PLANT HORMONES

Basic concepts: growth, development, phytohormones, physiologically active substances, growth promoters, growth inhibitors, cell division, elongation and differentiation

Learning objectives:

1. Understanding of the concept of growth in plant

2. Understanding the concept phytohormones and their roles in growth of plant

3. Classification of phytohormones

4. Hormonal balance, growth and development in plant

Theoretical background:

Growth could be defined as a process of irreversible, quantitative change in plant. There are various dimensions of these changes; namely weight, form, volume, area and size. Development on the other hand is a qualitative change. The cellular processes underlying growth are:

1. Cell division

2. Cell elongation

3. Cell differentiation

Please find in table 1 a comparative analysis of the cellular basis of growth phase, using certain cytological and kinetic parameters.

Phytohormones are physiologically active substances that affect plant growth and development. They act as chemical messengers or plays signalling role in plant; hence they are functionally integrators and regulators of physiological processes in living organisms. Unlike the animal hormones, plant hormones are fewer in number, they affect most cells in the plant, the response of plants to them is diverse (pleitropic effect) and they are modulated by environmental, developmental and other hormones through cross-regulation of their actions, that could be antagonistic or synergistic in nature. They are required in small quantity, transported from the site of synthesis to mediate physiological response in other parts of the plant.

Recognised over the years are classical phytohormones; Auxin, Gibberellin, Cytokinin, Abscissic Acid and Ethylene and newer ones; Jasmonic Acid, Salicylic Acid, Brassinosteroid and Strigolactones. Apart from the aforementioned substances there are other substances in plant that play signalling role , though they cannot be classified as hormones, such as polyamines, Reactive Oxygen Species (ROS), Signalling Peptides and Nitric Oxide. Among the classical hormones are growth promoters (Auxin, Gibberellin and Cytokinin) and growth inhibitors (Abscissic Acid and Ethylene).

The mechanism of hormonal action is quite complex and attempts had been made to elucidate its action. After synthesis and accumulation of hormones it is transported to the site of action through the phloem or xylem stream or via diffusion. It it sometimes transported by regulated transport proteins. Perception of environmental perturbation is mediated through binding of hormones to transmembrane or intracellular receptors. Signal transduction or amplification is mediated by the activation of kinase activities through the process of phosphorylation where ATP molecules bind to protein through protein kinase eventually leading to signal amplification. The reverse process of inactivation is through the action of phosphatise. Other elements of signal transduction include the allosteric changes of protein, phophorelay system and regulated protease.

The downstream effect involves:

1. Alternation of gene expression pattern via transcription proteins

2. Non-genomic function

In crop production, most cultivated crops are subjected to actions of various stressors; biotic and abiotic. In the case the crop plant is subjected to both stressors, priority is given to amelioration of the actions of abiotic stressors at the expense of biotic stressors. In all instances of abiotic stressors, there is increased synthesis of ABA, production of induced proteins and other osmoprotective and regulatory substances like Heat Shock Proteins, Proline, Glycine Betaine etc.

Biotic stressors, depending on the nature of the biotic stressors leads to production of salicyclic acid if biotrophic or Jasmonic acid or Ethylene if necrotrophic. The production of these hormones interferes with GA/Auxin induced growth pathways. The non-genomic function leads to the production of antiherbivory function, anti microbial function i.e. defensin protein and the production of plant volatile to suppress the incidence of biotic stressors.

Hormonal actions vary throughout the phenological phases. At juvenile or vegetative phase, growth promoters are more predominant in their actions. Auxin aids cellular division and elongation. Cytokinin controls stomatal aperture and water potential of the leaf, while GA is responsible for the protection of chlorophyll, RNA and degradation of protein. With transition to reproductive phase, though genetically controlled and mediated by environmental factors, hormonal actions equally mediate this process, with growth inhibitors; ABA and Ethylene affecting rate of senescence and maturation, both physiological and harvest. Maturation referred to here is the expression of full reproductive potential, while at physiological maturity; there is a cessation of sexually induced reproductive growth.

