Post Harvest Operations and Processing of Fruits, Vegetables, Spices and Plantation Crop Products

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Lecture 03
Fruits and Vegetables (Part II: Respiration, Ripening & Senescence)

In the third lecture of the course, very important characteristics such as respiration, ripening, and senescence of fruits and vegetables are discussed.

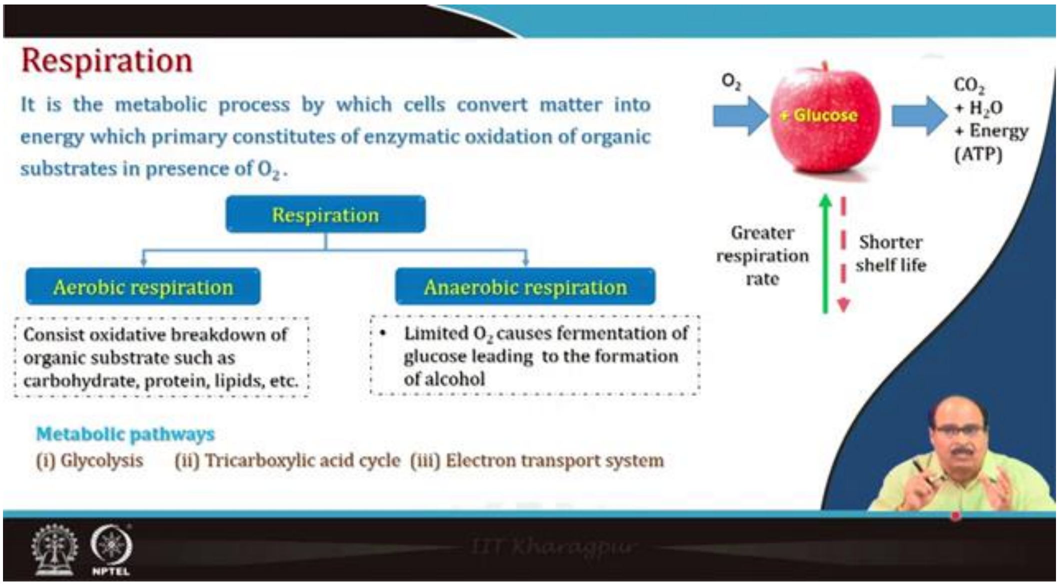
The broad concepts that are covered include respiration and its significance, respiration measurement and the various factors influencing the rate of respiration, ripening and senescence and finally, transpiration and condensation, which are very important factors that influence the quality of fruits and vegetables.

Respiration

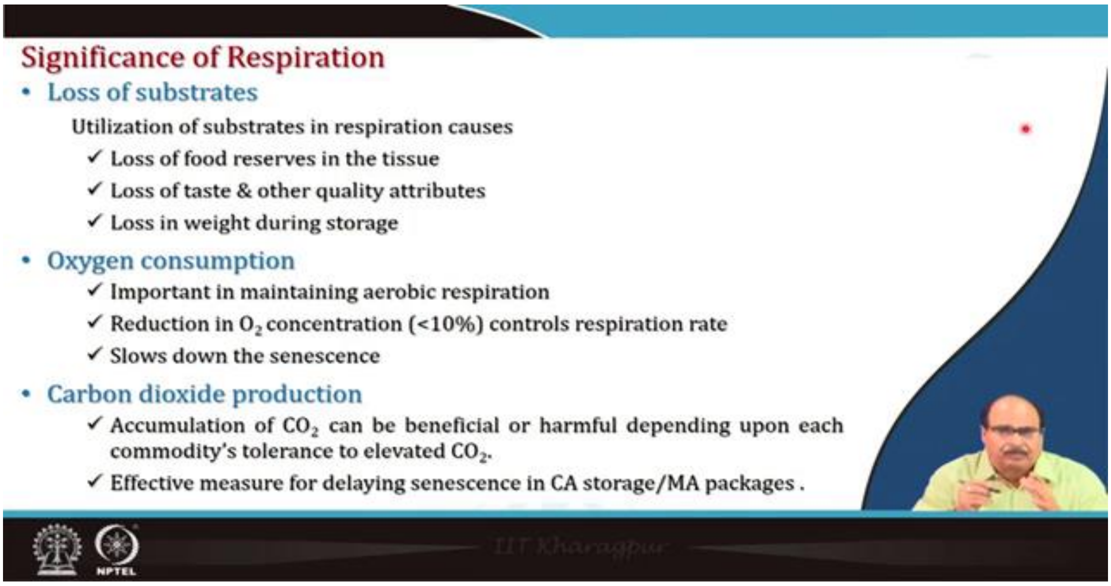
It is the metabolic process by which cells convert matter into energy which primary constitutes of enzymatic oxidation of organic substrates in the presence of oxygen. It can be seen in the figure that an apple contains sugars (glucose), after harvest consumes oxygen. These sugars are then oxidized and finally as a result of respiration, they produce carbon dioxide, water, and energy is generated in this process.

Types of Respiration

The respiration may be of two types, aerobic respiration and anaerobic respiration. Aerobic respiration consists of oxidative break down of organic substrates such as carbohydrate, protein, lipids, etc. In the anaerobic respiration, limited oxygen causes fermentation of glucose



leading to the formation of alcohol. In the process of respiration, various metabolic pathways are involved like glycolysis, tricarboxylic acid cycle, electron transport system etc. The details about these metabolic pathways can be acquired from any biochemistry or plant physiology books. Here basically, the science and engineering aspects of these things are considered.



Significance of respiration

Loss of substrates

In the process of respiration, there is a loss of substrates, i.e., utilization of substrates in respiration, which causes loss of food reserves in the tissue. There is loss of taste and other quality attributes and also there is loss in weight during respiration.

Oxygen consumption

In the process of respiration, there is consumption of oxygen (O_2), which is important in maintaining aerobic respiration. The reduction in O_2 concentration below 10% controls the respiration rate. It slows down the senescence. If the O_2 concentration in the gaseous environment, where the material is kept, is lowered down, the rate of the respiration will go down and the rate of senescence process will also be slowed down.

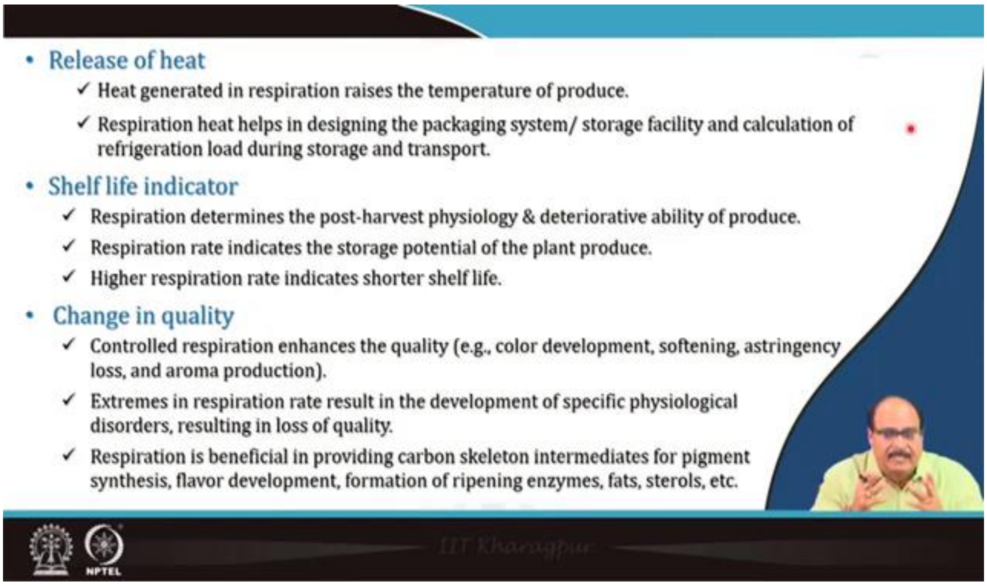
Carbon dioxide production

Exactly opposite of this is the carbon dioxide (CO_2) production. In the respiration process, carbon dioxide production increases. There is accumulation of carbon dioxide and this can be beneficial or harmful depending upon the commodities tolerance to elevated carbon dioxide.

Effective measures for delaying senescence in control atmosphere (CA) storage or modified atmosphere (MA) packaging

In fact, the whole principle of the operation of the CA storage or MA packaging is based on the respiration i.e., providing the O_2 at a slowest possible rate and maintaining the carbon dioxide concentration little elevated depending upon the commodity. The respiration is allowed to continue by maintaining proper concentration of O_2 and CO_2 in the environment.

The material is in good condition as long as it is respiring aerobically, once aerobic respiration stops, anaerobic respiration will take over and the material will expire.



