

## Interaction Between Genes and Environment

### Environmental Effects on Gene Expression & Inheritance of Continuous Characteristics

#### 1. Interaction Between Genes and Environment (G×E Interaction)

Genes determine the potential of a trait, but environment influences the degree of its expression. This combination of genetic and environmental influence is called gene–environment interaction (G×E Interaction).

#### 2. Environmental Effects on Gene Expression

##### A. Temperature Effects

- Siamese cats and Himalayan rabbits show darker extremities because the pigment-producing enzyme is active only at lower temperatures.

### Environmental Effects and Gene Expression

#### The Himalayan Rabbit

*Temperature sensitive allele*



Reared at 20°C or less



Reared at temperatures above 30°C

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#### Genetic Basis

Himalayan rabbits carry a temperature-sensitive allele of the tyrosinase gene (C gene series).

This allele is active only at cooler temperatures.

Tyrosinase is needed for melanin synthesis, so pigment production depends on temperature.

## 2. Mechanism

Warm body areas (core) → enzyme inactive → no melanin → white fur

Cooler body regions (extremities) → enzyme active → melanin produced → dark fur

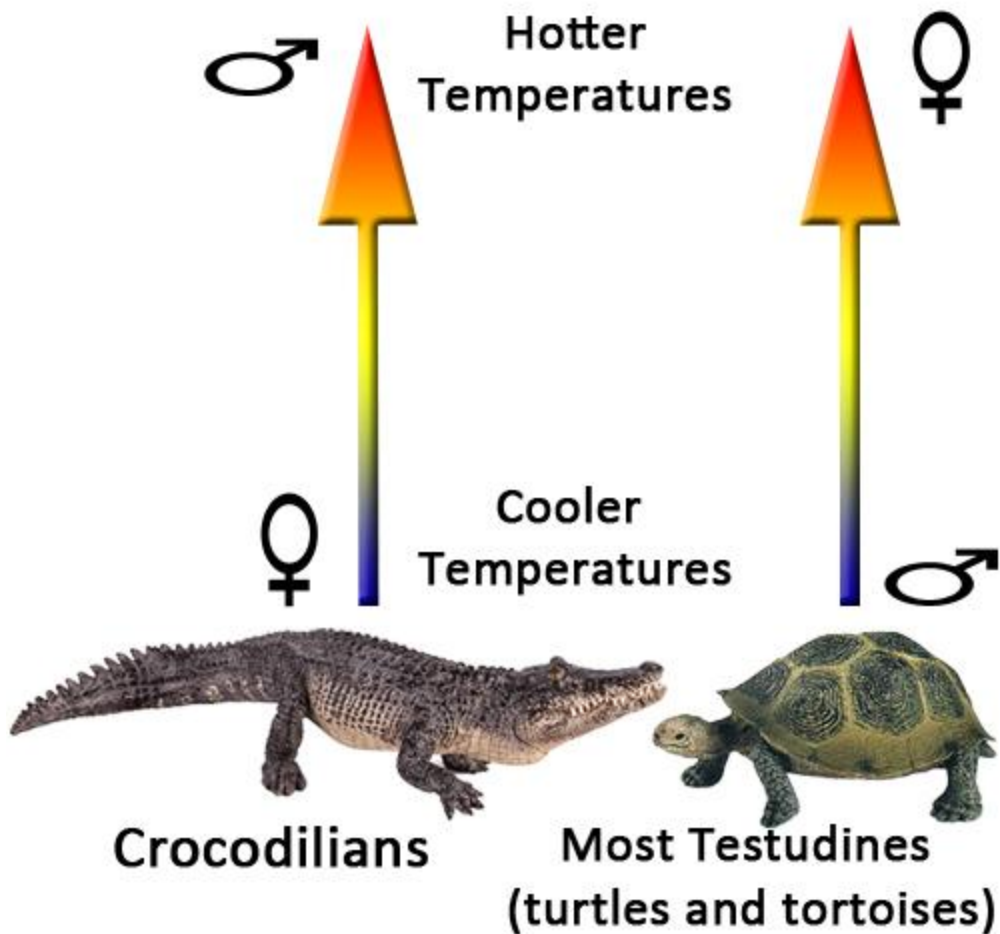
Thus, rabbits develop black ears, nose, feet, and tail, while the rest of the body remains white.

## 3. Temperature Threshold

Tyrosinase becomes inactive above ~30–33°C.

Below this temperature, the enzyme works, producing dark pigment.