See table 3 for a comparative analysis of different phytohormones

Table 3 Hormone types, characteristics and their plant physiological response to their actions

Hormone Type	Source	Transport Direction	Response dimension		
			Biochemical	Physiological	
				Growth	Fl in

Auxin	Apical Bud	Basipetal/Polar	o Nucleic acid activity o Amylase activity o Increase in cell wall permeability o Formation of ATP o Cell wall plasticity o Protoplasmic viscosity	o Shoot/root ratio o Apical dominance o Cell elongation o Cell division o Tropism	
Gibberellin	o Young leaves o Root Tips o Embryo	All direction, no polarity	De novo synthesis of the above stated enzymes	o Stem elongation o Apical dominance	
Cytokinin	o Root tip o Developing seed o Cambial tissue	Acropetally	o Nucleic acid metabolism o Protein synthesis o Incorporation of RNA	o Cell division o Lateral bud formation	
Abscissic	o Matured leafs	Acropetally	o Induction of	o Growth inhibitor	

Acid	o All plants parts		hydrolase o Induction of α amylase activity	o Stomatal physiology	
Ethylene	All parts of plant	Diffusion	o Climacteric raise o Activity of malic and pyruvate decarboxylase o Degreening of citrus o Activity of chlorophyllase	o Growth inhibitor	

Table 4 Comparative analysis of growth phases

Growth phases	**Parameters for comparison**				
	Cytological parameters				**Kinetic parameters**
	Cell wall	**Protoplasm**	**Vacuole**	**Nucleus**	**Growth rate**

Division	Thin/isodiametric	Most dense	Smallest	Largest	Slowly
Elongation	Thicker	Medium	Bigger	Medium	Rapid
Differentiation	Thickest	Least dense	Biggest	Smallest	Steady

Table 5 Dimensions of Physiologically Active Substances

Parameters for comparison	Dimensions of physiologically active substances		
	Phytohormones	Elicitor Molecule	Growth Substances
Nature	Endogenous or naturally occurring	Naturally occurring or synthetic	Naturally occurring or synthetic
Quantity produced	Small	Small	Small
Plant response mode	o Physiological changes o Changes in growth and development o Signalling element	Initiation or improvement of specific compound with hormone-like activities	o Induction of physiological processes o Changes pattern of growth and development
Type of physiologically active substance	o Auxin o Gibberellin o Cytokinin o Abscissic Acid o Ethylene	Brassinosteroids Jasmonic Acid Salicylic Acid Polyamines	

Topic: Homeostasis

Basic concepts: Homeostasis, control, regulation, growth, nasty, tropism, photomorphogenesis, thigmotropism, osmoregulation, autopoiesis

Learning Objectives:

1. Understanding of the concept of homeostasis, regulation and control

2. Life as organisational homeostasis and its biological implications

Theoretical Background:

The concept of homeostasis is pervasive in biological sciences. Conceptually it could be defined as biological stability. The basis for this biological stability could be ascribed to circularity observed in living systems. Present knowledge as proposed by Humberto Maturana indicated that the basis of life is organisational invariance, that is the organisational homeostasis observed in all living things. Though not generally accepted by the mainstream of biologist, it could serve as our working hypothesis in the definition of life as opposed to what is obtainable today, where a list of certain characteristics are given in profiling what could be regarded as life.

According to Humberto Maturana Life is an Autopoietic system that is semantically or operationally closed but thermodynamically opened. It is this closure that confers on the system organisational invariance, i.e organisational homeostasis.

The picture below indicated the basic mechanism underlying an autopoietic system, where the system is self-referential, autonomous without input and output.