Release of heat

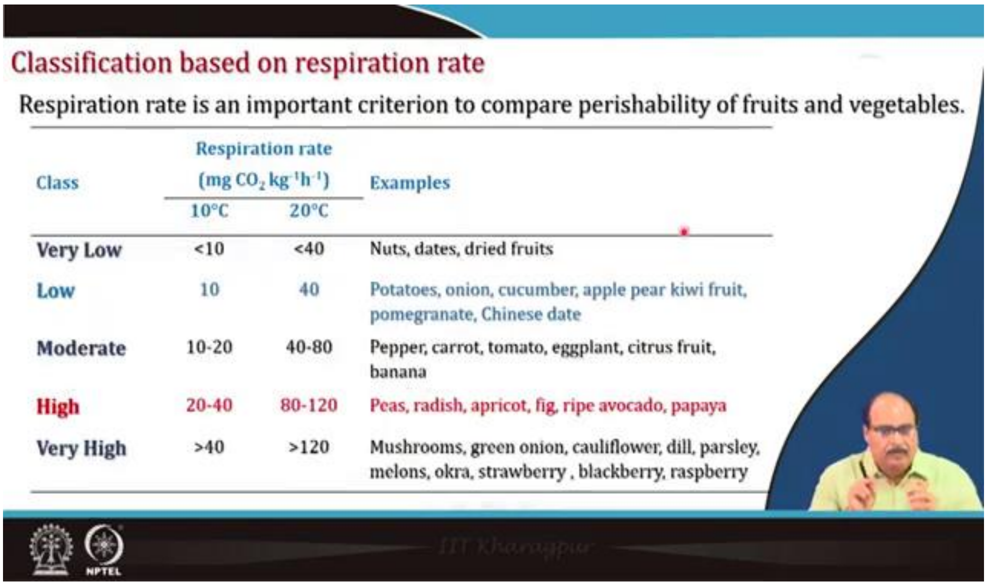
The heat generated in respiration rate raises the temperature of the produce. Respiration heat helps in designing the packaging system, storage facility and calculation of refrigeration load during storage and transportation.

Shelf-life indicator

Respiration rate or respiration behaviour of a commodity is very good indicator. Respiration determines the post-harvest physiology and deteriorative ability of the produce. Respiration rate indicates the storage potential of the plant to produce. Higher the rate of respiration shorter will be the shelf life of the produce.

Change in quality

Controlled respiration enhances the quality like colour development, softening, astringency, loss, aroma, etc. Extremes in respiration rate result in development of specific physiological disorders resulting in loss of quality. Respiration is beneficial in providing carbon skeleton intermediates for pigment synthesis, flavour development, formation of ripening enzymes, fats, sterols, etc.



Classification based on respiration rate

The rate of respiration is also considered an important criterion to compare perishability of the fruits or vegetables. Respiration rate can be measured either in the terms of O_2 consumed or in terms of CO_2 produced (mg of CO_2 kg^{-1} $hour^{-1}$).

Very low respiring commodities

If at a temperature 10 °C, the CO_2 produced is less than 10 mg kg^{-1} $hour^{-1}$ or at 20 °C, it is less than 40 mg kg^{-1} $hour^{-1}$, then the produce is categorized as a very low respiring. It will have a good shelf life at room temperature. Examples of this category include nuts, dates, dried fruits, etc.

Low respiring commodities

If at a temperature 10 °C, the CO_2 produced is 10 mg kg^{-1} $hour^{-1}$ or at 20 °C, it is 40 mg kg^{-1} $hour^{-1}$, the produce is categorized as low respiring. Examples of this category include potatoes, onion, cucumber, apple, pear, kiwi fruit, pomegranate, Chinese date etc.

Moderate respiring commodities

In the other case, if the CO_2 production is in the range of 10 to 20 mg kg^{-1} $hour^{-1}$ at 10 °C or in the range of 40 to 80 mg kg^{-1} $hour^{-1}$ at 20 °C, the commodity is considered as moderate respiring. The examples of this category include pepper, carrot, tomato, citrus fruits, banana etc.

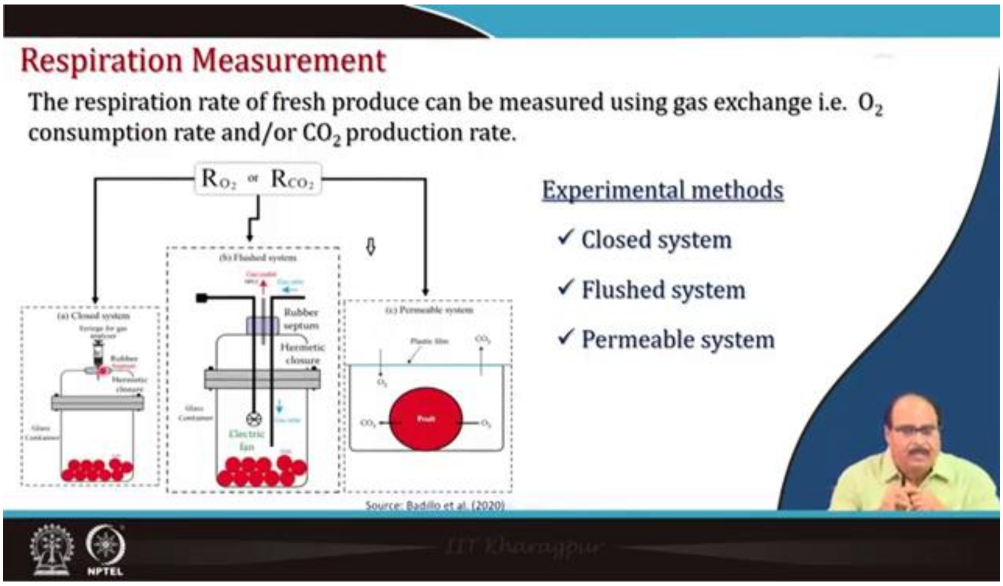
High respiring commodities

High respiring commodities are those, which produce CO_2 in the range of 20 to 40 mg kg^{-1} $hour^{-1}$ at 10 °C or 80 to 120 mg kg^{-1} $hour^{-1}$ at 20 °C. The examples are peas, radish, apricot etc.

Very high respiring commodities

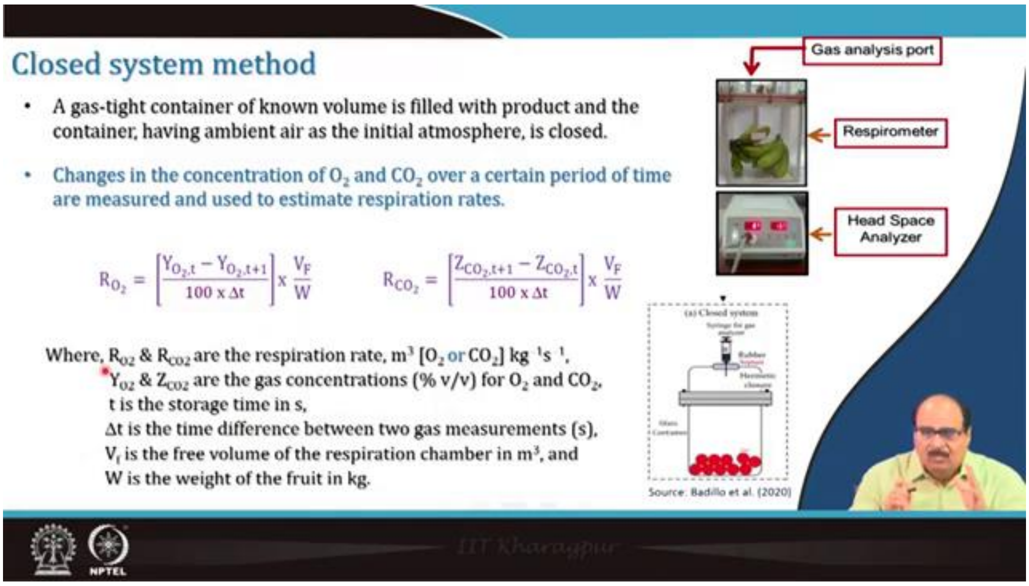
The very high respiring commodities are those, where the CO_2 production is more than 40 mg kg^{-1} $hour^{-1}$ at 10 °C or more than 120 mg of CO_2 kg^{-1} $hour^{-1}$ at 20 °C. The examples of these highly respiring fruits or vegetables include mushrooms, green onion, cauliflower, blackberry, raspberry etc.

The post-harvest management practices are depend on the rate of respiration of agricultural commodities.



Respiration Measurement

The rate of respiration of the fresh produce can be measured using gas exchange either in terms of the O_2 consumption rate or CO_2 production rate. There are three experimental methods, which are generally used including closed system, flushed system and permeable system.



Closed system method

In the closed system method, a gas tight container of known volume is filled with the commodity having ambient air inside as the initial atmosphere. The materials are kept inside the container and the container is closed. As shown in the figure syringes are connected with the headspace gas analysers.

