INTERNATIONAL SECONDARY CERTIFICATE EXAMINATION
MAY 2023

BIOLOGY: PAPER II

SOURCE MATERIAL BOOKLET FOR QUESTIONS 1, 2 AND 3

SECTION A

QUESTION 1

Read the information below and use it and your own knowledge to answer Question 1 in the question paper.

INTRODUCTION

Rice is the seed of a type of grass (*Oryza sativa*). It is the world's second-most important staple* cereal crop (after maize), feeding about half of the world's population. Rice provides a large proportion of carbohydrates, but little protein and fat.

A variety of rice called 'Golden Rice' was developed in 1999 by genetically engineering rice to increase its nutritional value. The goal was to provide a solution to combat vitamin A deficiencies in developing countries.

Golden Rice has been modified to produce a golden yellow pigment called beta-carotene, which is not normally present in rice. Beta-carotene is converted into vitamin A when metabolised by the human body. The gene for beta-carotene was taken from a yellow-flowered plant called a daffodil.

Golden Rice is named for its golden colour caused by the presence of beta-carotene. Vitamin A is necessary for development of the retina in the eyes.

*staple = most important food item providing the bulk of nutrients for a certain population group

Figure 1: Appearance of white and Golden Rice

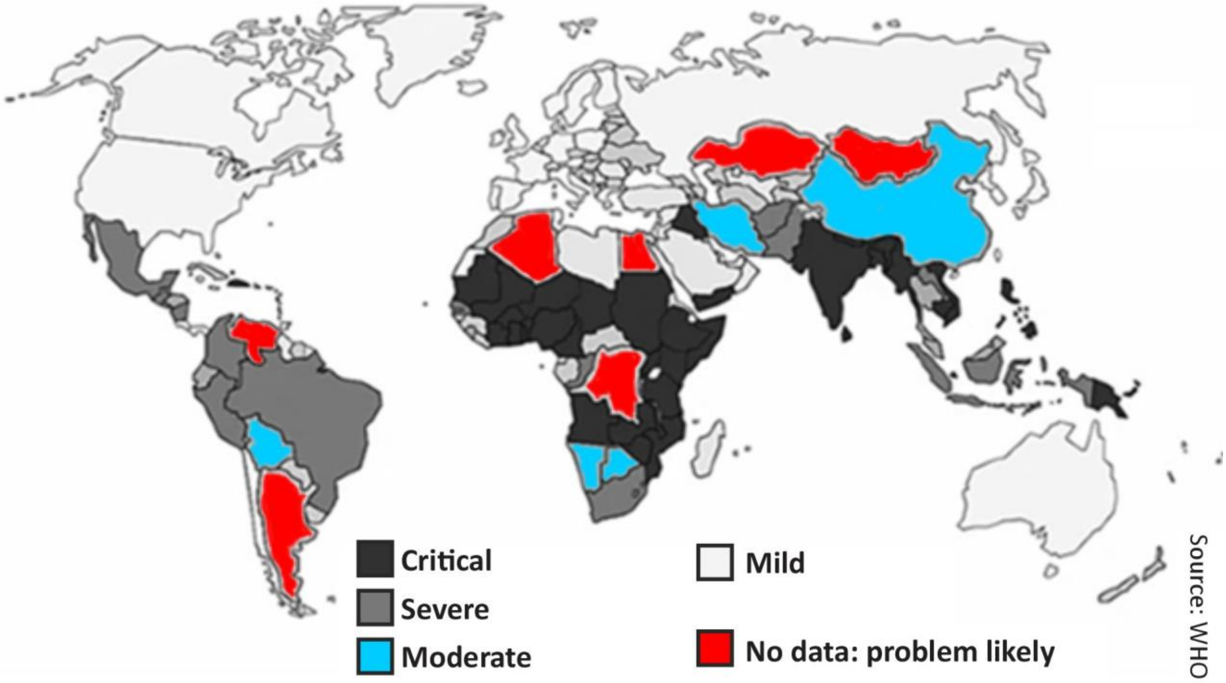
[<https://www.theguardian.com>]

Vitamin A deficiency (VAD) can have numerous negative health effects, such as:

- dryness of the eye that can lead to blindness if untreated
- reduced effectiveness of the immune system
- an increase in the severity of infections and risk of death from infections

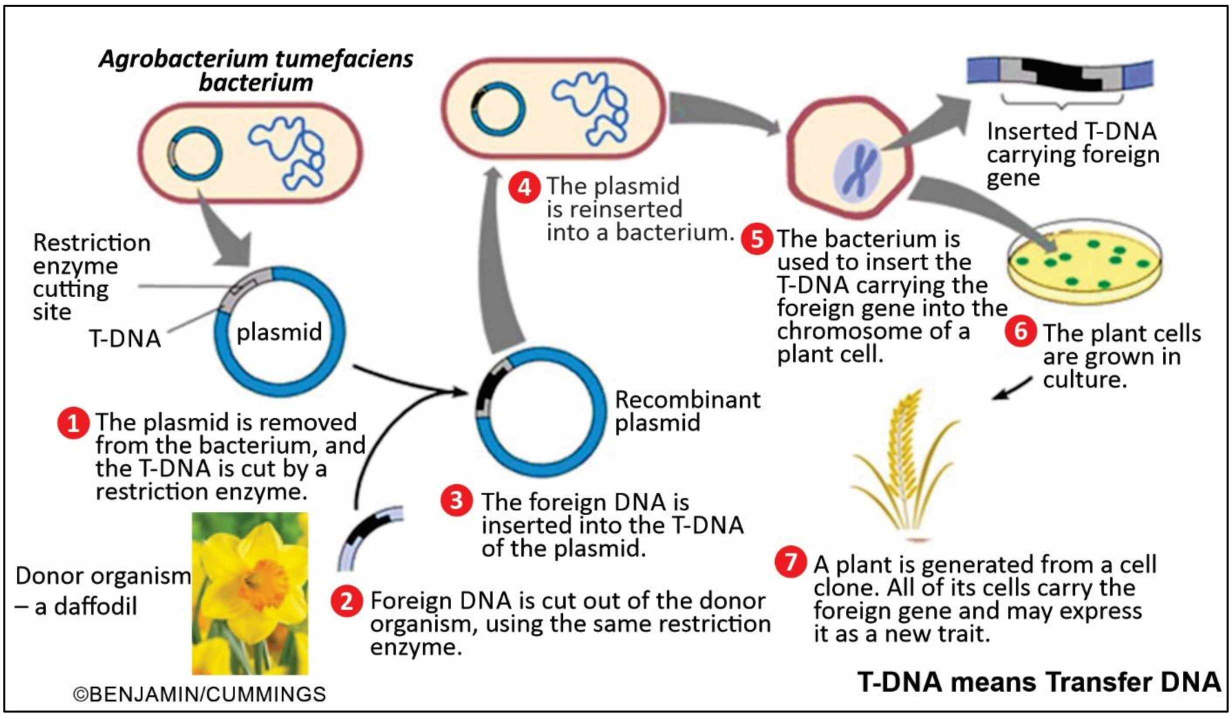
VAD is one of the main causes of preventable blindness in young children from developing countries. The World Health Organisation estimates that about 250 million preschool children are affected by VAD and that vitamin A supplements could prevent 2,7 million childhood deaths. In South Africa 45% of rural South Africans suffer from VAD.