- In *Drosophila*, eye color varies with temperature.
- **In crocodiles, incubation temperature influences sex determination.**



## Temperature-Dependent Sex Determination (TSD) in Crocodiles

### 1. Introduction

In crocodiles, incubation temperature plays a crucial role in determining the sex of the developing embryos. This phenomenon is known as Temperature-Dependent Sex Determination (TSD), which is a common reproductive mechanism among many reptilian species.

### 2. How Temperature Influences Sex

Crocodiles generally exhibit the Type II (FMF) pattern of TSD, where:

- Low temperatures produce females
- Intermediate temperatures produce males
- High temperatures again produce females

General temperature range:

- Below  $\sim 30^{\circ}\text{C}$   $\rightarrow$  Mostly females

- 31–33°C → Mostly males
- Above ~33–34°C → Mostly females

### 3. Temperature-Sensitive Period (TSP)

Sex determination occurs during the middle third of embryonic development. Even a small shift of 1–2°C during this period can significantly alter the sex ratio of hatchlings.

### 4. Biological Mechanism

Temperature influences the activity of aromatase, an enzyme that converts androgens into estrogens. At low and high temperatures, aromatase activity increases, promoting ovary formation. At intermediate temperatures, aromatase activity decreases, leading to testis development.

### 5. Evolutionary Significance

TSD may help maintain stable population structures and align sex ratios with environmental conditions that improve survival and reproductive success.

## B. Light Effects

Light is a major environmental factor that regulates gene expression in many organisms, especially **plants**, **fungi**, and **animals**. Light acts as a **signal**, triggering specific molecular pathways that turn genes **ON** or **OFF**.

### Introduction

Light influences a wide range of biological processes by controlling gene expression. Organisms detect light through specialized **photoreceptors** and convert this signal into biochemical responses.

- Plants require light to synthesize chlorophyll; without light, chlorosis occurs.

Chlorophyll (the green pigment in plants) is essential for photosynthesis. Its synthesis is a **light-dependent process**, meaning certain steps require light to proceed.

### Key reasons light is required:

- Light activates enzymes involved in chlorophyll biosynthesis.
- Light converts **protochlorophyllide** → **chlorophyllide**, a crucial step catalyzed by the enzyme **protochlorophyllide oxidoreductase (POR)**.
- This enzyme becomes active *only in light*.

Thus, without exposure to light, the plant cannot convert precursor molecules into functional chlorophyll.

- **Seasonal coat color changes in Arctic animals depend on daylight duration.**

## INTRODUCTION

Arctic and sub-Arctic animals such as the Arctic fox, snowshoe hare, Arctic hare, ptarmigan, and ermine display remarkable seasonal coat color changes. This adaptation enables them to blend with their environment and survive harsh seasonal conditions. These changes are primarily regulated by daylight duration (photoperiod), not temperature.

## MECHANISM OF COAT COLOR CHANGE

### 1. Photoperiod Detection

Arctic animals detect seasonal changes in daylight through the eyes. Light signals travel to the suprachiasmatic nucleus (SCN), the biological clock, which measures day length. This allows the body to anticipate seasonal transitions.



### 2. Role of the Pineal Gland and Melatonin

The pineal gland secretes melatonin during darkness. Thus:

- Long winter nights → High melatonin.
- Short summer nights → Low melatonin.

Melatonin secretion patterns help the body determine the season.

### 3. Hormonal Regulation

Melatonin influences the pituitary gland, altering hormone release, especially prolactin.

- High prolactin (summer) → Brown coat.

- Low prolactin (winter) → White coat.

#### 4. Gene Expression in Hair Follicles

Prolactin and melatonin regulate melanogenesis genes such as TYR, MITF, and DCT.

- Summer: Melanin production increases, resulting in brown pigmentation.
- Winter: Melanin production decreases, and unpigmented white hair grows.

### EXAMPLES OF ARCTIC ANIMALS

#### 1. Snowshoe Hare

Changes from brown in summer to white in winter. Photoperiod is the primary trigger, but temperature and snow cover fine-tune the exact timing.

#### 2. Arctic Fox

Shifts from a brown/gray coat in summer to a completely white coat in winter for perfect camouflage in snow-covered landscapes.

#### 3. Ptarmigan

Undergoes molting of feathers with photoperiod-regulated hormonal control, switching from mottled brown (summer) to pure white (winter).

#### 4. Ermine (Stoat)

Turns white except for its black tail tip in winter. The tail tip may confuse predators.