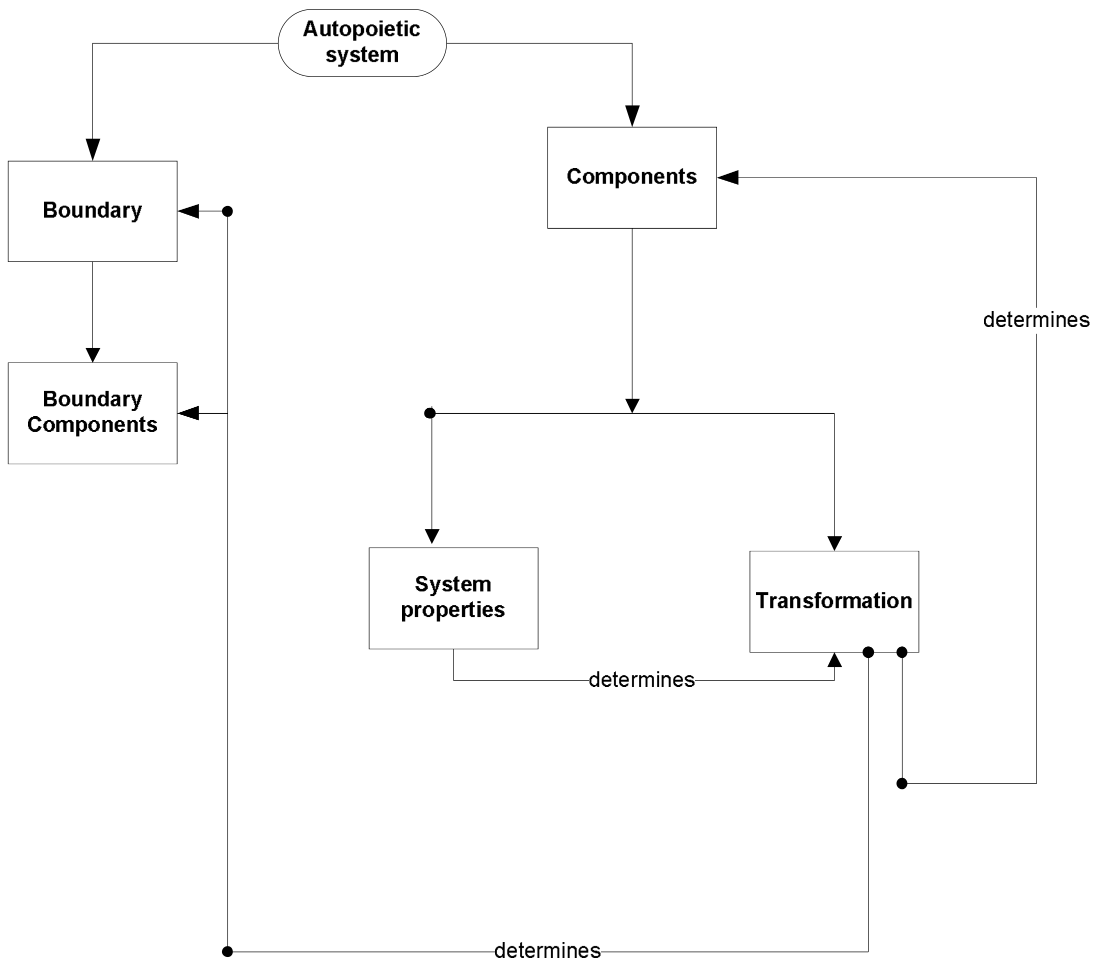

Figure 2

The dimensions of this biological stability are:

1. Physiological

2. Ecological

The basic axiom in any physiological process is that its level of activities is within certain limit for it to operate; all physiological processes operate within certain concentration of solutes, temperature and pH.

The ecological dimension of biological stability presupposes that there is a certain correspondence; functional and structural between the biological system and its environment. This is evident in the cycle of certain elements in nature, such as water, nitrogen, carbon, phosphorus cycles and the formation of different adaptive mechanisms to various ecological conditions. One vivid example is the formation of different ecotypes of plant depending on their adaptability to available water.

1. Mesophytes
2. Hydrophytes
3. Xerophytes
4. Halophytes

Conceptually, biological stability could be considered as a process of coordination and control, while control is a process of regulation. A graphical illustration is provided below depicting homeostasis in a living system.