Figure 2: World distribution of VAD



[<https://www.agricultureandfoodsecurity.biomedcentral.com>]

Figure 3: The process of genetic engineering of Golden Rice



The creation of the Golden Rice plant involves the following main steps:

1. Researchers transfer chosen genes into the rice plant embryos.
2. The embryos incorporate the new genes into their DNA resulting in the production of the desired beta-carotene.
3. The embryos grow and produce seeds.
4. The successful inheritance of the new genes allows the modified plants to pass on the inserted genes to their offspring.

THE GOLDEN RICE DEBATE

When the Golden Rice Project was first announced, it was promoted as an exciting solution to VAD in developing countries. However, opposition to the GMO rice developed.

The opposition to Golden Rice

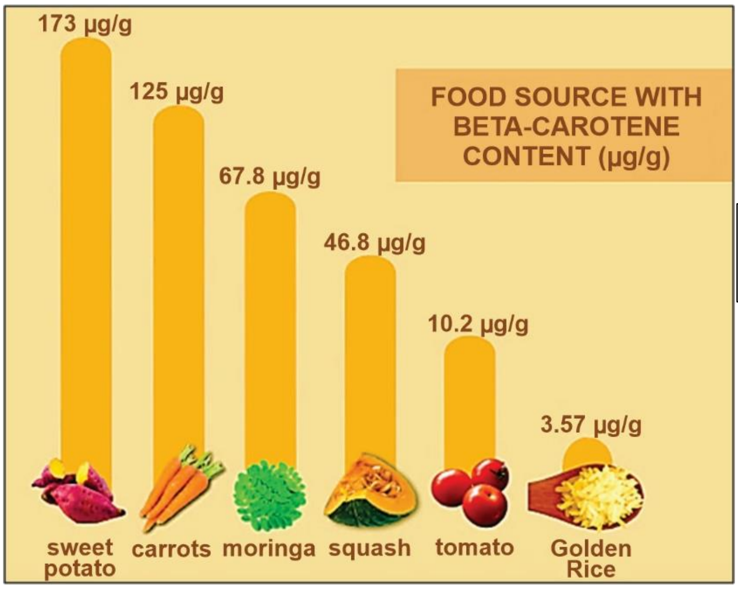
Those in opposition say the project is deeply flawed. Daily vitamin A requirements are already readily available in various natural food sources. Therefore, planting Golden Rice will not solve the VAD crisis. They point out that other planned solutions for malnutrition are cheaper and do not require GMOs, thereby making Golden Rice unnecessary.

Golden Rice risks and concerns

Many anti-GMO activists highlight the potential negative consequences of planting and consuming Golden Rice. Risks and concerns include the following:

- Beta-carotene levels in Golden Rice may not be high enough to make a difference to VAD.
- There are fears that it will cross-breed with and contaminate wild rice when the two crops are grown near one another.
- Seeds for GM plants are expensive and have been developed simply to make money for biotech companies.
- They may cause allergies.
- Genetically modified crops could pass their genes to wild species, resulting in a threat to biodiversity.

Figure 4: Beta-carotene content in other food crops



NOTE:
µg/g = microgram per gram

[Adapted: <https://www.grain.org>]