The changes in the concentration of O_2 and CO_2 over a certain period of time are measured and used to estimate the respiration rate. The respiration rate can be measured either in terms of O_2 consumption or in terms of CO_2 production by using the following equations:

$$R_{O_2} = \left[\frac{Y_{O_{2,t}} - Y_{O_{2,t+1}}}{100 \times \Delta t}\right] \times \frac{V_F}{W}$$

$$R_{O_2} = \left[\frac{Z_{CO_{2,t+1}} - Z_{CO_{2,t}}}{100 \times \Delta t}\right] \times \frac{V_F}{W}$$

Where, R_{O2} & R_{CO2} are the respiration rate, m^3 [O_2 or CO_2] $kg^{-1}s^{-1}$, respectively,

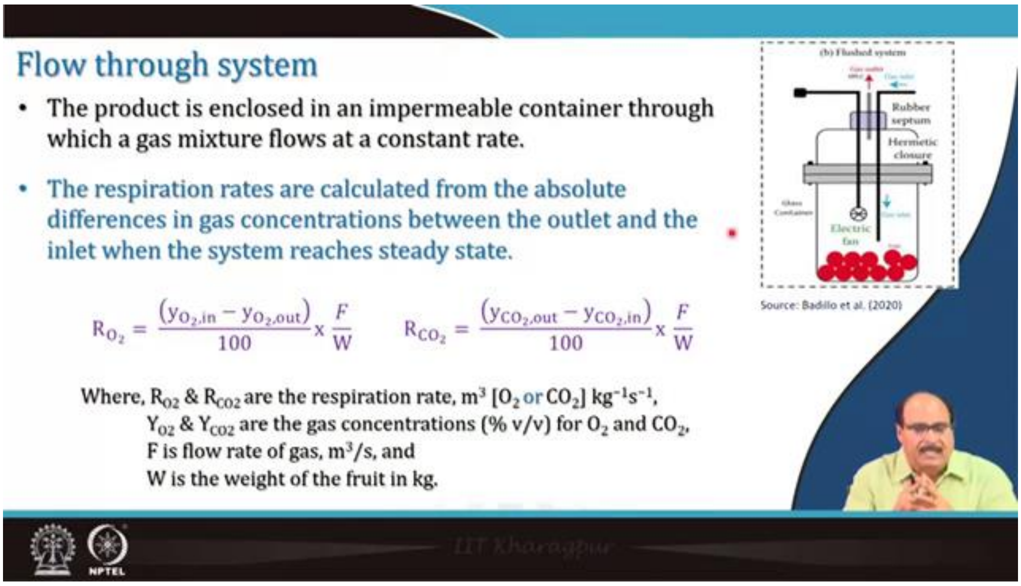
Y_{O2} & Z_{CO2} are the gas concentrations (% v/v) for O_2 and CO_2, respectively,

t is the storage time in s,

Δt is the time difference between two gas measurements (s),

V_f is the free volume of the respiration chamber in m^3, and

W is the weight of the fruit in kg.



Flow through system method

In this method, the product is enclosed in an impermeable container through which gas mixture flows at a constant rate. As shown in the figure, the material is kept in an impermeable container and there is facility for gas inlet and outlet.

The respiration rates are calculated from the absolute differences in the gas concentrations between the outlet and the inlet, when the system reaches steady state.

$$R_{O_2} = \frac{y_{O_{2,in}} - y_{O_{2,out}}}{100} \times \frac{F}{W}$$

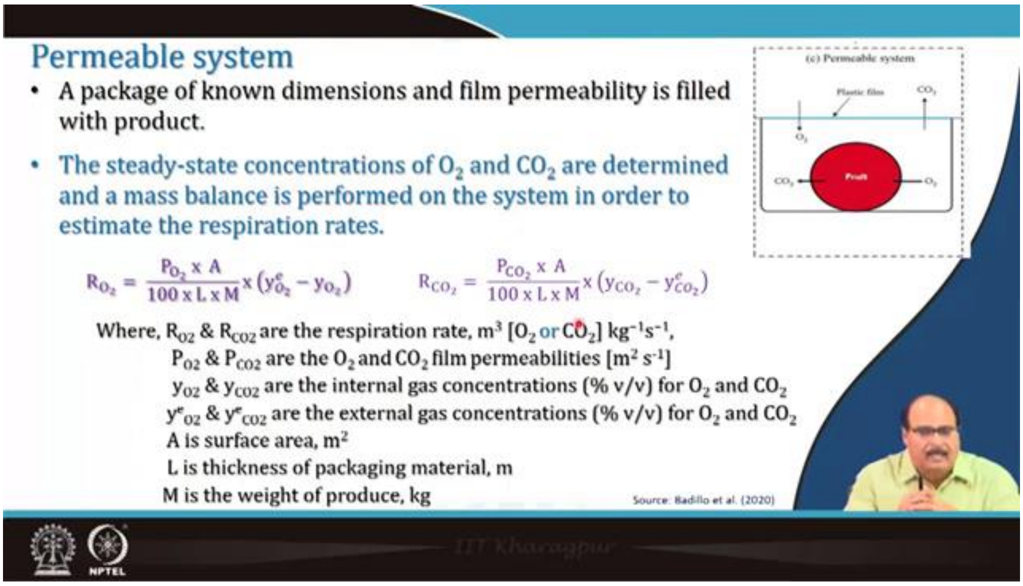
$$R_{CO_2} = \frac{y_{CO_{2,in}} - y_{CO_{2,out}}}{100} \times \frac{F}{W}$$

Where, R_{O2} & R_{CO2} are the respiration rate, m^3 [O_2 or CO_2] $kg^{-1}s^{-1}$, respectively,

Y_{O2} & Y_{CO2} are the gas concentrations (% v/v) for O_2 and CO_2, respectively,

F is flow rate of gas, m^3/s, and

W is the weight of the fruit in kg.



Permeable system method

A package of known dimensions and film permeability (known O_2 permission rate or CO_2 permission rate) is filled with the product. The steady state concentration of O_2 and CO_2 are determined and a mass balance is performed on the system, in order to estimate the respiration rate. R_{O2} or R_{CO2} can be calculated as:

$$R_{O_2} = \frac{P_{O_2} \times A}{100 \times L \times M} \times (y^e_{O_2} - y^e_{O_2})$$

$$R_{CO_2} = \frac{P_{CO_2} \times A}{100 \times L \times M} \times (y^e_{CO_2} - y^e_{CO_2})$$

Where, R_{O2} & R_{CO2} are the respiration rate, m^3 [O_2 or CO_2] $kg^{-1}s^{-1}$, respectively,

P_{O2} & P_{CO2} are the O_2 and Co_2 film permeabilities [m^2 s^{-1}], respectively,

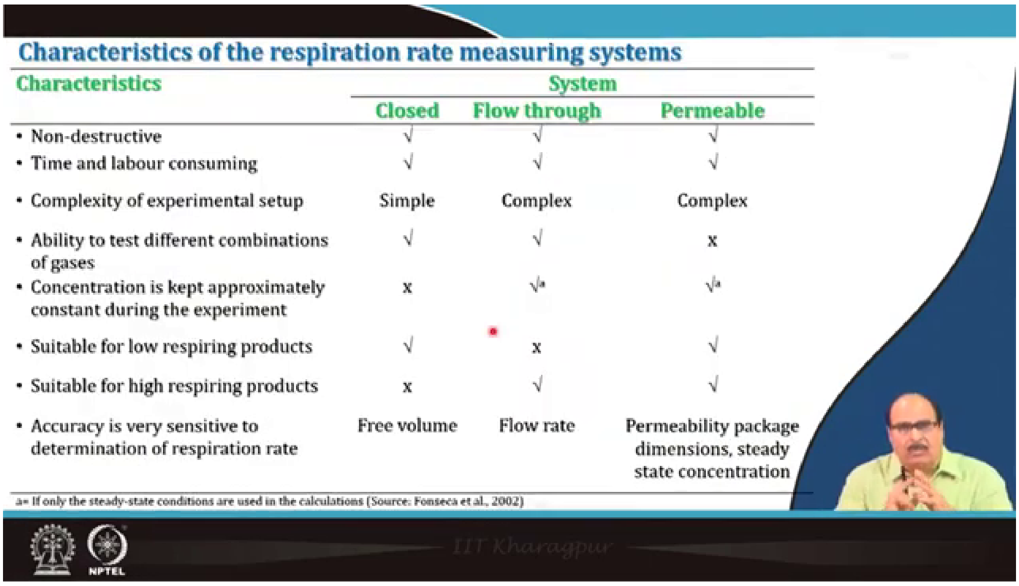
y_{O2} & y_{CO2} are the internal gas concentrations (% v/v) for O_2 and CO_2, respectively,

y^e_{O2} & y^e_{CO2} are the external gas concentrations (% v/v) for O_2 and CO_2, respectively,

A is surface area, m^2

L is thickness of packaging material, m

M is the weight of produce, kg



Characteristics of the respiration rate measuring systems

Characteristics	System		
	Closed	Flow through	Permeable
• Non-destructive	√	√	√
• Time and labour consuming	√	√	√
• Complexity of experimental setup	Simple	Complex	Complex
• Ability to test different combinations of gases	√	√	x
• Concentration is kept approximately constant during the experiment	x	√[a]	√[a]
• Suitable for low respiring products	√	x	√
• Suitable for high respiring products	x	√	√
• Accuracy is very sensitive to determination of respiration rate	Free volume	Flow rate	Permeability package dimensions, steady state concentration

a= If only the steady-state conditions are used in the calculations (Source: Fonseca et al., 2002)

