**Classification, Sources, physiological functions and deficiency symptoms of Major and trace minerals and Toxic minerals and Mineral interactions and Role of fat-soluble and water soluble vitamins in the body, their sources and deficiency symptoms.**

**UPSC PYQs**

1. Why is Vitamin A important for the animal body? What are the deficiency symptoms of Vitamin A in animals? (2014)
2. Enumerate the water soluble vitamins. Write the coenzymes or prosthetic groups and enzymic or other functions of B vitamins. Write the functions and deficiency symptoms of Vitamin E in poultry? (2015)
3. Write in brief about mucosal block theory of iron absorption? (2017)
4. Write in brief about the role of Vitamin A in vision? (2017)
5. Differentiate between curled toe paralysis and polyneuritis? (2017)
6. What are the common sources of calcium and phosphorus? How high intake of calcium affects the utilization of other minerals? Explain how nutritional secondary hyperparathyroidism develops in animals? (2017)
7. Write in brief about nutrient parasite interrelationship ? ( 2018)
8. Write in brief about the role of Vitamin D in calcium absorption? (2018)
9. Write the Chemical nature, physiological functions and deficiency symptoms of Vitamin A in animals? (2018)
10. Mention different metalloenzymes and their functions in livestock? (2018)
11. Classify the minerals and explain the role of calcium, phosphorus and vitamin D in bone formation? (2019)
12. Classify vitamins. What do you mean by essential and non- essential vitamins? Mention the coenzymes and enzyme prosthetic groups of B vitamins along with their function in metabolism? (2020)
13. Describe the mineral deficiency disorders of animals? (2022)
14. Mention the general functions of minerals in animals. Justify the importance of Vitamin D in optimum calcium and phosphorus nutrition in animals? (2023).

## 3.1 Minerals Classification:

Minerals are essential nutrients required by animals for various physiological functions. They are classified into major minerals (macrominerals) and trace elements (microminerals) based on their concentration in animal tissues and feeds. Here is a breakdown of this classification:

**Major Minerals (Macrominerals):** These minerals are required in relatively large quantities, and they are present in animal tissues and feed in concentrations greater than 70 mg/kg of live weight. The major minerals include:

1. **Calcium (Ca):** Calcium is crucial for bone and teeth formation, muscle function, blood clotting, and various metabolic processes.

2. **Phosphorus (P):** Phosphorus is essential for bone and teeth formation, energy metabolism (as a component of ATP), and various cellular functions.

3. **Magnesium (Mg):** Magnesium is involved in muscle and nerve function, bone health, and enzymatic reactions.

4. **Potassium (K):** It is Chief intracellular Cation which is important for muscle and nerve function.

5. **Sodium (Na):** It is Chief extracellular Cation which is important for electrolyte and acid base balance in the body.

6. **Sulphur (S):** Sulphur is present mainly in cysteine, cysteine and methionine amino acids and Vitamin Biotin and thiamin it is also an integral part of hormones: insulin and oxytocin.

7. **Chloride (Cl):** It is the chief intracellular anion involved in functions like maintaining acid-base balance, nerve impulse transmission, and muscle contraction.

**Trace Elements (Microminerals):** These minerals are required in smaller quantities (trace amounts) but are still essential for various physiological functions. They are generally present in lower concentrations in animal tissues and feeds. The trace elements include:

1. **Iron (Fe):** Iron is essential for oxygen transport in hemoglobin, energy metabolism, and enzyme function.

2. **Chromium (Cr):** Chromium may be involved in carbohydrate metabolism and insulin function.

3. **Copper (Cu):** Copper is necessary for various enzymatic reactions, including those related to iron metabolism and collagen formation.

4. **Cobalt (Co):** Cobalt is required by microorganisms in the rumen for the synthesis of vitamin B12.

5. **Iodine (I):** Iodine plays an important role in the synthesis of the two hormones, triiodothyronine (T3) and tetraiodothyronine (thyroxine) T4 produced in the thyroid gland which increases the basal metabolic rate, accelerating growth.

6. **Selenium (Se):** Selenium is a component of glutathione peroxidase, an enzyme which catalyzes the removal of hydrogen peroxide, thereby protecting cell membranes from oxidative stress/damage. Selenium has a sparing effect on vitamin E by ensuring normal absorption of the vitamin.

7. **Zinc (Zn):** It acts as Cofactor for enzyme Carbonic anhydrase and helps to increase feed utilization by enhancing feed conversion ratio and enhances cellular immunity.

8. **Manganese(Mn):** It acts as an activator of many enzymes such as hydrolases and kinases and as a constituent of enzymes such as arginase, pyruvate carboxylase and superoxide dismutase.

**Sources of Minerals:**

**Major Minerals:**

1. **Calcium (Ca):** Natural Feed Ingredients: Legumes, alfalfa, clover, and other forages, as well as some grains. Mineral Supplements: Calcium supplements, calcium carbonate, limestone.

2. **Phosphorus (P):** Natural Feed Ingredients: Grains, oilseeds, and some forages. Mineral Supplements: Dicalcium phosphate, monocalcium phosphate.

3. **Magnesium (Mg):** Natural Feed Ingredients: Forages, especially lush pastures. Mineral Supplements: Magnesium oxide, magnesium sulfate (Epsom salt).

**Trace Minerals (Micro Minerals):**

1. **Iron (Fe):** Sources: Present in grains and forages.

2. **Copper (Cu):** Sources: Present in forages, grains, and legumes.

3. **Zinc (Zn):** Sources: Present in grains, forages, and legumes.

4. **Selenium (Se):** Sources: Present in soils, transferred to plants and forages.

## General functions of minerals:

1. **Structural function:** Structural components of bone & teeth eg. Ca, P, Mg and act as constituents of body cells of soft tissues such as muscles, liver etc. eg. P

2. **Regulatory function:** Help in regulating the activity of nerves with regard to stimuli & contraction of muscles eg. P & K.

- Help in maintaining acid base balance of body fluid eg. Cl, P, S, Na, K
- Help in maintaining osmotic pressure eg. Na, K, Cl. Through osmotic pressure control water balance in body & regulate the permeability of cell membrane

3. **Protective function:** Provide clotting power to the blood e.g. Ca. Ca and P form enamel of teeth and thus avoid wearing of teeth.

4. **General metabolic functions:**

- Formation of Hb – Fe & Cu
- Formation of thyroxine hormone
- Constituent of insulin – Zn
- Constituent of Vit. $B_{12}$ - Co
- Constituent of gastric juice – Cl
- Function as component or activator of various enzymes – Fe, Mn, and Cu.

### Major Minerals

**1. Calcium (Ca):** Calcium is the most abundant mineral in the animal body majority of which is present in Bones & teeth

1. **Structural Component:** Calcium is a major structural component of the skeletal system, including bones and teeth.

2. **Nerve and Muscle Function:** Calcium ions are involved in nerve impulse transmission and muscle contraction.