Support for Golden Rice

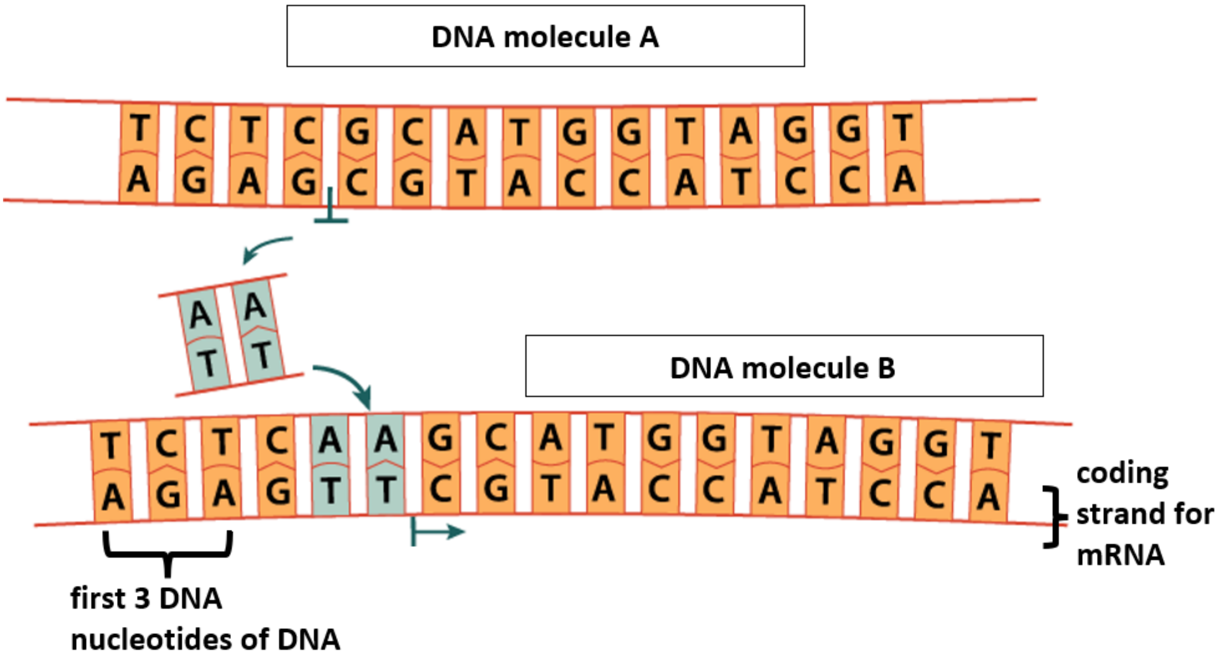
- Rice is a staple food that feeds half the world daily and is therefore an ideal source of vitamin A in countries where deficiency of this vitamin is widespread.
- Planting and consuming Golden Rice alongside other interventions (like UNICEF's vitamin supplement programme) will make more of a difference than any one intervention alone.
- The Golden Rice Project will provide seeds for Golden Rice free of charge in developing countries.
- All commercial GM crops have been shown to have no difference in food safety or environmental impact.
- The new proteins expressed in this rice are not similar to any known allergen or toxin, and they disintegrate in the digestive system.

Genetic variations in crop plants

New characteristics in crop plants are not always the result of direct genetic manipulation. They can also be caused by mutations or as a result of genetic recombination during meiosis in sexual reproduction in plants.

An example of a mutation occurring in the gene coding for beta carotene.

Figure 5: Simplified diagram showing original DNA molecule A and the DNA molecule B acquiring a mutation



[Adapted: <https://www.technologynetworks.com>]

[Adapted: UN Food and Agriculture Organisation, Corporate Statistical Database (FAOSTAT).2020]
[Adapted: <https://med.nyu.edu/>]
[Adapted: <https://sphweb.bumc.bu.edul>]
[Adapted: <https://www.vectorstock.com>]
[<https://embryo.asu.edu/pages/golden-rice>]

QUESTION 2

Read the information below and use it and your own knowledge to answer Question 2 in the question paper.

The genetic diversity of indigenous African cattle

Background

During the Neolithic period (roughly 6 000 to 12 000 years ago), ancient humans switched from a hunter-gatherer way of life to agriculture and food production. They domesticated animals and cultivated cereal grains.

One of the animals that was domesticated was an extinct species of large herbivore called an aurochs. This animal once inhabited large areas of Europe and Asia. These cattle were domesticated on at least two distinct occasions approximately 10 000 years ago: once in south Asia – leading to the Zebu or humped cattle – and the other in the Middle East – leading to the Taurine or humpless cattle.

Cattle were originally introduced to Africa from the East, Europe and India at various times in history. In Africa, the oldest archaeological evidence of domestic cattle dates back to between 6000 and 5000 BC in western Egypt. The history of African indigenous cattle and their adaptation to environmental and human selection pressure are at the root of their remarkable diversity on the African continent. As indigenous African people migrated from the north down through Africa to the south, interbreeding of their cattle took place and different traits were selected by farmers to suit the particular environmental conditions where they lived. Resistance to African parasites and diseases was also selected for. A breed is a collection of organisms within a species that have different characteristics as a result of artificial selection. The three main breeds represented in African cattle are:

(a) Zebu – this is a breed of domestic cattle originating in India. They are well adapted to withstanding high temperatures and are farmed throughout the tropical countries. In meat-producing countries they are produced largely for their beef.

(b) Taurine – they are good milk producers and are also called European cattle. They are primarily found in Europe. They do not perform well in the hot tropics and are adapted to temperate* environments.

(c) Sanga – this is the collective name for indigenous cattle of sub-Saharan Africa that were bred by hybridisation of Taurine and Zebu breeds (shown in Figure 6 on the next page).

Today there are an estimated 800 million livestock keepers across the African continent. Cattle provide nutritious and calorie-dense food, much-needed income, and nitrogen-rich manure for replenishing soils. There are few regions of Africa where cattle do not play a central role, both economically and culturally.

***temperate** = moderate rainfall and temperatures as opposed to tropical where rainfall and temperatures are extreme

Figure 6: A diagram showing development of the Sanga cattle breed.

