same species, originating a new animal.	1. Somatic cells are extracted from the body of an animal (animal Y). The cell nuclei are removed. 2. Unfertilized eggs are extracted from a second animal (animal Z). The nuclei of the eggs are removed. 3. The nucleus removed from the somatic cell of animal Y is implanted in the anucleated egg cell of animal Z. The new cell begins to divide itself, forming an embryo. 4. The embryo is reimplanted in the uterus of a third animal (animal W), originating a new animal.

A. Are all the animals produced by technique I genotypically equal to animal X? Explain.
B. The animal formed by technique II can be labeled a "clone" of individual Y, Z, or W? Explain.

Question 11: GMOs. There are mechanisms that hinder the exchange of genes between different species. In the past few years, however, the boundaries between species have been transcended with the advent of genetically modified organisms (GMOs). The implementation of soybean and other transgenic plants has generated sizable controversy because not much is known about the long-term risks of this technique.
A. Name two mechanisms that block or hinder the exchange of genes between different species.
B. Define a genetically modified organism.
C. Name one benefit associated with the use of GMOs and one possible risk that use of GMOs may pose to the environment or to humans.

Question 12: A Food Web. Moths of species *Diataea saccharalis* place their eggs on the lower part of sugarcane leaves. These eggs hatch into larvae that penetrate the stem of sugarcane plants and feed on parenchyma. The recesses excavated by these larvae serve as entry points for *Colleotrichum falcatum*, a species of funghi that feeds on sucrose stored in the stem. One way to fight *Diataea* in sugarcane cultures is to introduce populations of *Cofesia flavipes* wasps, whose eggs are placed over the moth larvae. After the eggs hatch, the wasp larvae begin to feed on the moth larvae.

A. Based on the text above, name the organisms that occupy the following trophic levels:

A_1) Producer;

A_2) Primary consumer;

A_3) Secondary consumer;

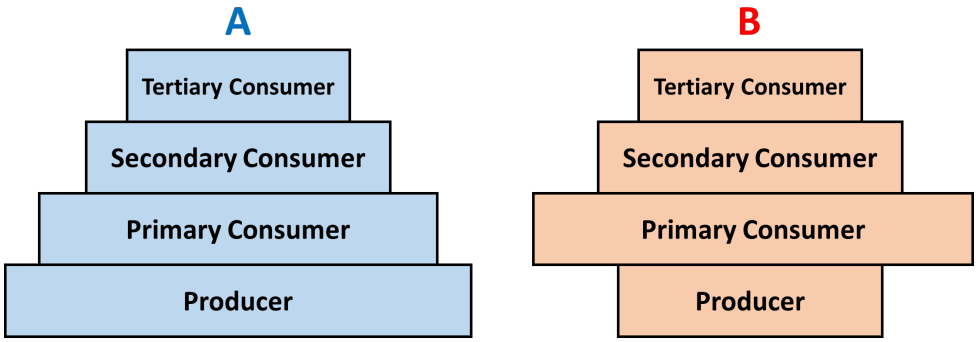
B. Among the interactions described in the text above, name one that you would classify as an example of parasitism.

Question 13: Speciation. Due to the appearance of a geographic barrier, two populations of the same species were isolated for thousands of years. As a result, the two populations became morphologically distinct.

A. How can one explain the fact that the two populations became morphologically distinct with time?

B. Regarding reproduction, define the two situations that might occur if the geographic barrier disappears and the two populations are placed in contact again. In which situation will speciation have occurred?

Question 14: Biomass Pyramids. The following pyramids represent the biomass in different trophic levels for two types of ecosystem.



A. Which pyramid, A or B, represents a typical terrestrial ecosystem? Which one represents a typical marine ecosystem?
B. Explain how sulfur dioxide (SO_2), released in the atmosphere by industrial pollution, might affect the populations of the various trophic levels in pyramid A.

Question 15: Lichens. In 2007, the European Space Agency attempted to investigate whether an organism can travel from one planet to another "on board" of meteorites. In their experiment, scientists sent to space cultures of lichens, chosen because of their inherent resistance to demanding environments, and placed them in devices that simulated conditions of a moving meteorite.
A. What are the organisms involved in the formation of lichens?
B. Some experiments have shown that, when the organisms that constitute lichens are separated, one of the organisms has a better physiologic performance than when it is in a liken-like association. This has led some to question the notion that lichens are mutualistic associations. Why is that the case?

Solutions

Q.1

A) The mRNA segment is shown in red.