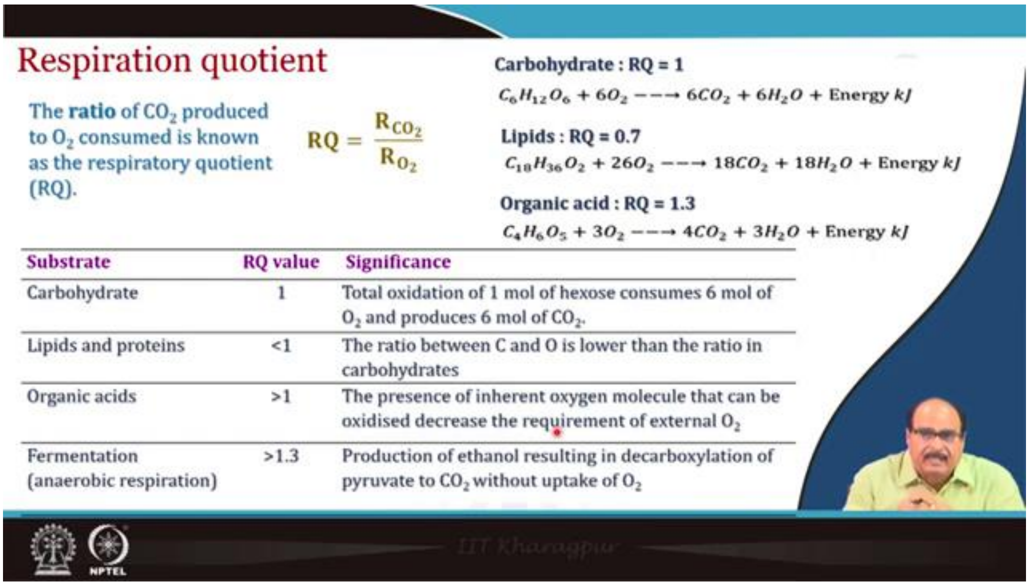
Characteristics of the respiration rate measuring systems

If the three methods are being compared, it can be seen from the table, that all these three methods are non-destructive. All these three methods are time and labour consuming. If the simplicity and complexity are considered, then it can be seen from the table, that the closed system is simple in nature, whereas the flow through and permeable system methods are little complex. If the ability of these methods to test the different combinations of gases are considered, then the closed system and flow through system methods are good, but the permeable system method becomes difficult. The closed system and permeable system methods are suitable for low respiring products. The flow through system and permeable system methods are suitable for high respiring products. The major factors, which will influence the accuracy of the R_{O2} or R_{CO2}, it is the free volume, in the case of closed chamber and flow rate of the gases, in the case of the flow through system. In case of the permeable system method, the permeability of the packaging material, package dimension, steady state concentrations etc are considered.

Respiration quotient (RQ)

The respiration quotient is the ratio of the CO_2 produced to O_2 consumed.

$$RQ = \frac{R_{CO_2}}{R_{O_2}}$$



If the value of RQ is 1, it means that the respiring material is carbohydrate which signifies that total oxidation of 1 mole of hexose consumes 6 mol of O_2 and produces 6 mol of CO_2. If it is the case of organic acid, the RQ value will be more than 1. In the case of lipids and proteins, the RQ will be less than 1 and in case of fermentation reaction i.e., anaerobic respiration RQ will be more than 1.3, which means that its production of ethanol is resulting in decarboxylation of pyruvate to CO_2, without any uptake of O_2. In the case of organic acid, it is more than 1, which signifies the presence of inherent oxygen molecule in the acid, that can get oxidized, it decreases the requirement of the external O_2. The RQ value is a good indicator of the substrate, which is getting oxidized in the respiration process.

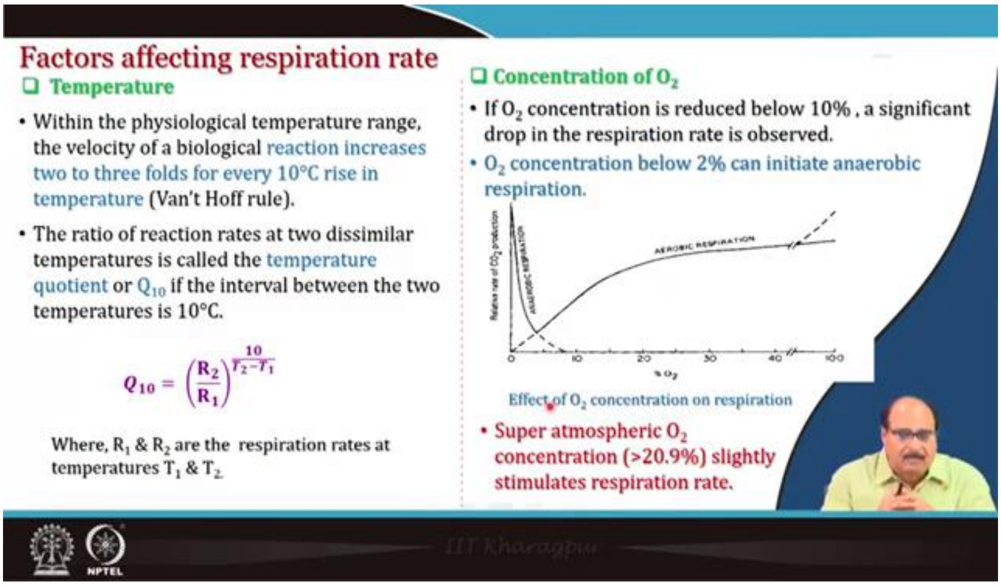
Factors affecting respiration rate

Temperature

There are different factors that affect the rate of respiration. Among these, temperature is one of the most important factors. Within the physiological temperature range, the velocity of a biological reaction increases two to three folds for every 10 °C rise in temperature (Van't Hoff rule). The ratio of reaction rate at two dissimilar temperature is called temperature quotient (Q_{10} i.e. by changing the temperature by 10 °C, how much the respiration rate will increase or decrease.).

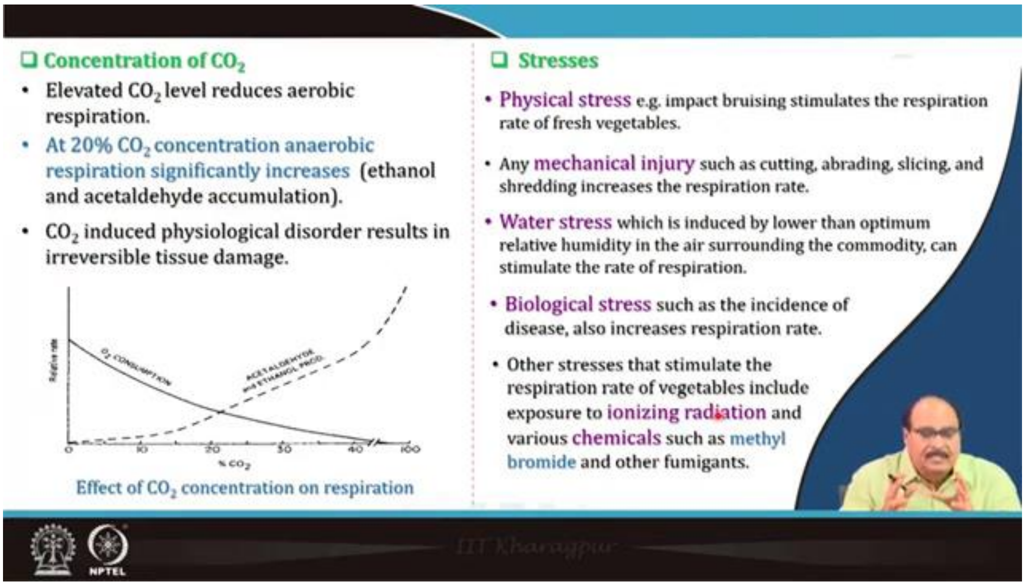
$$Q_{10} = (\frac{R_2}{R_1})^{\frac{10}{T_2-}}T_1$$

Where, R_1 & R_2 are the respiration rates at temperatures T_1 & T_2. This will provide an important input to manage the commodity post-harvest during its handling, transport etc.



Concentration of O_2

Similarly, if the O_2 concentration is reduced below 10%, a significant drop in the respiration rate is observed. If also the O_2 concentration is below 2%, it will initiate anaerobic respiration in many commodities. In the figure, the effect of O_2 concentration on respiration is clearly observed. It is clearly indicated by the figure, that when the super atmospheric O_2 concentration goes more than 20.9%, it slightly stimulates the respiration rates.