3. **Blood Clotting:** Calcium plays a crucial role in the blood clotting process. It is necessary for the activation of various clotting factors and enzymes.

4. **Cell Signaling:** Calcium ions serve as important secondary messengers in cell signaling pathways.

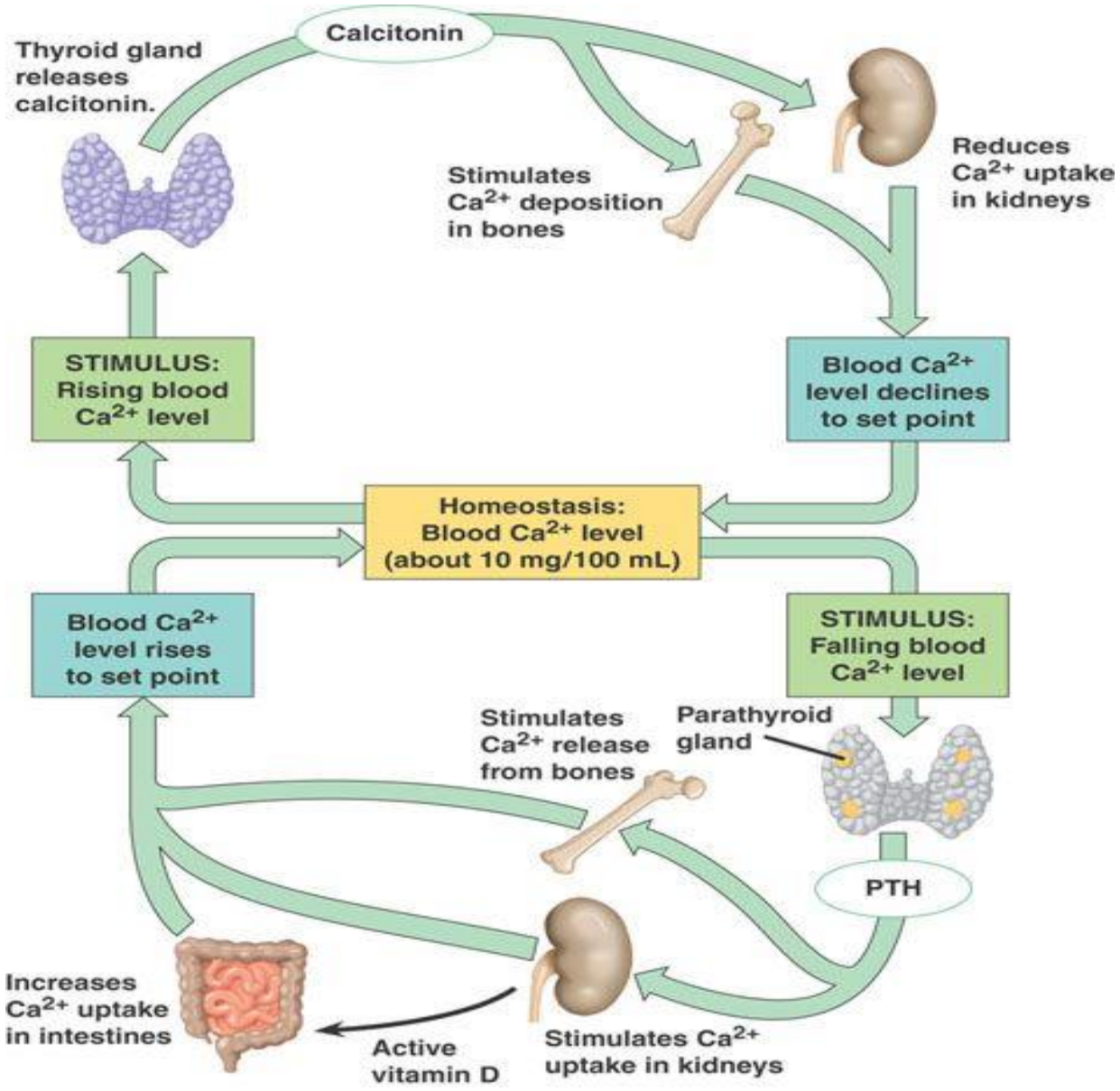
Hormones associated with Ca regulation includes: Parathormone and Calcitonin
Normal blood conc. = 9-11 mg/dl

**Deficiency Symptoms of Calcium:**

**A. Rickets (Young Animals):** Common symptoms include misshapen bones, joint enlargement, lameness, and stiffness.

B. **Osteomalacia (Adult Animals):** In adult animals, calcium deficiency can lead to osteomalacia, a condition characterized by weak and fragile bones.

**C. Milk Fever (Parturient Paresis - Dairy Cows):** Dairy cows are particularly prone to calcium deficiency shortly after calving. This condition, known as milk fever or parturient paresis, is characterized by a drop in serum calcium levels. Symptoms may include muscle spasms, paralysis, and unconsciousness.




**2. Phosphorus:** It is found in body mostly as Phosphoproteins, nucleic acids (nucleotide) and phospholipids. It plays a vital role in energy metabolism in the form of ATP (source of energy).

Normal Blood conc.: 4-8 mg/dl

Normal Ca:P = 2:1

Functions:

1. **Bone Formation:** Phosphorus is a crucial structural component of bones and teeth, just like calcium. It combines with calcium to form hydroxyapatite crystals, providing strength and rigidity to skeletal structures.

2. **DNA and RNA Synthesis:** Phosphorus is a fundamental component of nucleic acids, such as DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), which are essential for genetic information transfer and protein synthesis.

3. **pH Regulation:** Phosphates act as important buffer systems in the body, helping to maintain the acid-base balance and stabilize pH levels in body fluids.

**Deficiency Symptoms of Phosphorus:**

1. **Rickets/Osteomalacia:** A deficiency of phosphorus, similar to calcium, can lead to poor bone development, resulting in conditions like rickets in young animals and osteomalacia in adults. These disorders are characterized by weakened, soft, and deformed bones.

2. **Pica:** Animals with phosphorus deficiency may exhibit abnormal eating behaviors, known as pica. They may chew on non-food items like wood, bones, or other foreign materials in an attempt to obtain more phosphorus.

3. **Post-parturient Hemoglobinuria/PPH:** Due to decrease in P level there is decline of adenosine triphosphate (ATP) in the RBCs which results in intravascular RBC hemolysis, hemoglobinuria, red color urine and anemia soon after parturition.

4. **Fertility Issues:** In female animals, inadequate phosphorus levels can lead to reproductive problems, including irregular estrus cycles and reduced fertility.

**3. Potassium:** It is Chief intracellular Cation.

1. **Muscle Function:** Potassium is vital for proper muscle function, including the contraction and relaxation of skeletal and smooth muscles. It helps regulate muscle tone and prevents muscle cramps.

2. **Nerve Function:** Potassium ions are involved in generating and transmitting nerve impulses. They help regulate the excitability of nerve cells, which is essential for sensory perception and coordination.