B) The first base triple after the methionine codon is AGU, which, according to the table, corresponds to serine. The next codon is UGG, which corresponds to tryptophan. The third codon is CCU, which corresponds to proline. The three amino acids translated by the RNAm segment, in sequence, are serine – tryptophan – proline.

C) The mutated RNA strand in written in green below.

The first codon continues to be AUG, so the first amino acid coded by the RNA is still methionine. Likewise, the next codon continues to be AGU, so the second amino acid is still serine. The third codon is GGC, so the third amino acid now becomes glycine.

Q.2

A) The arthropod is certainly the individual that produces ecdysone, a hormone involved in insect molting. This individual produces the RNAm sequence ACUCGCUUACAAGAU, which corresponds to DNA segment TGAGCGAATGTTCTA. With reference to the first table, we surmise that individual II is the arthropod.

B) Cholecystokinin is a peptide hormone associated with the digestion of fat and protein; it follows that an individual with a deficiency in the production of this hormone will have a defective fat-processing capability. Of the mRNA sequences given, the one linked to deficient cholecystokinin production is UAUAUCGAAAGUGCC, which corresponds to the DNA strand sampled from individual IV.

C) Monocytes are white blood cells, and as such play a crucial role in an individual's immune system; absence of these cells leads to a severely depressed immune response to pathogens. This is expected to occur in the owner of the mRNA sequence GGCAUCUAGUCAUGU, which was implicated in deficient development and maturation of monocytes. This sequence corresponds to the DNA sampled from individual III.

Q.3

A) The process hindered is cellular division by mitosis. Microtubules constitute the mitotic spindle, which is crucial for the separation of chromosomes during anaphase.

B) The cellular structure with a composition similar to a liposome is the plasma membrane; both structures are endowed with double layers of lipoprotein. This structural similarity enables the liposome to fuse with the membrane wall and introduce the chemotherapy agent directly in the cytoplasm of the target cell.

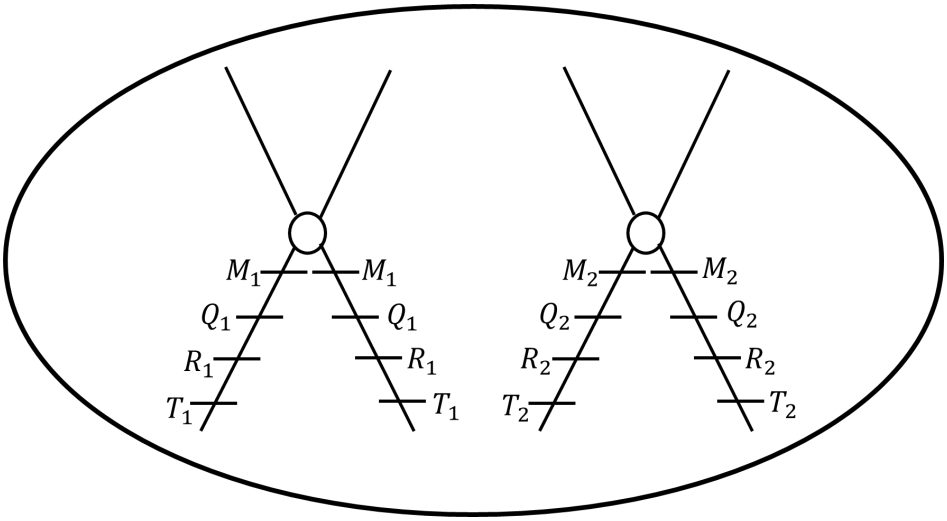
Q.4

A) No. Since the buccal mucosa cells do not produce hemoglobin, their DNA does not express the gene that produces the RNAm for this protein. Thus, it will not be possible to detect the base change in the complementary RNA extracted from the DNA of the mucosa cells.

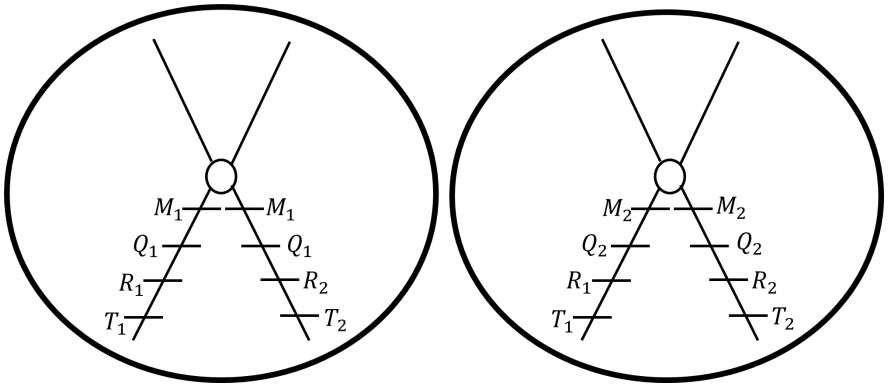
B) Yes, because the human genome is the same in all somatic cells.