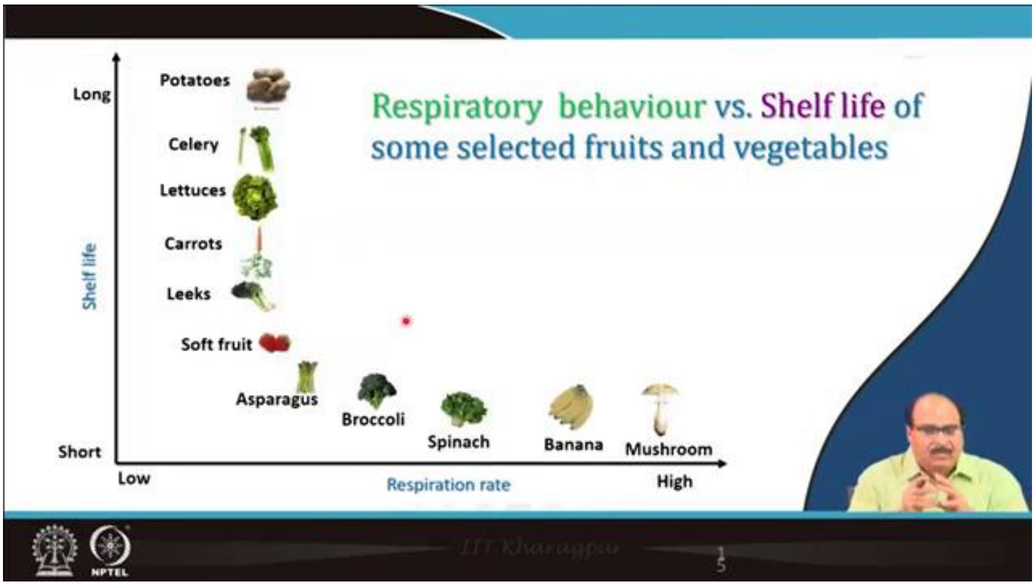


Concentration of CO_2

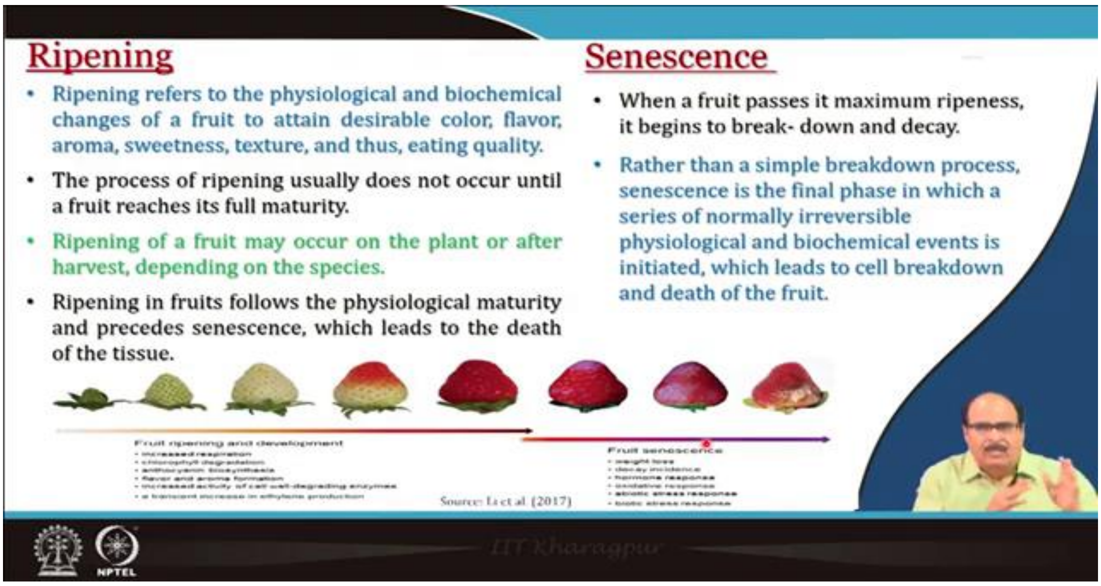
Again, elevated CO_2 level reduces aerobic respiration. At 20% CO_2 concentration, anaerobic respiration significantly increases, there is an ethanol and acetaldehyde accumulation. CO_2 induced the physiological disorders, which results in reversible tissue damage. The figure shows the effect of CO_2 concentration on the rate of respiration. As the CO_2 concentration increases, the rate of respiration decreases.

Stresses

The stress like physical stress, such as impact bruising stimulate the respiration rate of fresh vegetables. Any mechanical injury such as cutting, abrading, slicing and shredding increases the respiration rate. Water Stress, which is induced by lower than optimum relative humidity in the air surrounding the commodity, can stimulate the rate of respiration. Biological stress such as the incidence of disease, also causes an increase in the respiration rate. Other Stresses that stimulate the respiration rate of vegetables, include exposure to ionizing radiation and various chemicals such as methyl bromide and other fumigants etc.



The figure shows that how the rate of respiration is related to the shelf life. Lower the respiration rate, higher the shelf life at room temperature. Highest respiring commodities like mushroom have the lowest shelf life.



Respiration is directly related to ripening as well as senescence, particularly in the case of climacteric fruits.

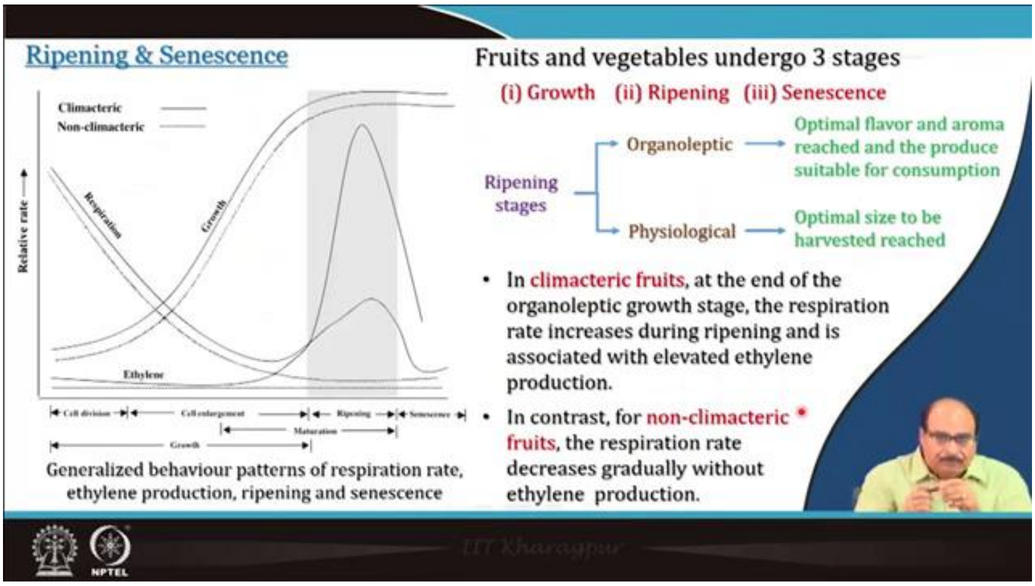
Ripening

Ripening, refers to the physiological and biochemical changes of a fruit to attain desirable colour, flavour, aroma, sweetness, texture, and thus, eating quality. The process of ripening usually does not occur until a fruit reaches its full maturity. Ripening of a fruit may occur on the plant or after harvest, depending on the species. Some species ripe on the plant itself, some species ripe after they are harvested. Ripening in fruits, follows the physiological maturity and proceeds senescence, which leads to the death of the tissue.

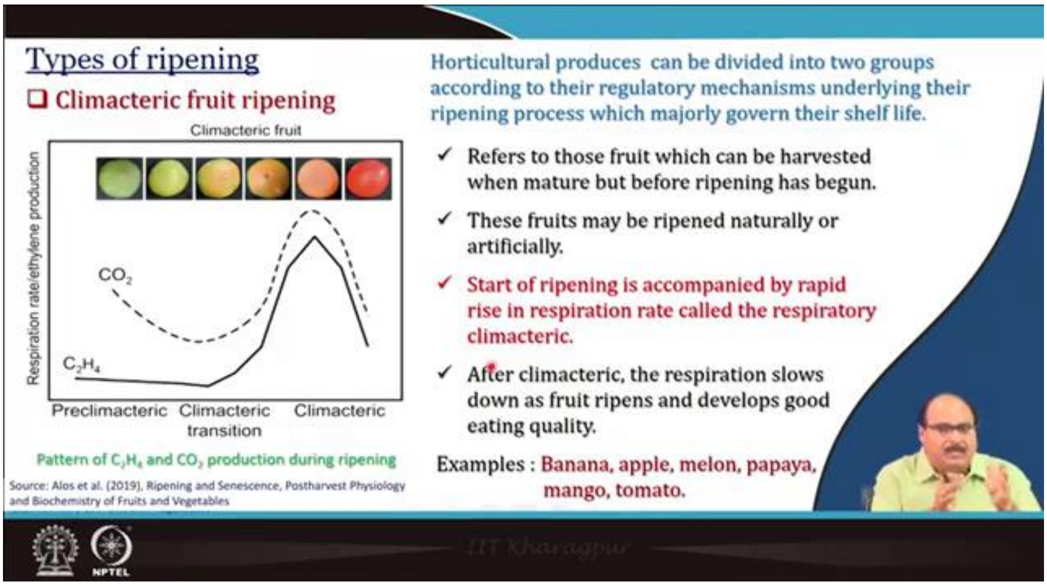
Senescence

When a fruit passes its maximum ripeness, it begins to break-down and decay. Rather than a simple breakdown process, senescence is the final phase, in which a series of normally irreversible physiological and biochemical events are initiated, which will lead to the cell breakdown and death of the fruit.

The figure shows the initial stage of fruit ripening and development stage of strawberry. Finally, it has come to its maximum maturity or ripening maximum quality and then senescence.