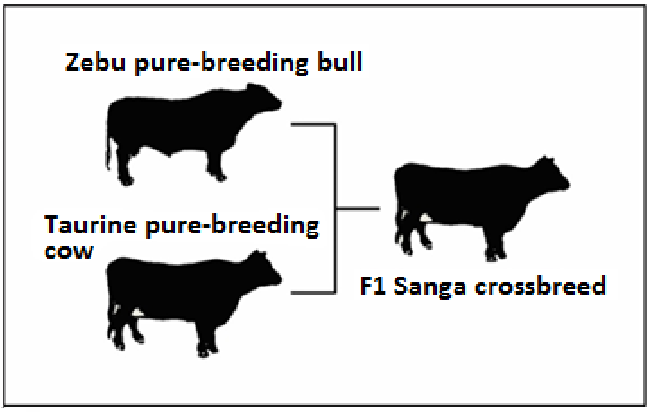


Figure 7: Some of the unique crossbred cattle of Africa

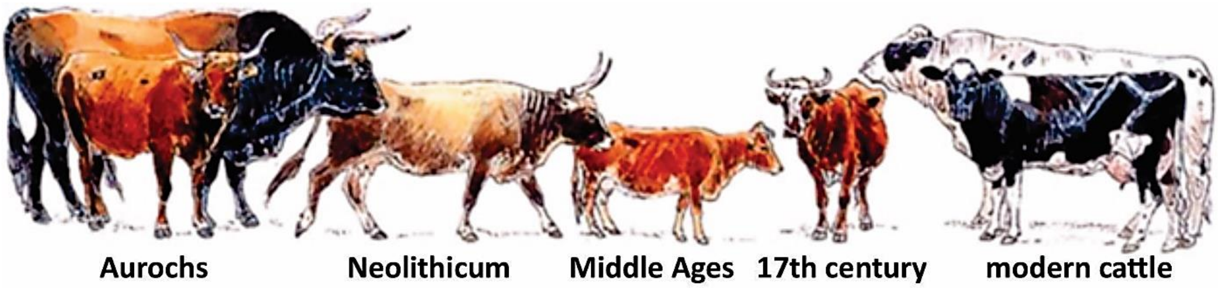
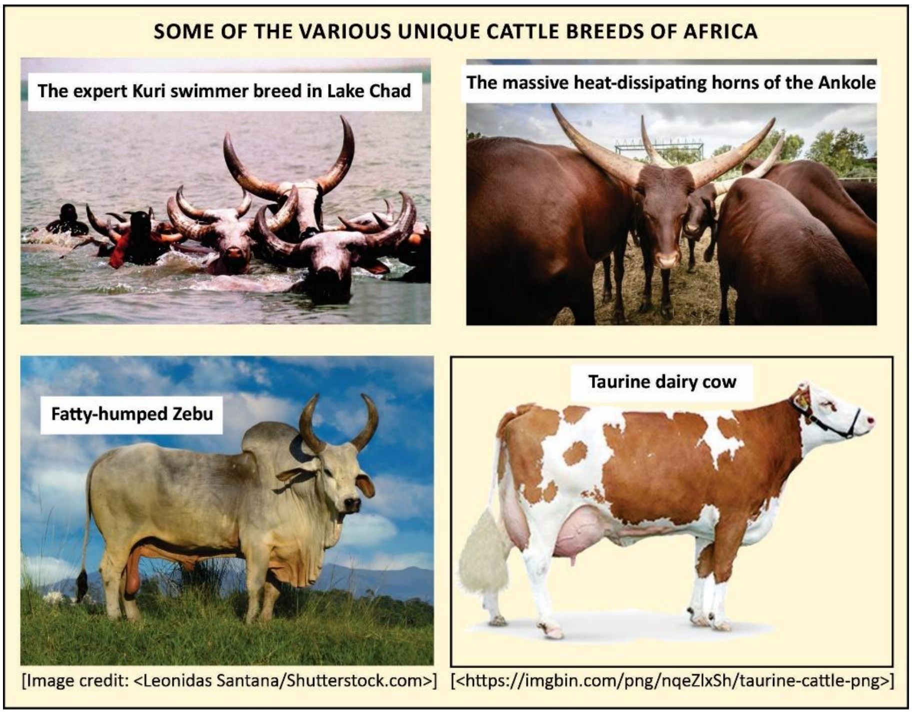


Figure 8: Different cattle breeds of Africa



African cattle breeds range from the dark-red *Ankole* of southern Uganda, with their massive heat-dissipating horns, to the *Boran* that thrive in the dusty plains of northern Kenya, to Ethiopia's sturdy *Mursi* cattle, with their prominent shoulder humps. The *Kuri* that graze on the grasses of Lake Chad are good swimmers; the *Red Fulani* can walk vast distances along the margins of the Sahara; and the famously disease-resistant *Sheko* inhabit tsetse fly-infested forests in southwest Ethiopia.

An important study done on the origin of African cattle

A study on African cattle breeds was conducted by Olivier Hanotte from the International Livestock Research Institute (ILRI) at the University of Nottingham, UK.

Hanotte and his colleagues recently published a paper detailing how African cattle acquired their adaptive characteristics. Since they were selected and bred for resilience, African cattle never became as productive, in terms of meat or milk, as breeds in more temperate climates.

Their new genome-sequencing work revealed that, about a thousand years ago, nomadic herders in the Horn of Africa began breeding the Asian Zebu cattle with local Taurine breeds. The Zebu offered traits that allowed cattle to survive in hot, dry climates. The Taurine traits provided cattle with the ability to endure humid climates, where vector-borne diseases that affect cattle, like *trypanosomiasis* (or 'sleeping sickness'), are common.

This allowed African cattle to spread across the continent and flourish into the breeds we see today. But these adaptations came at a cost. African cattle are often not as productive – in terms of growth rates, meat or milk – as are European and American cattle breeds. Canadian Holsteins, for example, can deliver 30 litres of milk per day, several times what most African breeds are capable of. Traditional African cattle, for example, produce only four to six litres of milk per day.

More productive

Today scientists at ILRI, in partnership with governmental institutions in Tanzania and Ethiopia, want to speed up the evolutionary process in cattle by identifying genetic markers* that signal both adaptability and productivity.

*A *genetic marker* is a DNA sequence with a known physical location on a chromosome.