Q.5

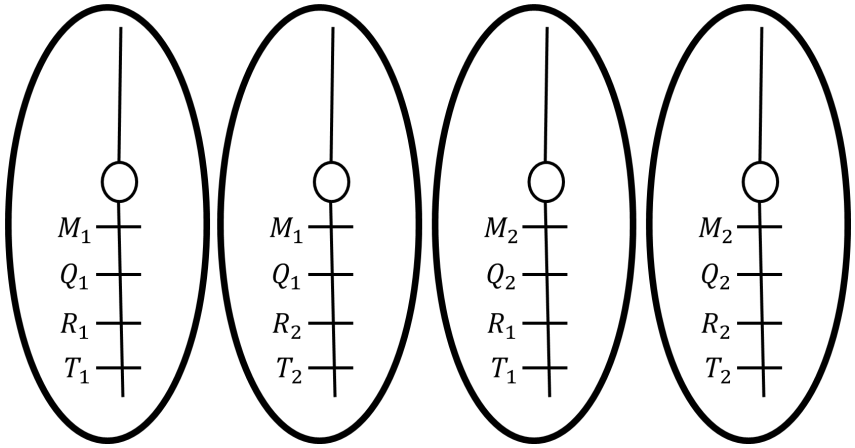
A) The alleles are arranged as follows.



B) After meiosis I, the following cells are formed.



After meiosis II, the following gametes are formed.



Q.6

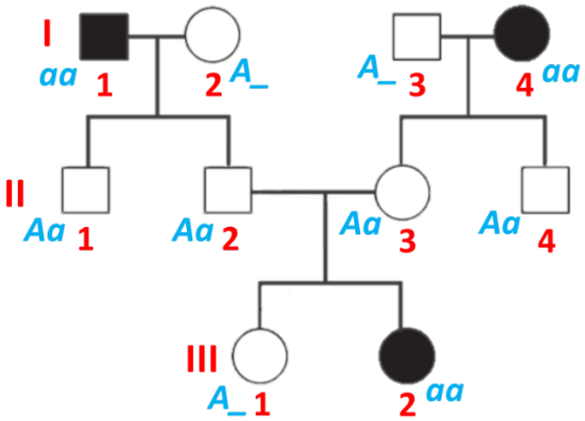
A) The cell can produce four types of gamete; the possible gamete genotypes are AbD, Abd, aBD, and aBd.
B) There are two pairs of gamete with independent segregation, namely (1) Aa and Dd; and (2) Bb and Dd.

Q.7

A) Over the course of several generations, inbreeding tends to increase the incidence of deleterious genes – especially recessive ones – that may be present in a family's gene pool, thereby augmenting the frequency of genetic disorders. This is in contrast to crossings between unrelated individuals, where a diverse gene distribution and genetic recombination ensure that genetic disorders are not easily transmitted to the offspring.
B) Phenylalanine is an essential amino acid, and amino acids are the building blocks of proteins. It follows that a child with PKU must avoid consuming protein-rich foods such as meat and eggs.

Q.8

A) All four individuals in generation II are necessarily heterozygous, as shown below. These individuals inherited a recessive allele a from the affected parent and a dominant allele A from the unaffected parent, which may or may not be heterozygous. Daughter III.1 also may or may not be heterozygous.



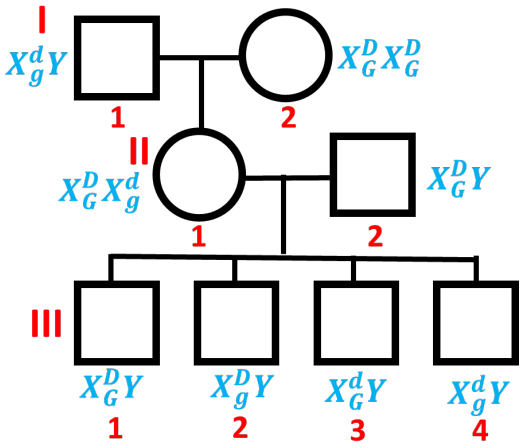
B) The probability that a child will be male is 1/2. Referring to the following Punnett square, the probability that the child will be affected is 1/4. It follows that the probability that the couple will have two male children, both affected by the disorder, is

$$p = \left(\frac{1}{2}\times\frac{1}{4}\right)\times\left(\frac{1}{2}\times\frac{1}{4}\right) = \boxed{\frac{1}{64}}$$