3. **Acid-Base Balance:** Potassium participates in maintaining the acid-base (pH) balance in body fluids. It acts as a buffer to regulate blood pH, ensuring that it remains within the normal range.

**Deficiency Symptoms of Potassium:**

1. **Muscle Weakness:** Hypokalemia can lead to muscle weakness, reduced muscle tone, and trembling.

2. **Cardiac Irregularities:** Potassium is essential for maintaining the electrical excitability of cardiac muscles.

3. **Reduced Feed Intake**

**4. Sodium:** Chief extracellular Cation

1. **Electrolyte Balance:** Sodium is a key component in maintaining the body's electrolyte balance.
2. **Nerve Function:** Sodium ions are critical for the generation and transmission of nerve impulses. They play a crucial role in nerve cell excitability, allowing for the propagation of signals throughout the nervous system.
3. **Acid-Base Balance:** Sodium plays a role in maintaining the body's acid-base (pH) balance.

**Deficiency Symptoms of Sodium:**

Sodium deficiency, known as hyponatremia, can lead to a range of health issues in farm animals:

1. **Muscle Weakness:** Animals with sodium deficiency may exhibit muscle weakness and decreased coordination. This can affect their ability to move and stand.
2. **Nervous System Abnormalities:** Hyponatremia can result in nervous system disturbances, including lethargy, depression, seizures, and abnormal behavior.

**5. Sulfur:** Sulphur is present mainly in cystine, cysteine and methionine amino acids and Vitamin Biotin and thiamin. It is also an integral part of hormones: insulin and oxytocin. Wool is rich in cystine and contains about 4% of sulfur.

1. **Amino Acid Synthesis:** Sulfur is a crucial component of amino acids, particularly cysteine and methionine. Amino acids are the building blocks of proteins, and sulfur-containing amino acids are essential for the synthesis of various proteins in the body.
2. **Protein Structure:** Sulfur bridges, known as disulfide bonds, form between cysteine residues in proteins.
3. **Detoxification:** Sulfur compounds, such as glutathione, play a role in the detoxification of harmful substances, including drugs and toxins.
4. **Vitamin Synthesis:** Sulfur is a component of some vitamins, such as biotin and thiamine. These vitamins are essential for various metabolic processes in animals.

**6. Magnesium:** It plays an important role in the Tricarboxylic acid cycle (TCA) in energy yielding reactions and in Carbohydrates and lipids metabolism as a component of various enzymes.

1. **Bone Formation:** Magnesium is an important component of bone structure and is essential for bone development and maintenance in animals.
2. **Enzyme Activation:** Magnesium acts as a cofactor for many enzymes involved in various metabolic processes.

**Deficiency Symptoms of Magnesium:**

1. **Grass Tetany (Hypomagnesemia):** This condition is characterized by low blood magnesium levels and is often associated with grazing animals, particularly cattle. Symptoms may include

muscle tremors, convulsions, and in severe cases, death. It is more common in animals grazing on magnesium-deficient pastures, especially in the spring.

2. **Reduced Growth:** Young animals with magnesium deficiency may experience reduced growth rates and developmental problems.

3. **Nervous Disorders:** Magnesium deficiency can lead to nervous system disturbances, including muscle spasms, irritability, and hyperexcitability.

## Minor Minerals:

**1. Iron:** More than 90 per cent of the iron in the body is present in the form of hemoglobin and myoglobin. Iron occurs in blood serum in a protein called transferrin, which is concerned with the transport of iron in the body. Ferritin is a storage form for iron and is present in the spleen, liver, kidney and bone marrow and provides a form of storage for iron. Hemosiderin is another storage form of iron.

1. **Oxygen Transport:** The primary function of iron in the body is to bind with hemoglobin, a protein in red blood cells. Hemoglobin carries oxygen from the lungs to the body's tissues and organs, ensuring proper oxygen supply for metabolic processes.

2. **Enzyme Cofactor:** Iron serves as a cofactor for enzymes involved in various biochemical reactions.

3. **Immune Function:** Iron is necessary for the proper functioning of the immune system.

## Deficiency Symptoms of Iron:

1. **Anemia:** Iron deficiency anemia is a common consequence of inadequate dietary iron. It results in reduced hemoglobin levels and, consequently, decreased oxygen-carrying capacity of the blood. Piglets are born with very limited iron reserves and sow milk is also deficient in iron. Hence they are most susceptible for Iron deficiency known as Piglet anemia/ Thumps.

2. **Reduced Growth and Development:** Young animals with iron deficiency may experience stunted growth, delayed development, and poor weight gain.

3. **Reduced Immunity:** Iron deficiency can compromise the immune system, making animals more susceptible to infections and diseases.

## Mucosal block theory of iron absorption:

The mucosal block theory of iron absorption is a mechanism that regulates the absorption of dietary iron in the small intestine. It involves the interaction between the hormone hepcidin and mucosal cells. When iron stores are sufficient or high, the liver releases hepcidin, which binds to ferroportin on mucosal cells, causing its internalization and degradation. This process reduces the release of absorbed iron into the bloodstream, effectively blocking iron absorption.

## 2. Copper:

1. **Enzyme Cofactor:** Copper serves as a cofactor for numerous enzymes involved in various metabolic processes. Copper is the integral component of following enzyme Ceruloplasmin (ferroxidase) which is needed for conversion of iron into transferrin and erythrocuprein which occurs in erythrocytes where it plays a role in oxygen metabolism. Cytochrome oxidase which is important in oxidative phosphorylation and myelin synthesis. Lysyl oxidase is needed for the conversion of lysine to desmosine which forms crosslinks in elastin and collagen fibres. Tyrosinase is necessary for the conversion of the amino acid tyrosine to melanin which is necessary for the normal pigmentation of hair, fur and wool. Copper is the integral component of Turacin, a pigment of feathers.

2. **Collagen Formation:** Copper is required for the synthesis of collagen, a structural protein that is a major component of connective tissues, including skin, bones, cartilage, and blood vessels. Copper is required for maintenance of crimps of wool.

## Deficiency Symptoms of Copper:

1. **Depigmentation of Hair and Wool:** One visible sign of copper deficiency is the loss of pigmentation in the hair, fur, or wool of animals. This can manifest as faded or discolored hair or wool.

2. **Brain and Spinal Cord Lesions:** Severe copper deficiency can lead to lesions in the brainstem and spinal cord, particularly in young lambs. This condition is known as **"swayback," "enzootic ataxia," or "neonatal ataxia."** Affected lambs may exhibit symptoms such as muscular incoordination, paralysis, or a swaying and staggering gait, especially in the hind limbs.

3. **Wool Quality:** Copper deficiency can affect the quality of wool produced by sheep. It may result in the loss of "crimp" in the wool, leading to a **"stringy" or "steely" appearance.**

4. **Falling Disease:** In some cases, copper deficiency can lead to a condition referred to as "falling disease." This condition is characterized by sudden death due to the rupture of major blood vessels.