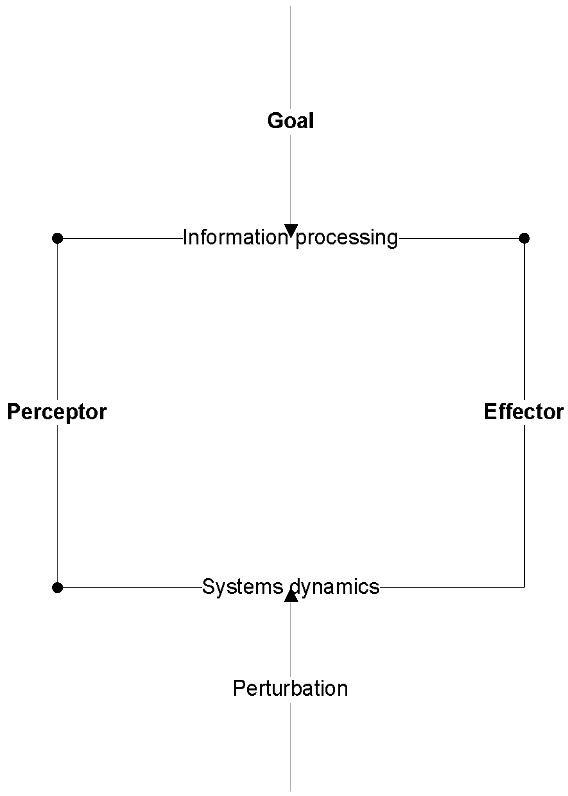

Figure 3

The following elements are depicted in the illustration

1. Perturbation: Any environmental factor, capable of disrupting system's stability. These factors are Abiotic and biotic in nature

2. Sensor: element for detecting difference in status from the system goal. Within the context of a plant, there are different sensors; such as phytochrome, cryptochrome, phototropin and zeaxianthin.

3. Perceptor: plant organs

4. Model: The genetic composition of the plant

5. Goal: homeostasis

6. Information processing: signalling elements and signal transduction

7. Decision making: System survivability and senescence

8. Effector: Plant organ

9. Action: System's response, in plant they could take the following forms; growth, nasty, morphogenesis, tropism and thigmotropism.

Table 6 Comparative plant and animal homeostasis matrix

		Organ/regulatory mechanism	
Scope of balance	Process nomenclature	Animal	Plant
Water	Osmoregulation	Kidney	Active accumulation of osmolyte independent of cellular volume change Uptake of compatible ions Ion extrusion, sequestration and
Nitrate		Kidney and Liver	Nitrogen cycle
Glucose		Pancreas and Liver	Glycolysis and glycogenesis
Temperature	Thermoregulation	Skin	Transpiration

Topic: Growth and Development

Basic concepts: Growth, development, phenology, shoot growth pattern, determinate, indeterminate

Learning expectations:

1. Articulate the concepts of growth and development as it is related to agricultural plants

2. Understand shoot growth pattern

3. Understand factors affecting growth and development in Agricultural plants

4. Understand process involved in reproductive growth and factors affecting it

5. Understand transformative process in fruit growth

Basic theoretical background:

Growth is a process of irreversible increase by cell division and enlargement, including synthesis of new cellular material and organisation of sub cellular organelles. This process also involves conversion of reserve materials into structural materials. There are various dimensions for measuring plant growth:

1. Increase in fresh weight

2. Increase in dry weight

3. Volume

4. Length

5. Height

6. Surface area

Depending on the growth pattern, shoots are classified as:

1. Determinate- flower buds initiate terminally, while shoot elongation stops.

2. Indeterminate- flower buds born laterally, while shoot terminals remain vegetative.

Other classification of the shoot growth pattern is based on the duration of the plant development; shoots are classified annuals, biennials and perennials. Annuals complete their life cycle in one growing season. Biennials require two growing to complete their life cycle, not necessarily two full years. The stem growth is limited during first growing season. Perennials are either herbaceous or woody.

Development is qualitative change in a living system over time. The qualitative aspect of development involves morphological changes and different stages of development over time-phenology. The stages of development are classified as:

1. Vegetative/ Reproductive

2. Exponential, stable and decline, based on the trajectory of dry matter accumulation

3. Functional classification that takes into cognizance the stages of leaf formation, seed/grain set and seed/grain fill

Quantitatively, development is measured as duration; Days-to-harvest-maturity, days-to-flowering, days-to-actual-accrual-of-yield. The inverse to duration of development is the rate of development. The rate of reproductive development is controlled by genetic factors but modulated by environmental influences. The predominant environmental influence is temperature and photoperiod. The rate of reproductive development to these environmental factors at the sub-optimal level is first linear, reaching a plateau at the optimal level, eventually declining at supra-optimal level.

The predominant model proposed concerning development in plant is **phasic theory of development.** The basic assumptions underlying this process are:

a. Development is phasic in nature, i.e. progression from one physiological system state of the meristerm to another

b. Identified are two phases; vegetative and reproductive phases

c. Plant system possesses the capability of development to progress autonomously

d. The identifies phases of development are irreversible

e. Development process is controlled by various environmental and genetic factors, mainly; temperature and photoperiod (G X PX T)

f. Photoperiod gene and vernalisation genes possesses delaying impact on the process of development

g. Temperature effect is through Q_{10} effect on the activities of the enzymes and ultimately on the biochemical reaction

Developmental process is controlled by genetic factors and modulated by the environment. The predominant environmental factor is temperature and photoperiod.