	A	a
A	AA	Aa
a	Aa	aa

Q.9

A,B) The genotypes of each individual are shown below. Note that III.1 to III.4 need not necessarily have the genotypes drawn below; all we know is that each child of II.1-II.2 has a *different* genotype combination relatively to the two traits at hand.



C) Child III-1 has genotype X_G^DY and phenotype combination normal sight-normal G6PD synthesis. Child III-2 has genotype X_g^DY and phenotype combination normal sight-deficient G6PD synthesis. Child III-3 has genotype X_G^dY and phenotype combination color blindness-normal G6PD synthesis. Child III-4 has genotype X_g^dY and phenotype color blindness-deficient G6PD synthesis.

D) Children III-1 to III-4 are all male, and hence should have inherited an Y chromosome from the male parent II-2 and an X chromosome from the female parent II-1. This X chromosome may have been a X_G^D chromosome, which explains the genotype of child III-1, or a X_g^d chromosome, which explains the genotype of child III-4. The X_g^D and X_G^d chromosomes found in the genotypes of children III-2 and III-3,

respectively, are made possible by permutation during gametogenesis in mother II-1.

Q.10

A) Only half of the genetic material of individuals obtained in technique I is inherited from the mother X; the other half stems from the male gamete and thus varies from one artificial fertilization to the next. In short, the animals produced by technique I are not genotypically identical to X.
B) The genetic material of the new animal is entirely derived from the nucleus harvested from the somatic cell of animal Y. Accordingly, all somatic cells of the animal formed by technique II are clones of the cells of animal Y.

Q.11

A) Several mechanisms exist to block or hinder gene exchange between different species, including:
1. Habitat isolation;
2. Anatomical incompatibility of genital organs;
3. Behavioral differences in mating rituals;
4. Active reproductive cycles in different times of the year;
5. Hybrid inviability;

B) A genetically modified organism is an individual whose genetic material carries at least one gene extracted from another species, usually introduced via genetic manipulation techniques.
C) Benefits and risks of GMOs are listed below.

Benefits	*Risks*
Production of vegetables that are resistant to plagues or severe environmental conditions, leading to greater food productivity	Accidental transmission of exogenous genes to wild species, altering a population's gene pool with unpredictable results
Production of vegetables of greater nutritional value than "normal" plants	Loss of biodiversity due to large-scale homogenization of plant cultures
Mass production of substances of clinical interest, such as insulin	In humans, development of allergy to novel substances produced by genetically modified foods

Q. 12

A)
A_1) Sugarcane;
A_2) Moth larva and fungus;
A_3) Wasp larva;
B) The fact that fungi feed on the sucrose stored in a sugarcane plant is a +/− ecological interaction that could be described as parasitism.

Q. 13

A) The two populations were subjected to their own unique set of environmental conditions, and different patterns of selective pressure led, over the course of many years, to the development of distinct morphological characteristics.

B) If the two populations are placed in contact again, the individuals may or may not be capable of mating and producing fertile offspring. If they are incapable of producing fertile offspring, we can surmise that two different species will have formed.

Q. 14

A) In most terrestrial ecosystems, the biomass in the previous level is always greater than that of the next level, mostly due to the loss of energy in the transition between levels as a result of processes such as cellular respiration. Thus, A represents a terrestrial ecosystem. In marine ecosystems, the producers are unicellular algae, organisms that have much faster reproduction and much greater mortality than the zooplankton that serve as primary consumers. It follows that, in a given moment, the biomass of zooplankton is normally greater than that of phytoplankton, as illustrated in pyramid B.

B) Sulfur dioxide reacts with atmospheric water vapor, producing sulfuric acid and precipitating as acid rain that may kill plants outright or disrupt their supply of nutrients by contaminating the soil. Death or disturbance of producers eventually leads to deleterious effects on the entire food chain.

Q. 15

A) Lichens are associations between a fungus and an alga.

B) Mutualism presupposes that one organism fares better when associated with its mutualistic partner; in fact, one *depends* on the other to exist. If one organism has a better performance when not associated with its mutualistic partner, the usual definition of mutualism is violated.

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