## 3. ZINC:

1. **Enzyme Activation:** Zinc serves as a cofactor for numerous enzymes involved in various metabolic processes like carbonic anhydrase. It plays a crucial role in activating enzymes required for digestion, energy metabolism, and tissue repair.

2. **Immune Function:** Zinc is essential for a properly functioning immune system. It is involved in the production and activation of immune cells, antibodies, and cytokines, which help the body defend against infections and diseases.

3. **Skin and Hoof Health:** Zinc is important for maintaining healthy skin, hair, and hooves in animals. It contributes to the production of keratin, a protein that forms the structural basis of these tissues.

## Deficiency Symptoms of Zinc:

**Chicks:**

- Retarded growth: Chicks experience slower growth and reduced body weight gain.
- Foot abnormalities: Zinc-deficient chicks may develop foot deformities or abnormalities.
- Frizzled' feathers: Abnormal feather development, characterized by a frizzled or unkempt appearance.
- Swollen hock syndrome: A bone abnormality in poultry, often associated with zinc deficiency.

**Calves:**

- Inflammation of the nose and mouth: Zinc deficiency can lead to irritations and inflammation in the nasal and oral regions.
- Stiffness of the joints: Affected calves may experience joint stiffness and reduced mobility.
- Swollen feet: Swelling of the feet is a common symptom in zinc-deficient calves.
- Parakeratosis: This skin condition involves the abnormal development of keratinized tissue, resulting in rough, thickened skin.

**Pigs:**

- Zinc deficiency can manifest in pigs as skin lesions, crusty or scaly skin, and poor coat quality. Affected pigs may exhibit rough, dry skin and hair loss.
- Parakeratosis: This is a skin condition where the outer layer of skin cells does not properly mature, leading to thickened and scaly skin.

## 4. Manganese:

1. **Bone Development:** Manganese is involved in the formation and maintenance of healthy bones and cartilage.
2. **Enzyme Activation:** Manganese acts as a cofactor for several enzymes involved in various metabolic pathways.

## Deficiency Symptoms of Manganese in Farm Animals:

1. **Reproductive Problems:** Manganese deficiency can impair reproductive performance in both males and females. This may include reduced fertility, delayed sexual maturity, and increased rates of stillbirths or low birth weights in offspring.
2. **Joint and Connective Tissue Issues:** Manganese deficiency can affect joint health and lead to conditions like lameness and stiffness. It can also impact the integrity of connective tissues, causing structural weaknesses. Manganese is an important element in the diet of young chicks, a deficiency leading to **perosis** or '**slipped tendon**', a malformation of the leg bones. Manganese deficiency in breeding birds reduces hatchability and shell thickness, and causes head retraction

in chicks, causes a condition called as **nutritional chondro-dystrophy** which is characterized by the shortening of the bones of the wings and legs, shortening of the lower mandible leads to **parrot beak condition.**

## 5. Cobalt:

1. **Vitamin B12 Synthesis:** Cobalt is an integral component of vitamin B12 (cobalamin).
2. **Metabolism:** Vitamin B12, derived from microbial synthesis in the rumen, is essential for various metabolic processes in animals.

**Deficiency Symptoms of Cobalt:**

1. **Anemia:** Cobalt deficiency leads to reduced production of vitamin B12, which, in turn, results in anemia. Anemic animals have lower red blood cell counts, reduced hemoglobin levels, and may exhibit weakness, fatigue, and pale mucous membranes.
2. **Reduced Weight Gain:** Cobalt-deficient animals often experience reduced weight gain and growth rates. This can result in smaller-sized and less productive livestock.

## 6. Selenium:

**Functions of Selenium:**

1. **Antioxidant Defense:** Selenium is a key component of the selenoenzyme glutathione peroxidase, which protects cells from oxidative damage by neutralizing harmful reactive oxygen species (ROS).
2. **Immune Function:** Selenium supports the immune system by enhancing the activity of immune cells and promoting the production of antibodies.

## Deficiency Symptoms of Selenium:

Selenium deficiency in farm animals can result in a condition known as **"white muscle disease"** or nutritional myodegeneration, which is characterized by muscle weakness and degeneration. In pigs, the two main diseases associated with vitamin E and selenium deficiency are myopathy and cardiac disease.

1. **Muscle Weakness:** Selenium deficiency can lead to muscle weakness, stiffness, and difficulty in standing or walking. Affected animals may exhibit a shuffling gait or lameness. The most frequent and the most important manifestation of Selenium deficiency in farm animals is muscle degeneration (myopathy).
2. **Cardiac and Respiratory Distress:** Severe selenium deficiency can affect the muscles of the heart and diaphragm, leading to cardiac and respiratory distress. This can result in sudden death, especially in young animals. Sudden cardiac failure occurs and on post-mortem examination the

lesions of the cardiac muscles are seen as pale patches or white streaks. This condition is commonly known as **mulberry heart disease.**

3. **Enlarged Joints:** Young animals may develop enlarged joints, a condition known as "nutritional arthropathy," due to selenium deficiency. Nutritional myopathy also occurs in lambs, with similar symptoms to those of calves. The condition is frequently referred to as **stiff lamb disease.**

**7. Iodine:** It plays a crucial role in the synthesis of thyroid hormones, which are essential for maintaining metabolic functions and overall health.

**Deficiency Symptoms of Iodine:**

Iodine deficiency in farm animals can result in a condition known as "iodine deficiency disorder" or **"hypothyroidism."** The severity of deficiency symptoms can vary depending on the species, age, and duration of iodine deficiency. Common deficiency symptoms include:-

1. **Goiter:** The most recognizable sign of iodine deficiency is the development of a goiter—a swelling of the thyroid gland in the neck region. Goiters can be observed as a visible enlargement of the throat area and may interfere with breathing and swallowing.

**8. Molybdenum:**

**Functions:**

1. **Enzyme Activation:** Molybdenum is a component of the molybdenum cofactor (MoCo).
2. **Nitrogen Metabolism:** Molybdoenzymes, such as xanthine oxidase and aldehyde oxidase, play a role in the breakdown of purines and the conversion of xanthine to uric acid.

**Deficiency Symptoms of Molybdenum:**

1. **Reduced Growth**
2. **Loss of Appetite**

**Metalloenzymes:**

Metalloenzymes are a class of enzymes that require metal ions as cofactors for their catalytic activity. In livestock, various metalloenzymes play crucial roles in a range of physiological processes. Here are some examples of metalloenzymes and their functions in livestock:

**Function:**

1. **Cytochrome P450 Enzymes:** These heme-containing enzymes are involved in drug metabolism and the detoxification of xenobiotics in the liver. They also play a role in steroid hormone metabolism.