Find below photothermal response of crops and their effect on days to flowering (DTF)

DTF

Early

Late

Base Temperature

Low High

Temperature

At reduced temperature, the delaying effect of photoperiod genes and vernalisation genes is reduced, hence the vernalisation response,; reduction in days to DTF at low temperature, with increasing temperature due to Q_{10} effect, the delaying effects of those genes becomes pronounced, leading to late DTF, beyond the base temperature effects of photoperiod genes becomes predominant. There are distinctive morphological characteristics of the activities of these genes on the phenology of crops, these are listed below. One could infer that for proper development crops possesses vernalisation requirements; duration of days at low temperature to inhibit the activities of vernalisation genes, while the vernalisation response is the reduction in days to flowering due to the thermal effect at low temperature. Vernalisation responsiveness is inversely proportional to the age of the crop, but directly proportional to the duration of exposure to low temperature. Photoperiod responsiveness is directly related to the period of vernalisation and age of the crop.

Temperature effect on the rate of development in crops is expressed quantitatively as the air temperature, in Heat Units (Crop Heat Unit or Growing Degree Days) and as growing points. Quantitatively, the GDD is expressed as:

$$\textbf{GDD: } \frac{(T_{MAX} - T_{MIN})}{2} - T_{BASE}$$

Functionally, there are three different stages of plant development:

1. Juvenility; this stage terminates at the initiation of flowering and fruiting. It may be extensive in certain forest species.

2. Maturation; this stage in most crops coincides with between flowering and the time of crop physiological maturity.

3. Senescence; a physiological aging process in which tissues in an organism deteriorate and finally die. It is considered to be terminal and irreversible, though it can be postponed by removing flower before seeds start to form.

Reproductive growth of crop is considered important because of its agronomic implication. The reproductive structure serves in most cases as organs of economic importance, hence the need to study it and factors affecting its growth and development. Different phases in plant reproductive growth had been identified; namely:

1. Flower induction and initiation
2. Flower differentiation and development
3. Pollination
4. Fertilisation
5. Fruit set and seed formation
6. Growth and maturation of seed and fruit
7. Fruit senescence

The process of transforming vegetative structure into reproductive ones in mediated by various factors; endogenous and exogenous factors. Among the exogenous factors, temperature and photoperiod play a very vital part. Photoperiodism is a phenomenon of plant response to relative length of day to night. Hence plants with respect to their photoperiodic response could be classified as:

1. Short-day plants

2. Long-day plants

3. Day-neutral plants

Some of the agricultural crops require a period of low temperature to initiate flowering. This phenomenon is referred to as vernalisation. It was first observed in winter wheat and many biennials. After flowering, the next process towards complete reproductive growth is pollination; a process of transfer of pollen from anther to stigma. It may be same flower or different flower but same plant; self-pollination or different flowers from different cultivars; cross-pollination. Pollens are transferred by insects, wind or other minor agents like water, snails, slugs etc. There are cases where fruits are formed without pollination and fertilisation; parthenocarpy.

Flowering and fruit growth

Basic concepts: Fruit growth, flowering, climacteric fruits, fruit drop, fruit set

Learning Objectives:

1. Understand transformative process in fruit during maturation

2. Articulate the effect of transformative process on fruit quality profile

3. Articulate factors affecting fruit growth and its agronomic implications

4. Differentiate between climacteric and non-climacteric fruits and implication on fruit shelf life

Basic theoretical Background:

After fruit set, true fruit and associated tissues begin to grow. Food moves from other parts into the fruit tissue, depending on its sink strength and the characteristic quality profile begins to be noticed in the fruit. Physiologically, transformative process experienced during the fruit growth is respiratory in nature. Depending on the type of fruit, some fruits experience a surge in temperature as they ripen; such are referred to as climacteric, e.g. Banana. But not all fruits experience such, the non-climacteric fruits. A rise in temperature with fruit maturation has some economic implication. The shelf life of such fruits is limited. In table 7, the implication of this transformative process on the quality parameters of a fruit is indicated. High temperature, gas composition and relative humidity in the storage atmosphere play a significant role in the rate of this process. High temperature, presence of ethylene and oxygen could be responsible for the increase in the ripening process. At the end of the fruit maturation period, characterised by ripening process, fruits experience senescence- fruit drop, a process mediated by growth inhibitors most especially Abscissic Acid (ABA)