Figure 9: Karyotype of a cow

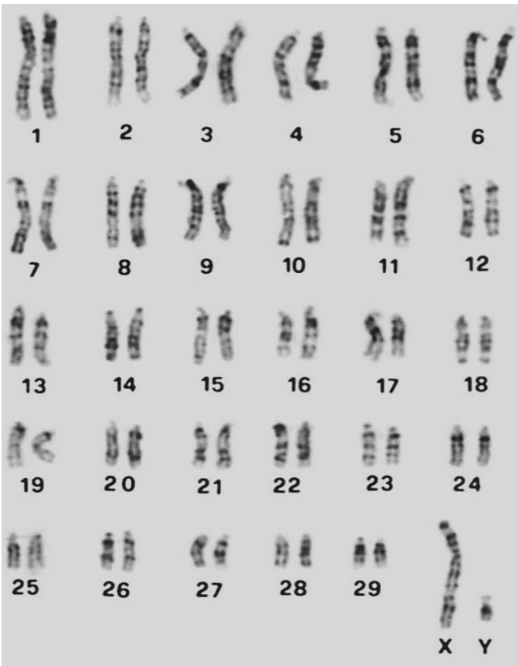
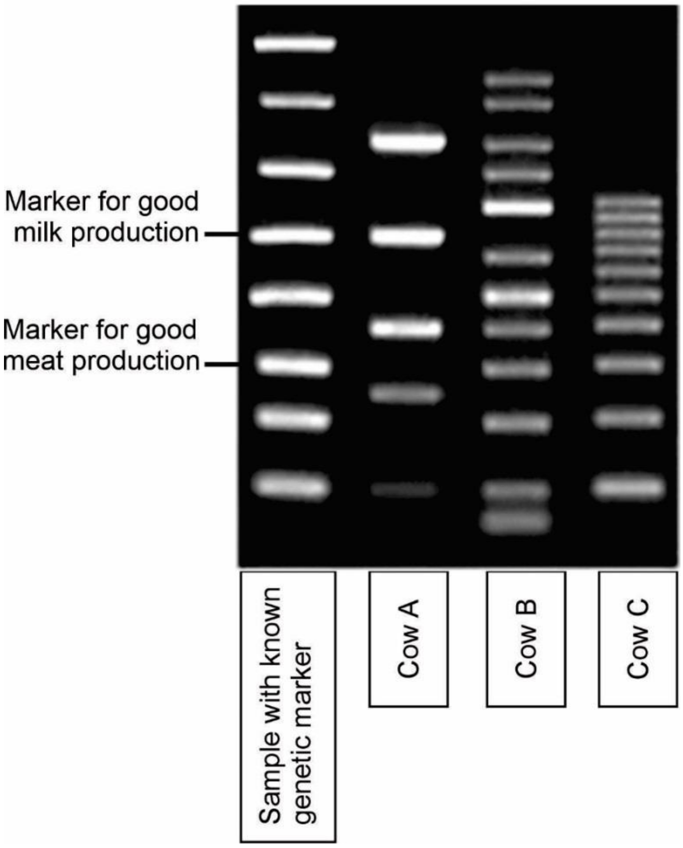


Figure 10: Image of a DNA profile that scientists could use to identify genetic markers.



[<https://www.assets.fishersci.com>]

As scientists experiment and crossbreed to increase productivity, it is vitally important to remember that the local breeds have adaptations – not all of them immediately obvious (a tolerance for episodes of drought, for example) – that have enabled their success. It is important that we do not lose those adaptive traits in the randomness of crossbreeding.

This will take innovative crossbreeding programmes that incorporate scientists, government ministries, private partners and farmers to ensure the conservation of genetic information across the long life-cycle of cattle generations. It is essential to consult and include the practical, accumulated experience of farmers in these processes.

[Adapted: <https://genomebiology.biomedcentral.com/articles>
[Adapted: <https://theconversation.com1>]
[Adapted: <https://www.sciencedirect.com>]
[Adapted: <https://unistelmedical.co.za>]

SECTION B

QUESTION 3

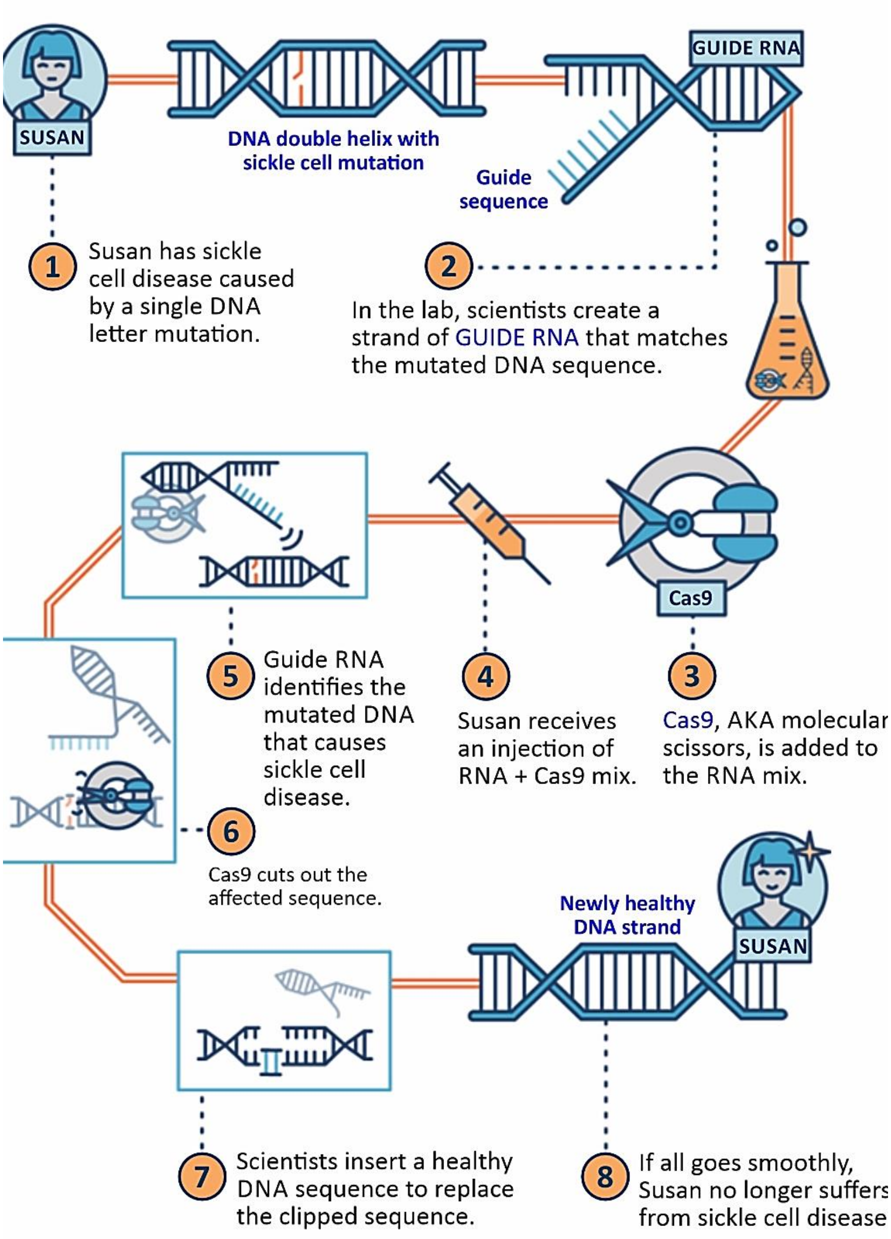
Read the information below. Use this information and your own knowledge to answer Question 3 in the question paper.