2. **Superoxide Dismutase (SOD):** SOD contains metal ions like copper, zinc, or manganese and is essential for the antioxidant defense system. It helps protect cells from oxidative damage by converting superoxide radicals into oxygen and hydrogen peroxide.

3. **Catalase:** Catalase is another antioxidant enzyme containing iron heme. It catalyzes the breakdown of hydrogen peroxide into water and oxygen, protecting cells from oxidative stress.

4. **Carbonic Anhydrase:** Carbonic anhydrase contains zinc ions and is involved in the regulation of acid-base balance and the transport of carbon dioxide in blood and tissues.

### 3.2 Toxic Minerals in Farm Animals:

While minerals are essential for the health and well-being of farm animals, excessive intake of certain minerals can be toxic and lead to various health issues.

1. **Iron (Fe):** Excessive iron intake can lead to iron toxicity, especially in young animals. It can result in diarrhea, liver damage, and reduced growth rates.

2. **Copper (Cu):** Although copper is essential, excessive copper intake can be toxic to sheep, particularly those with a genetic susceptibility to copper toxicity. Copper toxicity can lead to liver damage, hemolysis (breakdown of red blood cells), jaundice, and death.

3. **Selenium (Se):** Selenium toxicity, known as selenosis, can occur in animals consuming plants grown in selenium-rich soils or through excessive supplementation. It can lead to symptoms such as loss of hair and hooves, sloughing of hooves, lameness, and respiratory distress.

4. **Fluorine (F):** High levels of dietary fluoride can lead to fluorosis in farm animals. Fluorosis affects the teeth and bones, causing dental problems, skeletal deformities, and reduced growth.

5. **Arsenic (As):** toxicity of Arsenic causes GIT related problems like abdominal cramps, diarrhea and vomiting. After entering the body it concentrates in cutaneous tissues like nails, skin and hairs.

6. **Cadmium (Cd)**: higher concentration of cadmium in the body leads to many organ damages, including kidney failure, nerve and brain damage results in abnormal behavior. Body stores the vast majority of cadmium in the kidneys, liver and genitals.

7. **Lead (Pb)**: most common cause of accidental poisoning in animals. It is a slow and silent killer and source of contamination is from drinking water from lead pipe, from lead based paint, newspaper ink plants grown in lead rich soil. Higher concentration of lead causes anemia, abdominal pain, kidney damage, behavioral disturbances, seizures, coma and death.

8. **Mercury (Hg):** It enters in animal's life from medical and municipal waste and in sea organisms like fishes from the waste from large ships, leakage from ships and pipelines under the sea. Neurotoxicity is the most important health concern associated with consumption of fish contaminated with methylmercury. It affects the immune system, alters genetic and enzyme systems, and damages the nervous system, including coordination and the senses of touch, taste, and sight. It can also readily move through the placenta to developing fetuses and their developing brains, and is therefore a particular concern to pregnant women and young ones. Fish-consuming wildlife such as eagles and otters are also at risk from mercury contamination.

**3.3 Mineral Interactions in Farm Animals:** The interactions between minerals in the gastrointestinal tract and during tissue and cell metabolism are essential considerations in animal nutrition. These interactions can be both synergistic, where minerals enhance each other's absorption and metabolic functions, or antagonistic, where minerals inhibit each other's absorption and affect biochemical functions. Understanding these mechanisms helps prevent undesirable interactions and secondary mineral deficiencies in animals.

## Synergistic Interactions:

- **Gastrointestinal Tract:** Certain mineral pairs, such as calcium (Ca) and phosphorus (P) or sodium (Na) and chlorine (Cl), can enhance each other's absorption when provided at proper ratios.
- **Tissue and Cell Metabolism:** Minerals like Ca and P work together in the formation of bone hydroxyapatite, a crucial component of bones and teeth.

## Antagonistic Interactions:

One-Sided Antagonism: Examples include the inhibition of absorption between phosphorus (P) and magnesium (Mg) or between zinc (Zn) and copper (Cu) in the intestine.

## Mechanisms of Antagonism:

- **Complex formation:** Excess Mg in the diet may form complex magnesium phosphate, affecting the absorption of both elements.
- **Triple salt formation:** High levels of calcium (Ca) in the diet can lead to the formation of the triple Ca-P-Zn salt, affecting absorption.

## 1. Calcium and Phosphorus:

The interaction between calcium (Ca) and phosphorus (P) in the body is highly interconnected and plays a critical role in various physiological processes.

- **Optimal Absorption and Excretion:** Calcium and phosphorus interact to ensure the optimal absorption and endogenous excretion of both minerals in the digestive tract.
- **Maintenance of Concentrations and Proportions:** The body works to maintain normal concentrations and proportions of calcium and phosphorus in the blood and inter-tissue fluid.
- **Bone Formation and Resorption:** Calcium and phosphorus are deposited as hydroxyapatite in bone tissue during formation and can be liberated during resorption.

## 2. Vitamin D, Calcium and Phosphorus:

Vitamin D plays a crucial role in the regulation of calcium (Ca) and phosphorus (P) metabolism in animals. Here are the mechanisms through which vitamin D influences Ca-P metabolism:

**a.) Enhancement of Intestinal Absorption:** Vitamin D increases the efficiency of calcium and phosphorus absorption in the intestines by promoting the synthesis of calcium-binding proteins, which facilitate the transport of calcium across the intestinal wall into the bloodstream. This process is critical because without adequate vitamin D, the body cannot effectively absorb these minerals from the diet.

**b.) Regulation of Mineral Homeostasis:** Vitamin D helps maintain appropriate levels of calcium and phosphorus in the blood. When dietary intake is low, vitamin D promotes the mobilization of these minerals from bone to maintain serum levels, ensuring that vital physiological functions continue. This is particularly important during periods of growth or lactation when the demand for these minerals is higher.

**c.) Interaction with Hormones:** The active form of vitamin D (1,25-dihydroxycholecalciferol) works in conjunction with parathyroid hormone (PTH) to regulate calcium and phosphorus levels. PTH stimulates the conversion of vitamin D into its active form and enhances the reabsorption of calcium in the kidneys, while also promoting the release of phosphorus from bones. This synergistic action is essential for maintaining mineral balance and bone integrity

**d.) Influence on Bone Health:** Adequate levels of vitamin D are necessary for proper bone mineralization. It ensures that sufficient calcium and phosphorus are available for the formation of hydroxyapatite, the mineral complex that provides strength to bones. Deficiencies in vitamin D can lead to impaired bone mineralization, resulting in conditions such as rickets in young animals or osteomalacia in adults

## 3. Selenium and Vitamin E:

Selenium and vitamin E work together as antioxidants.Selenium and vitamin E have a synergistic relationship when it comes to their antioxidant functions in animals. Both selenium and vitamin E are crucial for protecting cells from oxidative damage. Selenium is a component of selenoproteins, such as glutathione peroxidase, which helps neutralize harmful reactive oxygen species (ROS). Vitamin E, as a fat-soluble antioxidant, protects cell membranes from lipid peroxidation caused by free radicals. Together, they mitigate oxidative stress, which can impair immune function.