Table 7 Dimensions of transformational processes observed during ripening of fruits

Quality Parameters	**Transformational process**	
	Scope	**Dimension**
Appearance	Pigmentation Green→ yellow or other characteristic colours	• Increase in the activity of chlorophyllase • Sequestration of pigment • Development of carotenoid and anthocyanin in the presence of light and phytochrome • Unmasking of certain pigments

Texture	Softening Hard→ Soft	Hydrolysis of • Cell wall (solubilisation of pectic substances in middle lamellae via methylation of galaturonic acid, reduction in size of polygalacturonide or both • Cell content
Flavour	Development of characteristic • Aroma • Taste Polymers→ monomers Loss of astringency	Production of the secondary metabolites Hydrolytic changes of biopolymers
Condition	Increasing degree of perishability • Climacteric respiratory pattern • Non-climacteric respiratory pattern	• Catabolic process>Anabolic process • Increasing activity of growth inhibitors e.g. C_2H_2 and ABA

ENZYMOLOGY

Enzymes- properties, compositions, Types, Mechanisms of action.

Enzymes are protein compounds that catalyse a specific reaction. Living cells contain thousands of different enzymes that accelerates or decelerates one kind of reaction without itself being changed. In some of these reactions, small organic molecules such as; acids, sugars, nucleotides and lipids are broken down to provide energy for the cell. In other reactions, small molecules are built into complex macromolecules, such as; proteins, DNA, RNA, and polysaccharides, or used to carry signals, or to control cell movement or gene expression. Sometimes the enzyme proteins have non proteins attachment called prosthetic group when bounded by covalent bond, e.g. metals like; Cu, Mg, and Fe, and co-enzyme or co-factors when bonded by loose hydrogen bond, e.g. Vitamins. The co-enzyme and prosthetic group may become attached to several different protein forming different enzymes. Enzymes exhibit enormous catalytic power, in some cases increasing reaction rates by a factor' of over 1014 (one hundred million). Enzymes dictate the pattern of chemical changes in a cell and without them life as we know it would be impossible.

Properties characteristics of Enzymes

a) Small amount of enzymes are needed to convert large amount of substrate into products.

b) Same substrate can be utilized by several enzymes. For instance, isomers, phosphoglucomutase and glucose – 6 – phosphate dehydrogenase act on glucose to produce fructose – 6- phosphate, glucose -1- phosphate and 6- phosphoglucolactone respectively.

c) Enzymes work at narrow range of temperature. Optimum temp is 40^{o}c and could be destroyed at 60^{0}c.

d) They work at specific pH. Most function at around neutral pH (5-7). However, pepsin in stomach works at pH 2-3 and trypsin in duodenum works at pH 8.5.

e) Catalytic actions of enzymes may be specific. Hence an enzyme which catalyse one reaction may not catalyse another. For instance, invertase works on sucrose to produce glucose while zymase act on glucose and give carbondioxide and ethanol.

f) Enzymes are not destroyed by the reactions they catalysed and could be used again.

g) Enzymes could be poisoned by chemical compound like; mercury, chloride, silver chloride and hydrogen cyanide. This inactivate the enzymes, for example HCN blocks the enzymes involve in respiration.

Mechanism of Action (working) of Enzymes.

This can be explained by chemical hypothesis A B. Chemical energy needed could be in the form of heat (temperature) to activate passive A by bombarding A's molecules to activate it and later turned into B molecules. The energy that A molecule required to react and be converted into molecule B is the activation energy of reaction. Enzymes are believe to catalyse reaction by lowering the activation energy e.g. in

$2H_2O$ catalase $2H_2O + 2O_2$ the activation energy in the absence of catalase is 18,000cal mol. While in the presence of catalase, it is 6,400 cal mol. Lock and Key Hypotheses: the enzyme is believed to be the padlock and substrate the key.

substrate

enzyme Enzyme –substrate complex Products

Classification of Enzymes.