### ADAPTIVE SIGNIFICANCE

- Camouflage improves predator avoidance.
- Enhances hunting efficiency.
- White fur provides better thermal insulation due to its structural properties.
- Enables survival in environments with extreme seasonal shifts.

### CLIMATE CHANGE IMPACT

Coat color changes are controlled by photoperiod rather than temperature. As climate change alters snow cover patterns, many Arctic animals suffer camouflage mismatch:

- White animals on snowless ground face increased predation risk.

### SUMMARY TABLE

Season	Daylight	Melatonin	Prolactin	Coat Color	Melanin Activity
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Summer | Long days | Low | High | Brown | Active

Winter | Short days | High | Low | White | Inactive

## CONCLUSION

Seasonal coat color change in Arctic animals is a sophisticated adaptation controlled primarily by photoperiodic regulation of endocrine and genetic pathways. This mechanism allows animals to optimize camouflage and energy balance throughout the year.

## C. Nutrition Effects

- **Human height is strongly influenced by nutrition, though genetically determined.**

### 1. Genetic Basis

- Human height is a **polygenic trait**, meaning it is controlled by **many genes**.
- These genes determine:
  - Growth rate
  - Bone length
  - Hormone levels (e.g., growth hormone, IGF-1)
  - Overall body proportions

Thus, genetics sets the **potential range** (maximum possible height).

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### 2. Nutritional Influence

Even though genes determine height potential, **nutrition strongly influences whether that potential is achieved.**

- **Protein-rich diet** supports muscle and bone growth.
- **Calcium, vitamin D, and minerals** are essential for bone formation.
- **Malnutrition during childhood or adolescence** leads to:
  - Stunted growth
  - Shorter adult height

- Delayed puberty and bone maturation

Good nutrition allows a person to reach the **upper limit** of their genetically determined height.

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### 3. Environmental Factors Also Play a Role

- Health and absence of chronic infections
- Hormonal balance
- Physical activity

• **PKU disease can be controlled through diet, showing how the environment modifies genetic effects.**

#### Phenylketonuria (PKU) – Dietary Control

##### Why PKU Occurs

- PKU is caused by a **deficiency of the enzyme phenylalanine hydroxylase (PAH)**.
- This prevents conversion of **phenylalanine → tyrosine**.
- Excess phenylalanine accumulates and becomes **toxic to the brain**, leading to intellectual disability if untreated.

### How PKU Can Be Controlled Through Diet

#### 1. Low-Phenylalanine Diet

- The main treatment is **restricting dietary phenylalanine**.
- Foods to **avoid or limit**:
  - High-protein foods (meat, fish, eggs, milk, cheese)
  - Nuts, soy, legumes
  - Artificial sweetener **aspartame** (contains phenylalanine)

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#### D. Hormones and Chemicals

- Hormones influence traits like voice, body hair, etc.

- Chemicals or pollutants may activate or suppress certain genes.

### **3. Phenocopy**

A phenocopy is an environmentally induced phenotype that resembles one produced by a specific genotype, but it is not caused by that gene. Example: Thalidomide-induced birth defects.

### **4. Norm of Reaction**

A single genotype can produce different phenotypes across different environments. Identical twins often show variation because of different environmental influences.

### **5. Inheritance of Continuous Characteristics (Quantitative Traits)**

These traits show continuous variation and are controlled by many genes (polygenes) and environmental factors. They form a bell-shaped distribution in populations.

Examples:

- Human height (100+ genes)
- Skin color (3–6 polygenes)
- Intelligence, body weight, milk yield in cattle

#### **6. Features of Continuous Variation**

- Gradual changes with no sharp boundaries
- Additive effect of multiple genes
- Strong environmental influence

#### **7. Polygenic Inheritance**

Each gene pair contributes a small additive effect. More dominant alleles produce greater expression. For example, height may be controlled by three gene pairs: A/a, B/b, and C/c.

#### **8. Environmental Influence on Polygenic Traits**

Traits like height, skin color, weight, and crop yield are highly influenced by environmental conditions such as nutrition, sunlight, soil quality, and lifestyle.

#### **9. Difference Between Discontinuous and Continuous Variation**

Discontinuous traits show distinct categories and are controlled by few genes (e.g., blood group). Continuous traits show gradual variation, are polygenic, and strongly influenced by the environment (e.g., height, weight).

#### 10. Summary

- Gene-Environment Interaction: Phenotype = Genes + Environment
- Environmental Factors: Temperature, light, nutrition, chemicals
- Continuous Traits: Polygenic, environmental influence, bell-shaped curve