Selenium enhances the effectiveness of vitamin E by facilitating its regeneration after it has neutralized free radicals. This interaction ensures that vitamin E remains available to continue protecting cells from oxidative damage, thereby supporting immune health

**4. Copper and Molybdenum:** Excessive molybdenum (Mo) intake can interfere with copper (Cu) absorption and utilization. This interaction can lead to copper deficiency in animals, especially sheep, resulting in health issues.

### How Nutritional Secondary Hyperparathyroidism (NSH) develops in animals:

1. **Inadequate Dietary Calcium:** NSH begins with a diet lacking sufficient calcium.

2. **Calcium Absorption Efforts:** The animal's body tries to absorb more calcium from the gut, primarily the small intestine.

3. **Parathyroid Gland Response:** Parathyroid glands detect low blood calcium levels. They respond by secreting increased parathyroid hormone (PTH).

4. **Phosphorus Imbalance:** PTH also decreases blood phosphorus levels by reducing kidney reabsorption.

5. **Bone Health Impact:** Continuous calcium release from bones and phosphorus imbalance weaken bones.

### 3.4 Role of fat-soluble and water soluble vitamins in the body, their sources and deficiency symptoms:

Vitamins play essential roles in the metabolic processes of farm animals and are required in small amounts to maintain their health and well-being. Vitamins can be classified based on their solubility into two main groups: fat-soluble vitamins and water-soluble vitamins.

**Fat-Soluble Vitamins:** These vitamins are soluble in fat and are stored in the body's fatty tissues and liver. The fat-soluble vitamins include:

1. **Vitamin A (Retinol):** Essential for vision, immune function, and skin health.
2. **Vitamin D (Cholecalciferol):** Important for calcium and phosphorus absorption, crucial for bone health.
3. **Vitamin E(Tocopherol):** Acts as an antioxidant, protecting cells from oxidative damage.
4. **Vitamin K(Phylloquinone):** Necessary for blood clotting and bone metabolism.

**Water-Soluble Vitamins:** These vitamins are soluble in water and are not stored in significant amounts in the body. They need to be regularly supplied through the diet or other sources. The water-soluble vitamins include:

1. **Vitamin B1 (Thiamin):** Essential for energy metabolism and nervous system function.
2. **Vitamin B2 (Riboflavin):** Involved in energy production and cellular growth.
3. **Vitamin B3 (Niacin/Nicotinamide/Nicotinic Acid):** Important for energy production and skin health.
4. **Vitamin B6 (Pyridoxine):** Necessary for amino acid metabolism and nerve function.

5. **Pantothenic Acid:** Plays a role in fatty acid synthesis and energy production.

## Essential v/s nonessential vitamins:

**Essential vitamins:** Vitamins that are required for normal bodily functions and must be obtained through diet because the body cannot synthesize them in sufficient quantities. These Must be obtained from food sources such as fruits, vegetables, grains, dairy, and meats. E.g. Vitamin A, C, E, B complex

**Nonessential vitamins:** Vitamins that the body can synthesize on its own and do not need to be obtained directly from the diet. These can be produced by the body, although dietary sources can still contribute to overall intake. E.g. vitamin D, K

## Coenzymes or prosthetic groups and enzymic or other functions of B vitamins:

B vitamins are a group of water-soluble vitamins that serve as coenzymes or prosthetic groups in various enzymatic reactions within the body. Each B vitamin plays a specific role in energy metabolism, enzyme function, and overall health.

**1. Vitamin B1 (Thiamine): Coenzyme:** Thiamine pyrophosphate (TPP)

**Enzymic Function:** TPP is essential for the conversion of pyruvate to acetyl-CoA in the citric acid cycle (Krebs cycle). It also plays a crucial role in carbohydrate metabolism.

**2. Vitamin B2 (Riboflavin): Coenzyme:** Flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD)
**Enzymic Function:** FMN and FAD are coenzymes involved in redox reactions in the electron transport chain. They play a vital role in energy production and metabolism.

**3. Vitamin B3 (Niacin): Coenzyme:** Nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP)
**Enzymic Function:** NAD and NADP are essential coenzymes in numerous redox reactions, including glycolysis, the citric acid cycle, and fatty acid synthesis.

**4. Vitamin B5 (Pantothenic Acid): Coenzyme:** Coenzyme A (CoA)
**Enzymic Function:** CoA is a crucial cofactor in the synthesis and breakdown of fatty acids, as well as in the citric acid cycle. It is involved in many metabolic pathways.

**5. Vitamin B6 (Pyridoxine): Coenzyme:** Pyridoxal phosphate (PLP)
**Enzymic Function:** PLP serves as a coenzyme in amino acid metabolism, including the transamination of amino acids and the synthesis of neurotransmitters.

**6. Vitamin B7 (Biotin): Coenzyme:** Biotin
**Enzymic Function:** Biotin is essential for carboxylation reactions involved in fatty acid synthesis, gluconeogenesis, and amino acid catabolism.

| Vitamin | Main co-enzymes | Main functions |
|---|---|---|
| Vitamin $B_1$ | Thiamine pyrophosphate | Carbohydrate metabolism |
| Vitamin $B_2$ | FAD, FMN (hydrogen transfer) | Energy metabolism |
| Vitamin $B_6$ | Pyridoxal phosphate | Amino acid metabolism |
| Vitamin $B_{12}$ | Cyanocobalamin (transfer of methyl groups) | Protein turnover |
| Biotin | Pyruvate-acetyl-CoA -carboxylase | Fatty acid metabolism and energy metabolism |
| Folic acid | Tetrahydrofolic acid | Amino- and nucleic acid metabolism |
| Niacin | NAD, NADP (hydrogen transfer) | Energy metabolism |
| Pantothenic acid | Co-enzyme A | Fat metabolism and energy conversion |
| Vitamin C | – | Redox reactions |
| Choline | – | Fat metabolism, transmission of neural impulses |

**Differentiation between Curled Toe Paralysis and Polyneuritis in poultry:**

| | Curled Toe Paralysis | Polyneuritis |
|---|---|---|
| **Definition** | A condition primarily caused by **Vitamin B2 (riboflavin) deficiency** or genetic factors, leading to curling of the toes. | inflammation of multiple peripheral nerves, due to Infectious agents, toxins, or nutritional deficiencies (e.g., **Vitamin B1 deficiency)** |

| | | |
|---|---|---|
| **Clinical Signs** | Inward curling of the toes, difficulty walking, standing on hocks. | Generalized weakness, abnormal postures, "stargazing" (head pulled back), paralysis of limbs. |
| **Age of Affected Birds** | Commonly seen in young chicks, especially during the first few weeks of life. | Can affect birds of various ages, often seen in chicks but can occur in older birds as well. |
| **Treatment** | Riboflavin supplementation, supportive care to improve mobility. | Supportive care, addressing underlying causes, and nutritional management. |
| **Prognosis** | Good if treated early with riboflavin; recovery is possible. | Variable; depends on the cause and severity of nerve damage. |

## 1. Vitamin A

**Sources:**

- Green forages and lush green pastures are rich in pro-vitamin A, beta-carotene, egg yolk, milk fat and cod liver oil. The conversion of beta-carotene to vitamin A takes place in the intestinal mucosa. One molecule of beta-carotene can be converted into two molecules of retinol (active vitamin A**).**

**Functions:**

1. **Epithelial Cell Integrity:** Vitamin A is essential for the synthesis of glycoproteins that maintain the integrity of epithelial cells, including those in the skin and mucous membranes.
2. **Bone Formation:** It plays a role in the synthesis of mucopolysaccharides, which are important in bone formation.
3. **Visual Pigment:** Vitamin A is required for the synthesis of the visual pigment called rhodopsin, which is crucial for vision in low-light conditions.