SOURCE A: WHAT IS Cas-9?

Cas9 (or 'CRISPR*-associated protein 9') is a technology that can be used to edit genes within organisms. Emmanuelle Charpentier and Jennifer Doudna were awarded the Nobel Prize in Chemistry in 2020 for the development of the CRISPR-Cas9 genome-editing technique.

*CRISPR: clustered regularly interspaced short palyndromic repeats

A diagram showing how CRISPR works



[<https://sciencebusiness.technewslit.com/?p=35920>]

[<https://www.en.wikipedia.org/>]

Gene Drive Research

A gene drive is any system that favours the inheritance of a particular set of genes. For example, research has been conducted into producing mosquitoes that are all male – this has been done using CRISPR technology. When they are released into the environment, there are few females and therefore little mating can occur. The end result is that few mosquitoes are born in the next generation, reducing the mosquito population substantially.

It can also involve producing individuals that are resistant to a certain parasite – this is also done by altering the genome of these individuals using CRISPR. Once these individuals are released into the environment, they will mate and pass on this ability to be resistant to the parasite. Eventually the parasite will become rare or even extinct.

[Adapted: <https://www.royalsociety.org>]

The following are three examples of the use of gene drives.

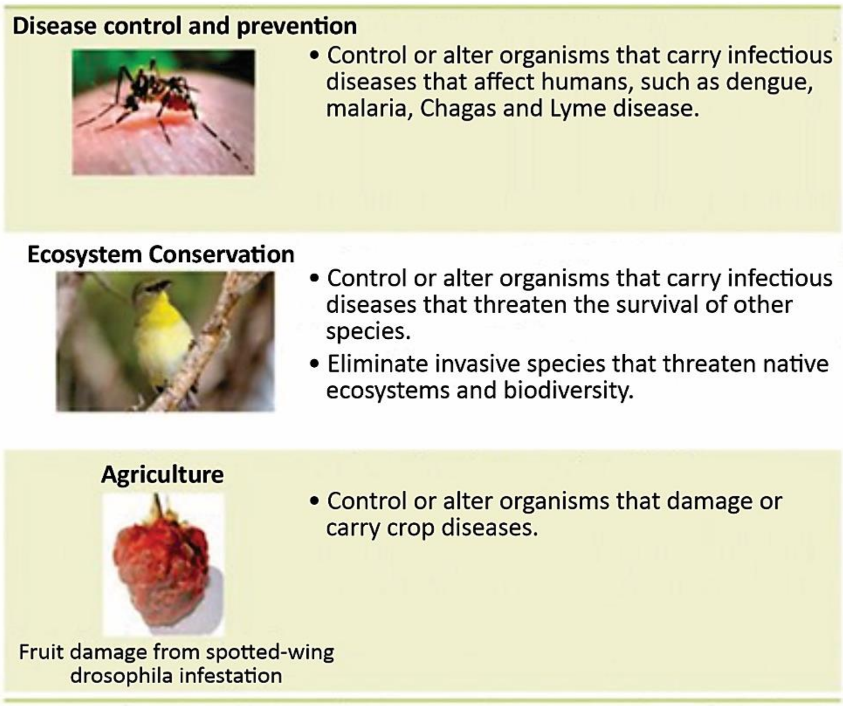


Image sources (top to bottom): US Centres for Disease Control and Preventation, US Fish and Wildlife Service, US Department of Agriculture, National Institutes of Health

[Adapted: <https://www.assets.weforum.org/>]

SOURCE B: CRISPR-Cas9 IN CROP PRODUCTION

CRISPR IN SUB-SAHARAN FOOD PRODUCTION

In this era where the world is facing threats from climate change, scientists are consistently trying to develop new crop varieties that are both high yielding and resistant to conditions, such as drought, flooding, insects and pathogens, through the use of CRISPR-Cas 9 technology.

Cassava production – an example of CRISPR technology

A cassava plant

[<https://www.weseedchange.org//>]

Cassava is a starchy edible root crop that is a staple food to most African countries. It provides excellent food security due to its tolerance to drought. However, it contains toxic substances that can cause cyanide poisoning when consumed. To avoid this poisoning, the cassava plant must be properly treated to detoxify it before it is safe for human consumption. CRISPR-Cas 9 technology has been used to remove the genes that code for the production of toxic substances in cassava.

[Adapted: <https://www.aripo.org/a/>]

African CRISPR-edited banana: KENYA

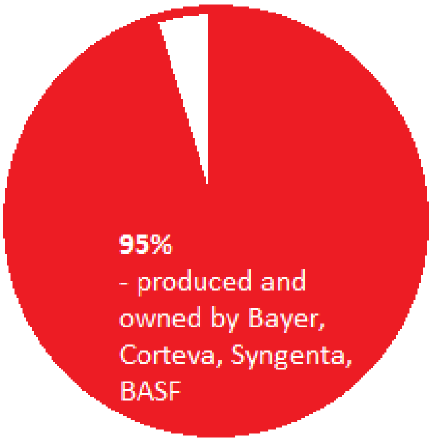
Banana Xanthomonas wilt (BXW) is a bacterial disease that spreads easily and kills any banana plant it infects. All species of cultivated bananas are susceptible to BXW disease. In places where the banana fruit is a primary source of both income and food, as is the case in some parts of Africa, an infection can threaten not only farmers' livelihoods but also entire local economies. The International Institute of Tropical Agriculture (IITA) scientists in Kenya set out to develop a disease-resistant banana using CRISPR technology.