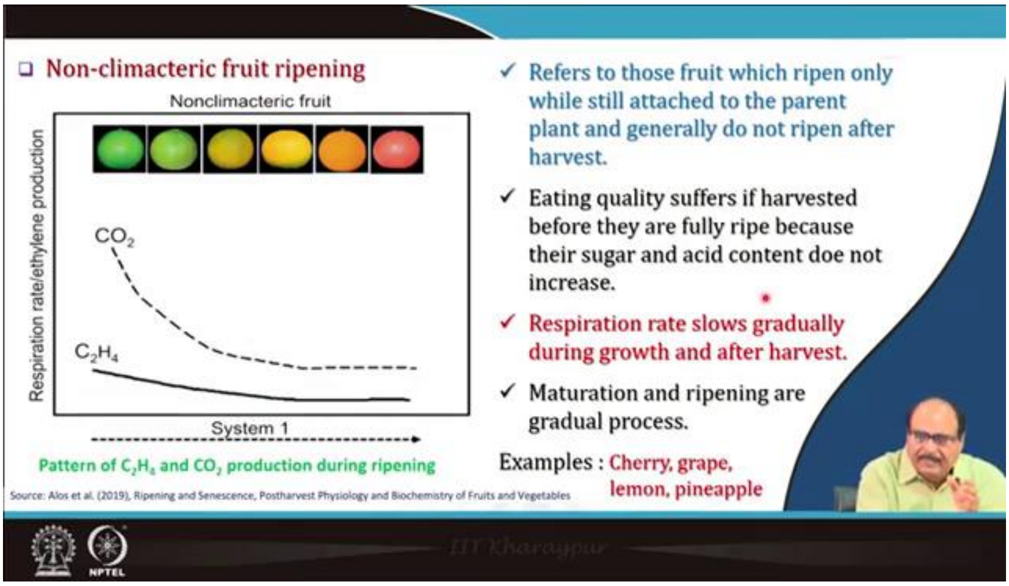
Fruits and vegetables undergo three stages i.e., growth, ripening and senescence. In climacteric fruits, at the end of the organoleptic growth stage, the respiration rate increases during ripening and is associated with elevated ethylene production. In the organoleptic ripening, the optimal flavour and aroma reached and the produce is suitable for consumption. In the physiological ripening, optimal size is to be harvested. In contrast, for non-climacteric fruits, the respiration rate decreases gradually without the ethylene production.



Types of ripening

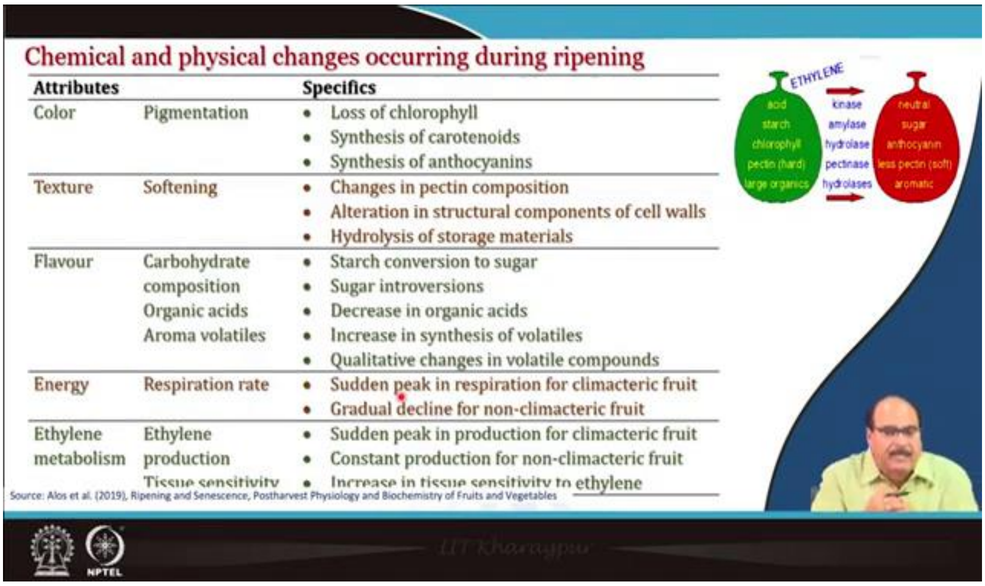
Climacteric fruits refer to those fruits which can be harvested when mature but before ripening has begun. In the climacteric fruit, the patterns of ethylene (C_2H_4) and carbon dioxide (CO_2) production are explained. The rate of respiration in the climacteric fruit is increased after the fruit is harvested due to the initiation of the production of the ripening hormone ethylene. After that, there will be slight decrease in the rate of respiration and it will come to the climacteric minima. After the climacteric minima, both there is an increase in the ethylene production, as well as in the respiration rate.

After the climacteric minima, the senescence stage comes. Horticultural produces can be divided into two groups according to their regulatory mechanisms underlying their ripening process, which majorly govern their shelf life. The climacteric start of ripening is accompanied by a rapid rise in the rate of respiration, which is called respiratory climacteric. After climacteric, the respiration slows down as the fruit ripens and develops good eating quality. The examples of these climacteric fruits include, banana, apple, melon, papaya, mango and tomato.



Non-climacteric fruit ripening

Non-climacteric fruits refer to those fruit, which ripen only while still attached to the parent plant and generally do not ripen after harvest. In the non-climacteric fruit, after harvest, there is a continuous decrease both in the carbon dioxide production and in the rate of respiration as well as ethylene production also continuously decreases. So, eating quality suffers, if the commodity is harvested before they are fully ripe, because their sugar and acid content does not increase, the respiration rate slows gradually during growth and after harvest. Maturation and ripening are the gradual processes in the case of non-climacteric fruit ripening. Examples of this category include cherry, grape, lemon and pineapple.

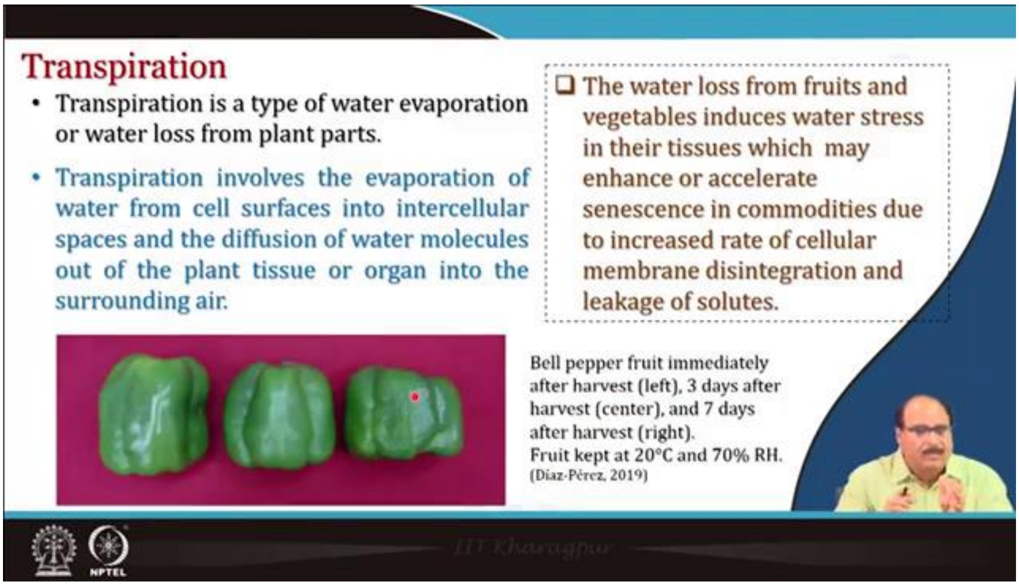


Chemical and physical changes occurring during ripening

The various chemical and physical changes that occur during ripening like colour and there is pigmentation such as a loss of chlorophyll i.e., green colour converts into various yellow colour, red colour, other colours, synthesis of carotenoids, synthesis of anthocyanins etc.

Similarly, texture, it becomes soft, because of changes in pectin compositions and alteration in the structural components of the cell walls. There is also hydrolysis of storage materials etc. Various carbohydrate compositions, organic acids, various aroma volatile compounds are formed, which cause the improvement of the flavour during this ripening.

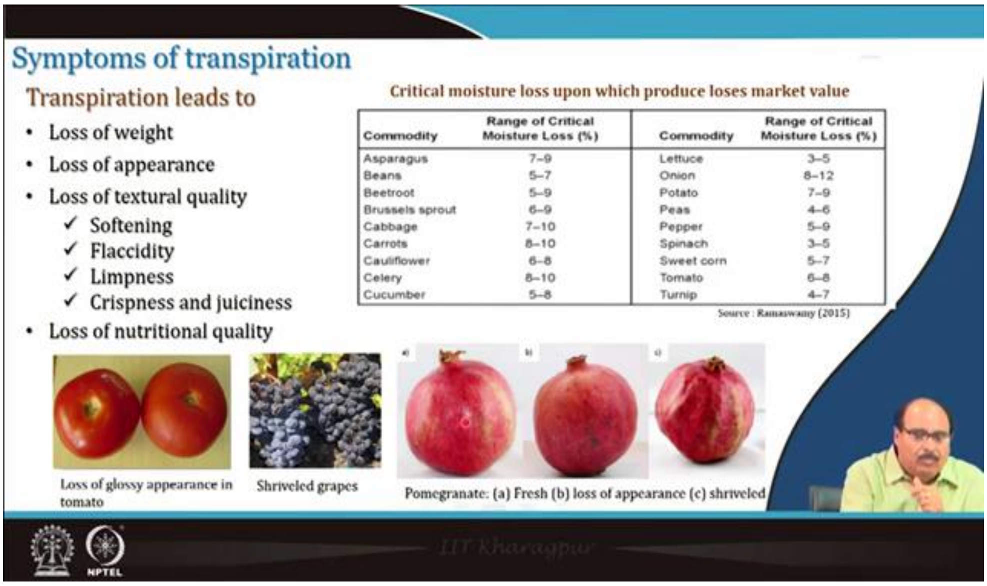
Also, there is a sudden peak in the respiration rate in climacteric fruit and gradual decline in the non-climacteric fruit. Ethylene metabolism i.e., sudden peak in the production of climacteric fruits and constant production for non-climacteric fruit. Also, there is increase in the tissue sensitivity due to ethylene.