4. **Embryonic Development:** Retinol and retinoic acid (RA), active forms of vitamin A, are essential for embryonic development during fetal development.

**Deficiency Symptoms**: Vitamin A deficiency results in night blindness or nyctalopia

1. **Xerophthalmia:** Severe or prolonged vitamin A deficiency causes a condition called xerophthalmia (dry eye) characterized by changes in the cells of the cornea that ultimately result in corneal opacity, keratinization of the cornea, corneal ulcers and blindness. Mild vitamin A deficiency may result in changes in the conjunctiva forming white foamy patches called Bitot's spots. Its deficiency results in congenital blindness.
2. **Nutritional roup:** In poultry, Vitamin A deficiency results in mucopurulent rhinitis, drying of tear glands retarded growth, weakness, ruffled plumage and a staggering gait.
3. Deficiency of vitamin A can lead to developmental bone deformities.
4. Vitamin A is commonly known as the anti infective vitamin so its deficiency lowers the immunity of the body to fight against pathogens.

**2. Vitamin D: Provitamin D: Ergosterol - plant and 7-dehydrocholesterol – skin of animals**

**Active form: 1,25- dihydroxycholecalciferol**

**Sources:** Cod Liver Oils, Sun-Dried Roughage/Grains, Colostrum contains 6 to 10 times the amount of vitamin D compared to regular milk.

**Deficiency Symptoms:**

1. **Rickets in Young Animals:** Vitamin D deficiency in young animals can lead to rickets, a condition where bones become weak, more prone to fractures, and may develop deformities.

2. **Osteomalacia in Adults:** In adult animals, vitamin D deficiency can result in osteomalacia, characterized by weakened bones.

3. **Poultry Issues:** In poultry vitamin D deficiency results in rubbery legs where bones and beak become soft and rubbery and legs become weak. Egg production is reduced and eggshell quality deteriorates. Hatchability in poultry is decreased and there will be penguin-like squat.

4. **Muscular and Skeletal Problems:** Deficiency may lead to bowing of legs, swollen knees and hocks, arching of the back, and occasionally paralysis.

5. **Rickety Rosary:** In some cases, there may be an enlargement of the osteochondral junction in ribs, leading to a condition referred to as "**Rickety Rosary**."

**3. Vitamin E** : active form - alpha tocopherol

**Sources:** Green fodders, cereal grains, vegetable oils, fats, and nuts, oil seeds and legumes

**Functions:**

- **Biological Antioxidant:** Vitamin E primarily functions as a biological antioxidant. It works in association with the selenium-containing enzyme glutathione peroxidase to protect cells against oxidative damage caused by free radicals. This protection is especially important in preventing the oxidation of polyunsaturated fatty acids.

- **Immune System Support:** Vitamin E also plays a vital role in the development and function of the immune system.

**Deficiency Symptoms:**

1. **Nutritional Myopathy:** Nutritional myopathy, also known as muscular dystrophy, frequently occurs in cattle, particularly calves. Affected animals may be unable to rise, and weakness of the neck muscles can prevent them from raising their heads. This condition is often referred to as white muscle disease.

2. **Stiff Lamb Disease:** Nutritional myopathy can also affect lambs, leading to symptoms similar to those in calves. It is frequently referred to as stiff lamb disease.

3. **Pig Diseases:** In pigs, vitamin E and selenium deficiency can lead to myopathy, cardiac disease, and **Mulberry heart disease.**

4. **Chick Diseases:** Vitamin E deficiency in chicks can result in several distinct diseases, including **nutritional myopathy** (affecting pectoral and leg muscles), encephalomalacia (**crazy chick disease**, characterized by the inability to walk or stand, accompanied by brain hemorrhages and necrosis), and **exudative diathesis.**

5. **Yellow fat disease:** occurs when high levels of PUFA are fed with low levels of vitamin E which lead to deposition of ceroid pigment in adipose tissue causing fat cell necrosis and inflammation.

**4. Vitamin K** : K1: Phylloquinone – Green plants & oil seeds K2: Menaquinone – Intestinal bacteria K3: Menadione – Synthetic product

**Sources:** Green leafy vegetables, egg yolk, liver, fish and synthesized by bacteria in GIT

**Functions:** Vitamin K is required for the synthesis of prothrombin in the liver. It is also necessary for the synthesis of factors like plasma thromboplastin and tissue thromboplastin, which are involved in the conversion of prothrombin to thrombin. Vitamin K helps convert inactive vitamin K-dependent zymogens into calcium-binding proteins, activating them and facilitating blood clotting.

**Deficiency Symptoms:**

1. **Hemorrhagic Conditions:** Vitamin K deficiency can lead to low prothrombin levels in the blood, resulting in hemorrhagic conditions. This means that animals with a deficiency may experience excessive bleeding and difficulty in clotting their blood.

2. **Sweet Clover Disease:** In cattle, sweet clover disease is associated with vitamin K deficiency. When sweet clover becomes mold-infested, it can contain a compound called dicoumarol, which lowers the prothrombin content of the blood, leading to hemorrhagic disease. For this reason, vitamin K is often referred to as the antihemorrhagic vitamin.

**5. Vitamin C (Ascorbic acid):** synthesized in all animals except human & guinea pigs: they lack L-gluconolactone oxidase required for Vit. C synthesis

**Sources:** Citrus Fruits and Green Leafy Vegetables

**Functions:**

1. **Collagen Formation:** Vitamin C plays a crucial role in the formation of collagen, which is an essential structural protein found in various tissues of the body, including capillaries, teeth, and bones.
2. **Oxidative Reduction:** It is involved in oxidation reduction reactions within living cells.

**Deficiency Symptoms:**

**Scurvy in Adults:** Scurvy is a classic deficiency disease associated with vitamin C. Symptoms in adults may include weakness, bleeding gums, loosening of teeth, swollen joints, and hemorrhages in various body tissues.