Enzymes are generally of two types, they are : intracellular enzymes and extracellular enzymes. But specifically, enzymes can be classified as follows:

1 According to substrate they act upon, e.g Arginase that act on arginine, tyrosinase act on tyrosine, lipase acts on lipids while proteinase acts on protein and carbohydrases and maltase on carbohydrates and maltose respectively.

2 According to the type of reaction they catalyse. For example: hydrolyses (hydrolytic enzyme), oxidases (oxidation reduction enzymes), phosphorylases (phosphate adding and deleting enzymes).

In both cases above, the suffix-ase is added to the name of the substrate or reaction type.

SPECIFIC ENZYME TYPE

1 Hydrolyses (hydrolytic enzymes)they catalyse the addition of the elements of water to specific bond of substrate. RCO-OR' HOH RCOOH + R'OH

E.G, lipases, carbohydrates, proteases

2 oxidases, (oxidation- reduction enzymes). These catalyse the removal or addition of hydrogen, oxygen or electron from or to substrate, which is thereby oxidised or reduced in the process.

RH +HA R+ AH_2(removal of H_2)

RO +$_{1\backslash 2)}$$O_2$ RO_2(addition of O_2)

R^{2+} R^{3+} +e e.g dehydrogenases and oxidases

3 Phosphoric; these catalyse the addition or removal of elements of phosphoric acids, e.g glucose + phosphate Hexokinase glucose – 1- phosphate

4 Carboxylase; these catalyse the removal or addition of CO_2 e.g, ribulose- 1,5 –diphosphate(5C) carboxydismutase Keto acid (6C)

5 Isomers: these catalyse the interconversion of aldose and ketose sugars e.g, Glucose – 6-phosphate Phosphoglucoisomerase fructose -6- phosphate

6 Lyase; these carry out breaking of double bonds e.g, lysozyme (found in tears, nasal mucus and egg) which dissolve certain airbone cocci (bacteria) by breaking the double bond of polysaccharides in their walls.

ESTIMATION OF RATES OF ENZYME ACTIVITIES

1 Use of turnover numbers; this is the number of moles of substrate converted per minute by 1 mole of enzyme. Succine dihydrogenase has turnover number of 1150 while carbonic anhydrase has turnover number 360,000,000.

2 Manometric; gases evolve as a result of enzyme activities are measured manometrically, e.g oxidase, carboxylase.

3 Spectrophotometric: uses the fact different quantities of product have different optical density at the same wavelength. The wavelength used depends on the enzyme type involved. E.g, for amylase, the wavelength is 490nm and for protease it is 700nm.

4 Colouration Method: works on the basis that the substrate and the product have different colour with dye. The disappearance of the colour with time is taken note of e.g. starch + iodine(blue black) Amylase maltose +iodine + E (iodine colour)

5 Chemical Estimation: this involve titration, chromatography and electrophoresis techniques. For instance, lipase are estimated by breaking lipids into fatty acids and glycerol using lipases and the liberated fatty acids quantities determined using titration with NaOH and Phenolphtalein as an indicator.

Enzyme Inhibitors

These are compounds that prevent, limit, or stop enzyme activities; they are divided into competitive inhibitors and non competitive inhibitors.

1. Competitive Inhibitors: have similar shape to the substrate and can fit into the active centre of enzymes. They lower enzyme activities e.g, the inhibition by malonic acid of the enzyme succinic dehydrogenase that catalyse the conversion of succnic acid to fumaric acid. Competitive inhibition can be overcome by increasing the concentration of the substrate.

2. Non Competitive Inhibitor: either undergoes chemical reaction with the enzymes and thereby alter the configuration of the enzymes or form bond with enzymes substrate complex to form inactive compound. They normally stop the working of enzymes and effect cannot be overcome by increasing the concentration of the substrate. Examples are effects of poison, heavy metals (Hg, Au, Ag). Cyanide, and carbon.

COMMERCIAL USES OF ENZYME

A papain obtains from plants like pawpaawa leaves- protease is sold as meat tenderizer (Aldolfs). It breakdown protein into peptones and make the meat soft.

B Protein digesting subtilism (from *Bacillus subtillis*) is incorporated into pre-soak laundry agent and detergent for cleaning purposes. It is effective in removing protein- containing stains (chocolate or coffee) from clothes etc.

C Synthetic amylase is used in beer laundry to break down starch substances into maltose.

D synthetic cellulose is used in the textile industry to breakdown clothes into pieces of yarns.