Banana with banana Xanthomonas wilt

[Adapted: <https://www.geneticliteracyproject.org//>]

Greenpeace warns that the use of editing techniques could increase the negative effects of industrial farming on biodiversity and people.

Supporters of GM technology want the European Union to exclude them from Europe's regulations governing genetically modified organisms (GMOs). This would mean that farmers, retailers and consumers would no longer be able to reject GM products and opt for GM-free choices. It would leave the fate of our food and nature in the hands of a few corporations that have shown to have little regard for people's health and the environment.



Percentage of soybeans and maize grown in Africa that is owned and produced by multinational biotechnology companies

Eighteen African countries have banned the cultivation of GM maize.

Many African countries have introduced voluntary 'GMO-free' labelling, and the range of 'GMO-free' animal products is steadily increasing.

Gene editing has its own specific problems. For example, the cutting often happens not only at the targeted site, but also in other places in the DNA, causing off-target effects. In addition, the subsequent repair can lead to deletions and rearrangements, affecting the functions of multiple genes. These 'genetic errors' can affect the biochemical pathways in plants and potentially lead to the production of novel toxins or allergens, or different levels of existing toxins and allergens.

[Adapted: Euroseeds. 2018. Position: Plant Breeding Innovation]
[Adapted: <https://www.greenpeace.org>]

New scientific publication shows the need for detailed investigation of ecological risks

A study using camelina (*Camelina sativa*) set out to explain possible unintended effects that the release of a genome-edited crop can have on ecosystems. The CRISPR/Cas application aimed to increase the amount of oleic acid in the camelina seeds.

It was found that, besides the desired properties, unintentional effects on various processes also occurred, e.g., the production of plant hormones was affected. A change in the composition of fatty acids can affect and influence existing food webs. Apart from this, there is also the possibility that genome-edited plants will hybridise with wild species leading to unintended effects in subsequent generations. At the same time, the genome-edited camelina has the potential to persist in the environment and spread uncontrollably.

[Genome-edited plants: negative effects on ecosystems are possible. Adapted: Institute for Independent Impact Assessment of Biotechnology <https://www.testbiotech.org>]

SOURCE C: ERADICATING MALARIA WITH CRISPR

Malaria is a life-threatening disease caused by parasites that are transmitted to people through the bites of infected female *Anopheles* mosquitoes.

Recent studies have investigated the use of CRISPR to make changes in mosquito genes that could reduce their ability to transmit malaria.

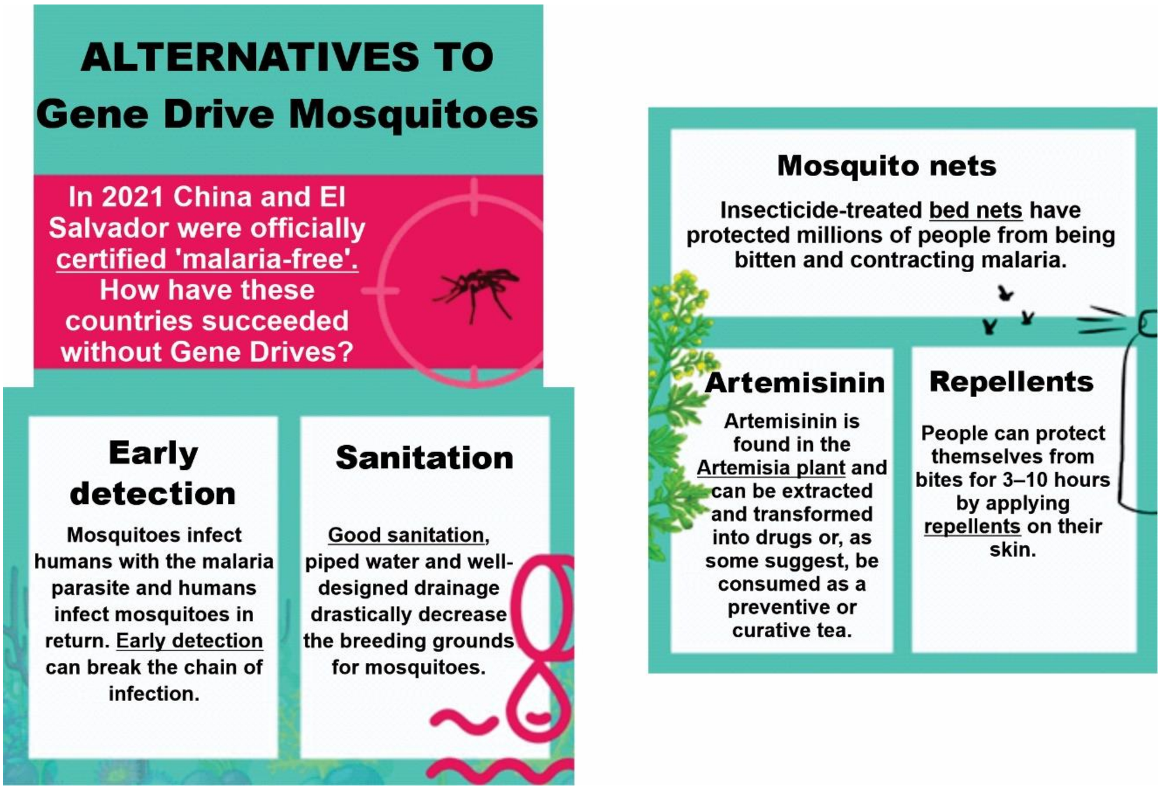
Using CRISPR technology, scientists from Johns Hopkins University were able to show that deleting the *FREP1* gene in mosquitoes made them develop more slowly into adults. They were less likely to feed on blood meals when given the opportunity and laid fewer and less viable eggs when compared to mosquitoes in the wild. They are also working on mosquitoes that have been modified so that they cannot transmit malaria.