**6. Thiamine (Vitamin B1)**

**Sources:** Yeast, bran, rice polish, egg yolk, liver, kidney. Pork is rich in thiamine.

**Functions:** Thiamine diphosphate, the active form of thiamine, serves as a coenzyme in various metabolic reactions. It plays a crucial role in the oxidative decarboxylation of pyruvate to acetyl coenzyme A and alpha-ketoglutarate to succinyl coenzyme A in the tricarboxylic acid (TCA) cycle, which is a central pathway in cellular energy production.

**Deficiency Symptoms:**

1. **Polioencephalomalacia (ruminants):** Thiamin hydrolyzed by thiaminase in rumen- Circling movements, opisthotonus, convulsion & death.
2. **Star-gazing posture:** polyneuritis in chicks due to accumulation of intermediates of carbohydrate metabolism (lactate, pyruvate & oxaloglutarate) causes neuritis. Chicks sit on flexed legs & draws head backward—**star gazing**

**7. Riboflavin (Vitamin B2)**: Synthesized by yeast, bacteria and fungi. Rich sources are liver, yeast, milk, egg and green leafy vegetables.

**Functions:** Riboflavin is a constituent of flavoproteins, including Flavin Mononucleotide (FMN) and Flavin Adenine Dinucleotide (FAD). These flavoproteins are involved in various metabolic pathways, including amino acid and carbohydrate metabolism.

**Deficiency Symptoms:**

**Curled toe paralysis:** In chicks, riboflavin deficiency can cause curled toe paralysis, characterized by peripheral nerve degeneration. Chicks with this condition walk on their hocks with their toes curled inwards.

### 8. Niacin (Vitamin B3)

**Sources :** Rich sources are liver, yeast, groundnuts and sunflower meals**.** Niacin can be synthesized in the body tissues from the amino acid tryptophan. This conversion from tryptophan to niacin is an important source of niacin in animals.

**Functions:** Niacin, in the form of nicotinamide, serves as the active group for two crucial coenzymes: nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP).

**Deficiency Symptoms:** Deficiency symptoms are more likely to occur in pigs and poultry when they are fed diets with a high maize (corn) content. Maize contains very little niacin or tryptophan, which can exacerbate niacin deficiency. Its deficiency causes Pellagra/ Black tongue.

- **In Pigs:** Niacin deficiency in pigs can lead to a range of symptoms, including poor growth, anorexia (loss of appetite), enteritis (intestinal inflammation), vomiting, and dermatitis (skin inflammation).
- **In Poultry:** Deficiency of niacin in poultry can result in bone disorders, feathering abnormalities, and inflammation of the mouth and upper part of the esophagus.

**9. Vitamin B6 (Pyridoxine)**: Groundnut meal, rice bran, wheat bran, molasses, liver and milk

**Functions:** Pyridoxal phosphate, the active form of vitamin B6, acts as coenzyme for transaminases & decarboxylases.

**Deficiency Symptoms:** In Pigs: reduced appetite, microcytic hypochromic anemia, convulsion, slow growth Poultry: Chicks show jerky movements, in adult birds hatchability & egg production are adversely affected

**10. Pantothenic Acid:** Pantothenic acid is a crucial component of coenzyme A (CoA), an essential coenzyme involved in acyl transfer reactions.

**Deficiency Symptoms:**

1. Pigs experiencing pantothenic acid deficiency may exhibit slow growth, diarrhea, hair loss, scaliness of the skin, and a characteristic **'goose-stepping' gait**. In severe cases, they may be unable to stand.
2. Mature birds may experience reduced hatchability.

**11. Folic Acid:**

**Sources:** Dark green leafy materials, cereals and extracted oilseed meals are good sources

**Functions:** Folic acid is converted into tetrahydrofolic acid within the body, and this active form of the vitamin serves as a coenzyme.

**Deficiency Symptoms:**

1. Anemia, characterized by a decreased number of red blood cells and reduced oxygen-carrying capacity.
2. Poor bone development, which can result in skeletal issues.
3. Reduced egg hatchability, leading to lower reproductive success.

**12. Vitamin H/ Biotin:**

**Functions:** Biotin acts as a prosthetic group for several enzymes involved in catalyzing the transfer of carbon dioxide from one substrate to another.

**Deficiency Symptoms:** Avidin in egg white protein is antimetabolite causing biotin Deficiency.

- Pigs: foot lesions, alopecia (hair loss) and dry scaly skin.
- Poultry: causes reduced growth, dermatitis, leg bone abnormalities, cracked feet, poor feathering, Parrot beak and fatty liver and kidney syndrome (FLKS).
- Ruminants – affect propionic acid metabolism

**13. Choline:** Green leafy materials, yeast, egg yolk and cereals are rich sources of choline

**Functions:** It is an essential structural component of body tissues, contributing to cellular structure and activity. Choline is a crucial component of lecithins, which are vital for cellular structure and function.

**Deficiency Symptoms:** In chicks, choline deficiency is associated with the prevention of perosis or slipped tendon, a condition affecting the joints and tendons in the legs.

**14. Vitamin B12 (Cyanocobalamin):** Vitamin B12 is primarily synthesized by microorganisms, and its presence in foods is ultimately of microbial origin. Synthesized by rumen bacteria when sufficient Co is available

**Functions:** It acts as a coenzyme in several essential enzyme systems, including isomerases and dehydrases. Vitamin B12 is involved in the biosynthesis of methionine from homocysteine, playing a role in amino acid metabolism.

**Deficiency Symptoms:**

- **Pernicious anemia**- failure of absorption of Vit B12 due to lack of intrinsic factor generally lacking in animals with pancreatic disorder hence interfere with B12 absorption which is characterized by arrest of RBC maturation in bone marrow causing macrocytic hyperchromic anemia.
- Poor growth, Poor feathering, Decreased hatchability, Dermatitis and rough coat.

| Vitamin | Main effect | Additional effect |
|---|---|---|
| A | Protection of the epithelium | Fertility, cell metabolism, immunity |
| β-Carotene | Vitamin A precursor | Health, fertility |
| D | Metabolism of calcium and phosphorus | Immunity |
| E | Antioxidant | Health, immunity, quality of meat , milk, eggs |
| K | Blood coagulation | Protein carboxylation |
| $B_1$ | Carbohydrate metabolism | Transmission of stimuli, nervous system |
| $B_2$ | Energy metabolism | |
| $B_6$ | Protein metabolism | Immunity |
| $B_{12}$ | Blood production and protein metabolism | |
| Biotin | Carbohydrate and fat metabolism | Quality of skin, hair, horn |
| Folic acid | Carbohydrate and nucleic acid metabolism | Fertility |
| Niacin | Energy metabolism | Metabolic activity, ketosis protection |
| Pantothenic acid | Energy metabolism | |
| C | Antioxidant | Stress reduction, health, immunity |
| Choline | Fat metabolism, methyl group donor | Transmission of stimuli, nervous system |

**Table 5:** Vitamins and their effects