Transpiration

Transpiration is another type of water evaporation or water loss from the plant parts. Transpiration involves the evaporation of water from the cell surfaces into intracellular spaces and the diffusion of water molecules out of the plant tissues or organs into the surrounding air.

The water loss from the fruits and vegetables induces water stress in their tissues which may enhance or accelerate senescence in commodities due to increased rate of cellular membrane disintegration and leakage of the solutes. The figure shows the different harvesting stages of Bell pepper fruit (kept at 20 °C and 70% RH) such as immediately after harvest (the left), 3 days after harvest (in the middle) and 7 days after harvest (the right). It can be seen in the figure that when Bell pepper fruit is transpiring, there is loss of the moisture.

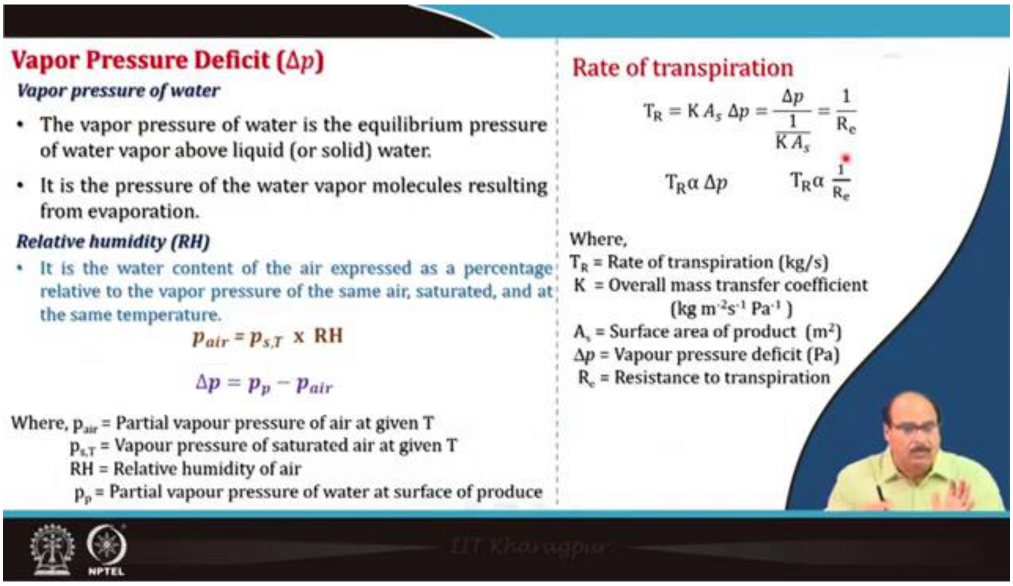


Symptoms of transpiration

Transpiration leads to loss in weight, loss in appearance, loss in textural quality like softening, flaccidity, limpness, crispness and juiciness, etc. Transpiration also leads to loss in nutritional quality. As shown in the figure, tomato loses glossy appearance due to transpiration.

The figure in the right hand side represents the effect of the transpiration in the pomegranate fruit. The picture shows its different forms such as a) fresh pomegranate, b) the loss of appearance c) shrivelled.

The process of transpiration is very important because the moisture is losing. The critical moisture loss upon which the produce loses its market value. For example, in case of cauliflower, if it loses its moisture content due to transpiration up to 6 to 8 % or Celery 8 to 10 %, they will lose their market value. Similarly in case of beans, if it loses its moisture content due to transpiration up to 5 to 7%, in case of asparagus, if it is 7 to 9 %, in case of sweet corn, if it is 5 to 7%, for tomato, if it is 6 to 8%, for lettuce if it is 3 to 5%, and for onion, if it is 8 to 12%, in all these cases the fruits or vegetables will lose their market value.



Vapor Pressure Deficit (Δp)

Vapor pressure of water

The vapor pressure deficit is called as the vapor pressure of water is the equilibrium pressure of water vapor above liquid (or solid) water. It is the pressure of the water vapor molecule resulting from evaporation.

Relative Humidity (RH)

Relative humidity is the water content of the air expressed as a percentage relative to the the vapor pressure of the same air, saturated, and at the air at the same temperature.

$$p_{air} = p_{s.T} \times RH$$

$$\Delta p = p_p - p_{air}$$

Where, p_{air} = Partial vapour pressure of air at given T,
$p_{s,T}$ = Vapour pressure of saturated air at given T
RH = Relative humidity of air
p_p = Partial vapour pressure of water at surface of produce

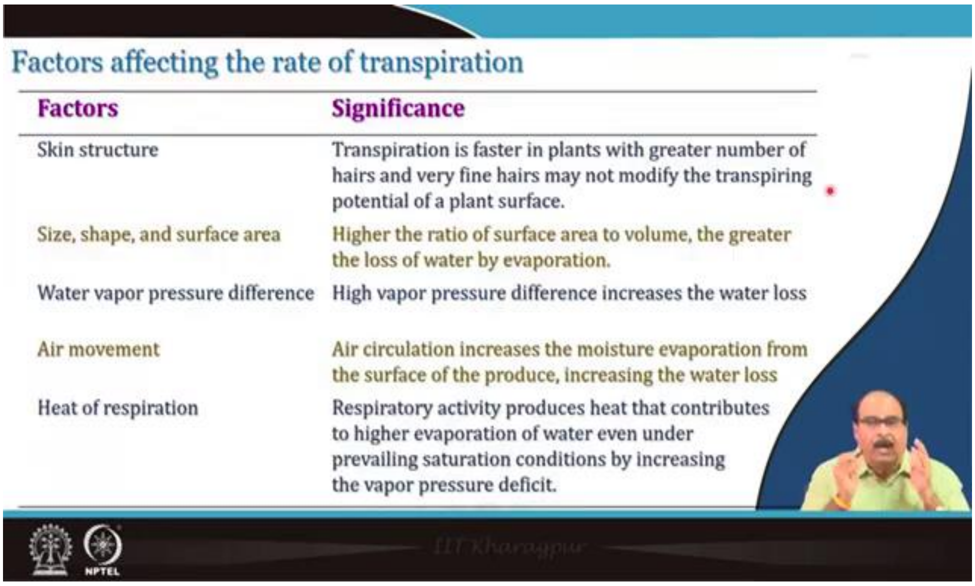
Rate of transpiration

$$T_R = K\, A_s\, \Delta p = \frac{\Delta p}{\frac{1}{K\, A_s}} = \frac{1}{R_e}$$

$$T_R \propto \Delta p \qquad\qquad T_R \propto \frac{1}{R_e}$$

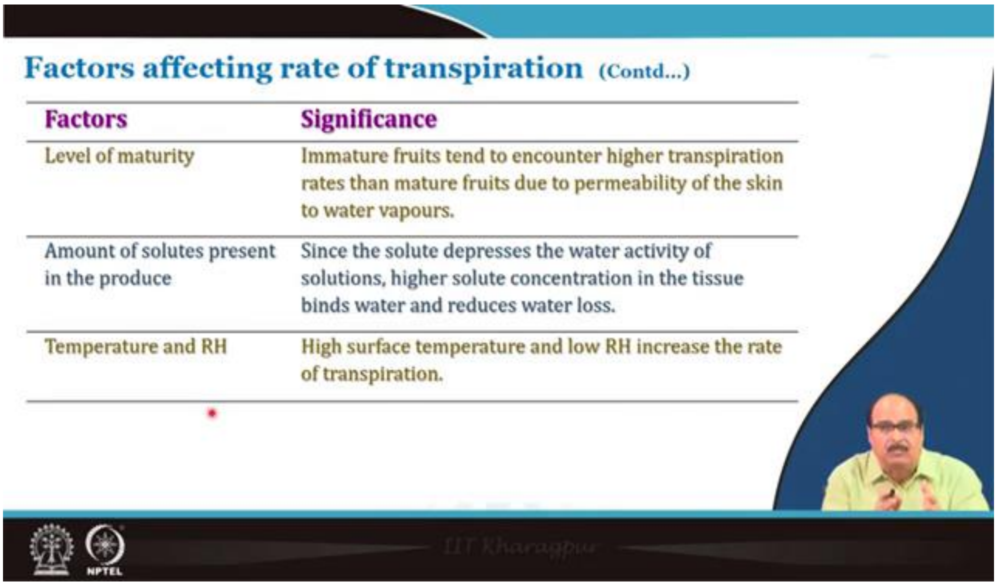
Where, T_R = Rate of transpiration (kg/s),
K = Overall mass transfer coefficient (kg m^{-2}s^{-1} Pa^{-1}),

A_s = Surface area of product (m^2)
Δp = Vapour pressure deficit (Pa)
Re = Resistance to transpiration