In 2020:

- There were 241 million cases of malaria worldwide.
- Nearly half of the world's population was at risk of malaria.
- The estimated number of malaria deaths stood at 627 000.
- Africa was home to 95% of malaria cases and 96% of malaria deaths.

The study cautions, however, that 'success in a few laboratory studies to date is not sufficient to support a decision to release gene-edited and modified organisms into the environment.'

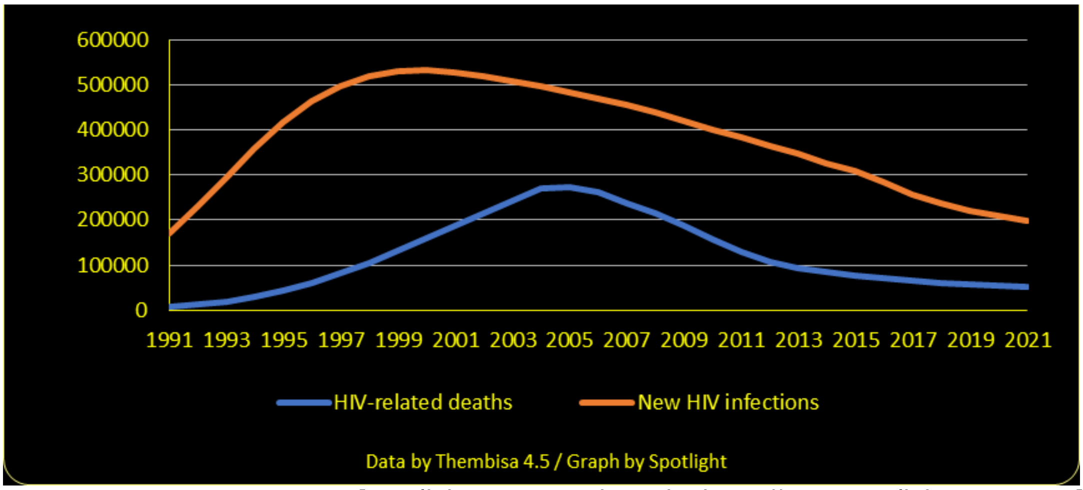
It is important to identify ways to reduce the potential for unintended consequences in the environment. Such impacts could result from mutations in the altered organisms, transfer of the edited genes into other related organisms, and transformation of ecosystems (mosquitoes are an essential part of many food chains).



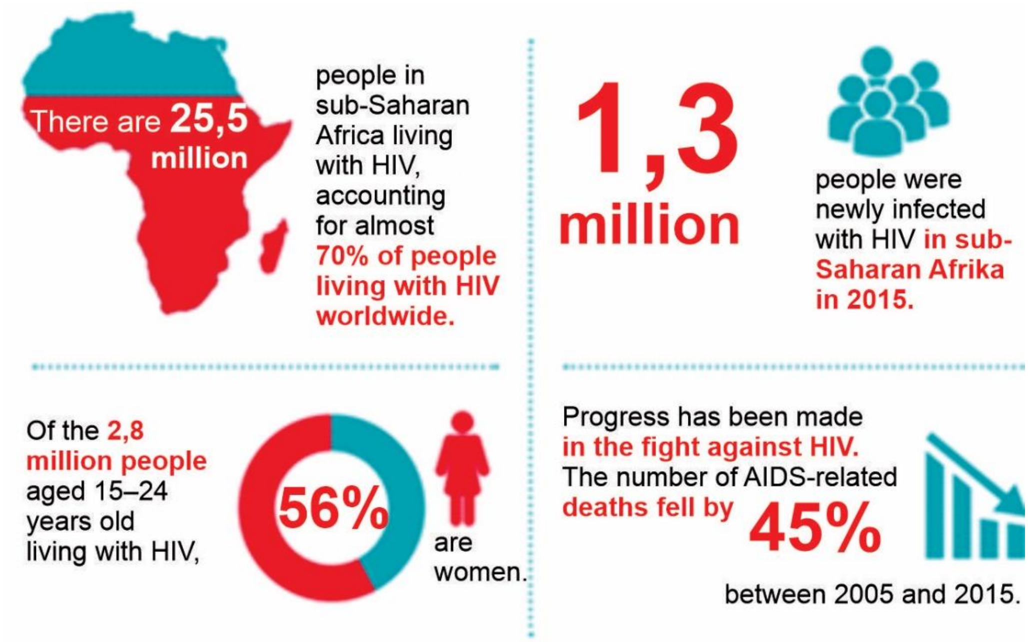
[<https://www.stop-genedrives.eu/>]

SOURCE D: ERADICATING HIV WITH CRISPR

Graph showing the number of new HIV infections and HIV-related deaths in Africa between 1991 and 2021



[Spotlight on HIV. Adapted: <https://www.spotlightnsp.co.za>]



[Adapted: <https://www.afro.who.int>]

The first people to be gene-edited – a pair of baby twin girls – may have been mutated in a way that shortens life expectancy, research suggests. Professor He Jiankui shocked the world when he genetically altered the twins to try to give them protection against HIV. Professor He's justification for the experiment was to provide HIV immunity to the embryos to avoid infection from the father, who is HIV positive.

Professor He Jiankui's method was full of technical errors and ethical mistakes. Only two of these are mentioned below:

- **The actual editing wasn't executed well.** Professor He's data had not been published or peer reviewed, so many of the details of his experiment were unclear.
- **There were problems with informed consent.** It is not clear if the participants in Professor He's trial were aware of what they were signing up for. Taking consent is a specific skill that requires training; Professor He had none of that.

Professor He's announcement was met with condemnation from hundreds of Chinese and international scientists. He has since been fired from his university post and is under investigation from Chinese authorities. A court in China sentenced He Jiankui to three years in prison for carrying out 'illegal medical practices'.

[Adapted: <https://www.theatlantic.com>]
[Adapted: <https://www.bbc.com/news/health>]