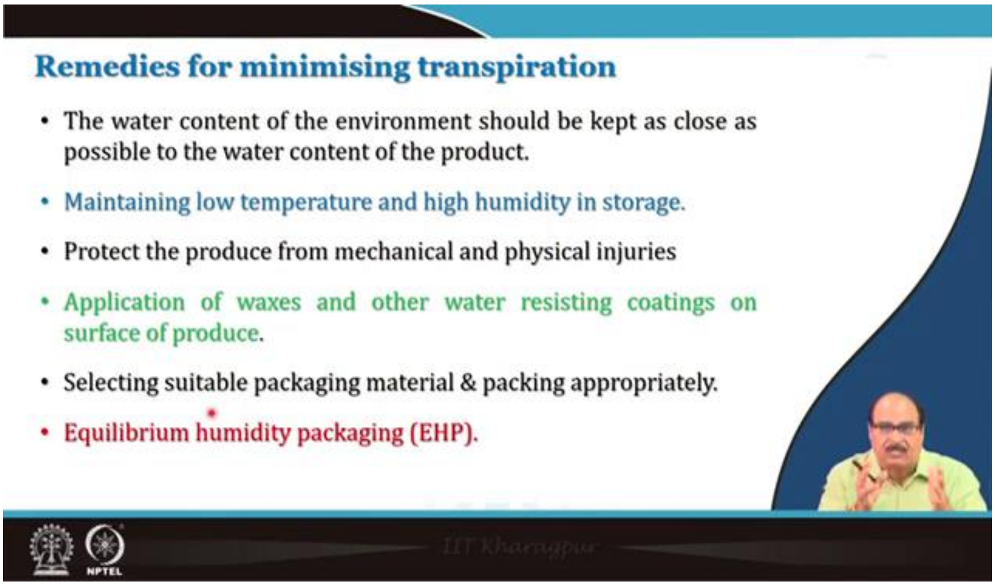
Factors affecting rate of transpiration

The factors like skin structure, size shape and surface area, water vapour pressure difference, air movement, heat of respiration, etc. influence the rate of the transpiration. For example, high vapor pressure difference increases the water loss, higher the ratio of the surface area to volume, the greater the loss of the water by evaporation, air circulation increases the moisture evaporation from the surface of the produce, increasing the water loss.



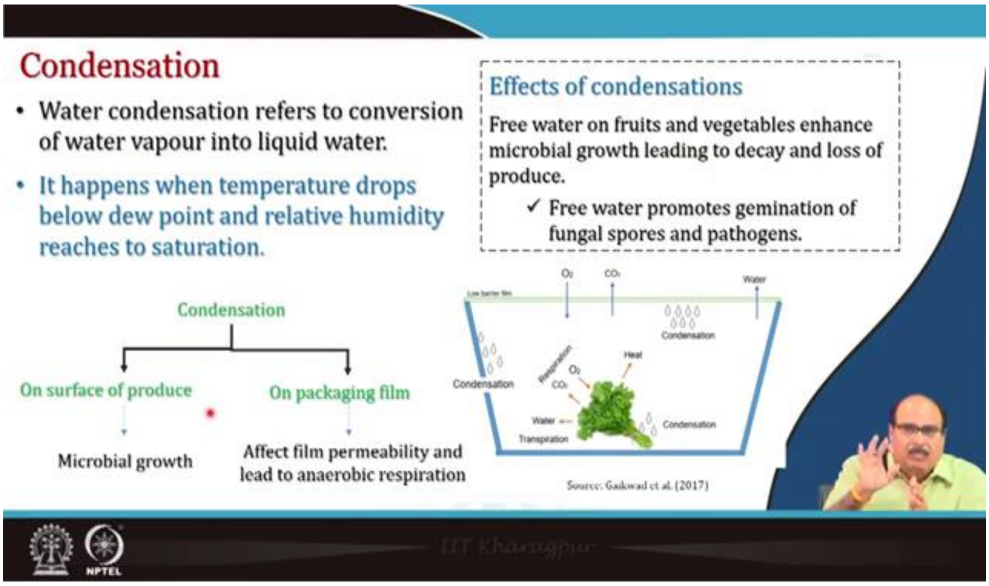
Factors affecting rate of transpiration

The level of maturity of the commodity signifies that immature fruits tend to encounter higher transpiration rate than the mature fruits and this is particularly due to the permeability of the skin to the water vapours. Amount of the solutes present in the produce signifies that since the solute depresses the water activity of the solutions, higher solute concentration in the tissue binds the water and it reduces the water loss. Temperature and relative humidity (RH) signify that high surface temperature and low RH increase the rate of the transpiration.



Remedies for minimizing transpiration

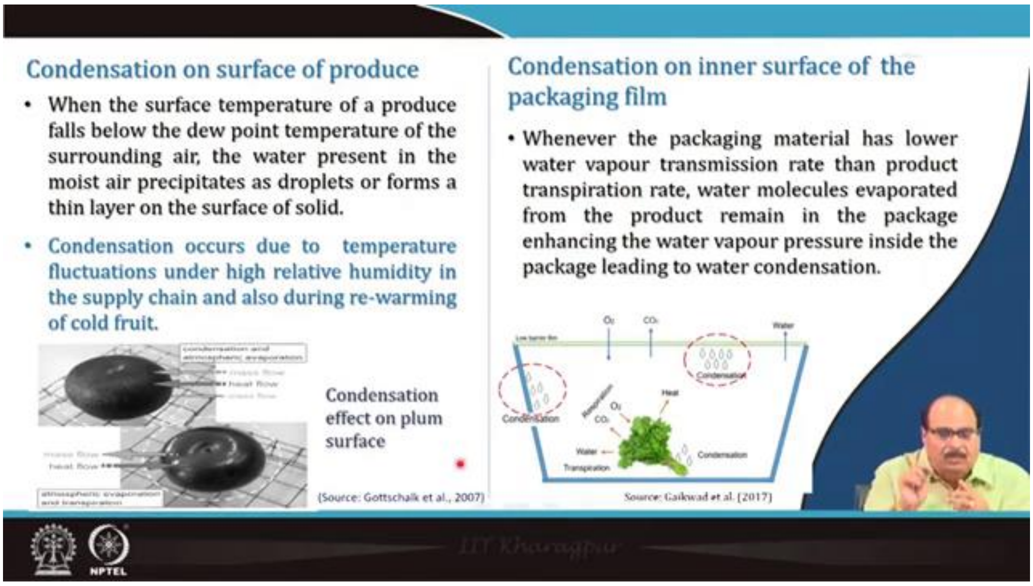
The water content of the environment should be kept as close as possible to the water content of the product to minimize transpiration. Maintaining low temperature and high humidity in the storage can also minimize transpiration. Protecting the product from mechanical and physical injuries, application of waxes and other water-resistant coatings on the surface of the produce, selecting suitable packaging material and packing appropriately, equilibrium humidity packaging (EHP) i.e., maintaining the proper equilibrium inside the packet and outside the environment can minimize transpiration.



Condensation

Another very important characteristic is the condensation of water. When the fruits or vegetables transpire, if the packaging is not proper, then there will be water condensation. Condensation refers to the conversion of water vapor into liquid water. It happens when the temperature drops below the dew point and relative humidity reaches to saturation.

The condensation may be on the surface of the produce, or it may be on the packaging film. The condensation at the surface of the produce leads to the microbial growth. Free water on the fruits and vegetables will enhance the microbial growth leading to decay and loss of produce. Free water promotes the germination of the fungal spores and pathogens. Condensation on the packaging film, affects the film permeability, which leads to anaerobic respiration.

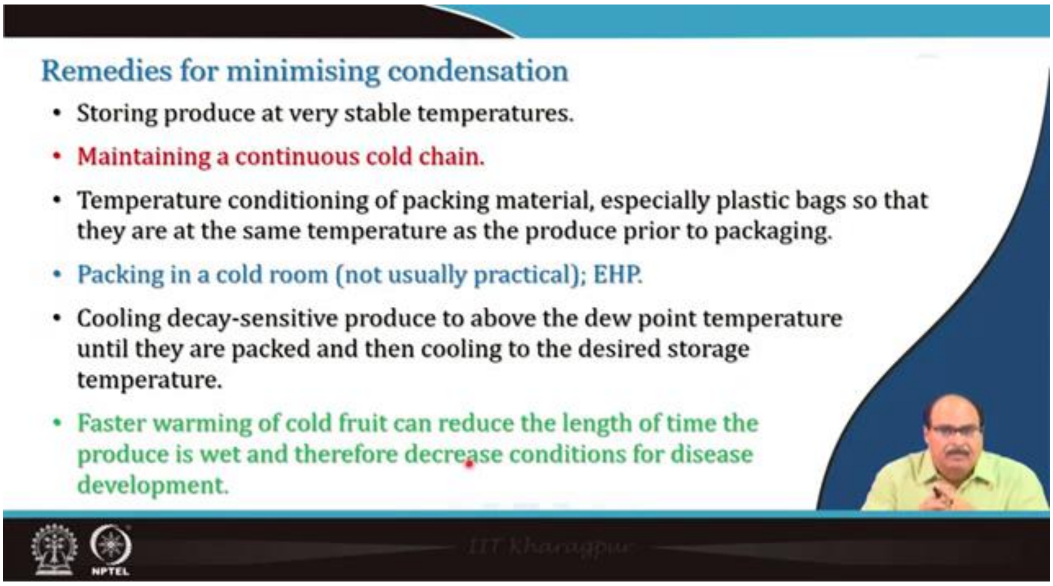


Condensation on surface of produce

When the surface temperature of a produce falls below the dew point temperature of the surrounding air, the water vapor in the moist air precipitates as droplets or forms a thin layer at the surface of the solid. Condensation occurs due to temperature fluctuations under high relative humidity in the supply chain and also during re-warming of the cold fruits.

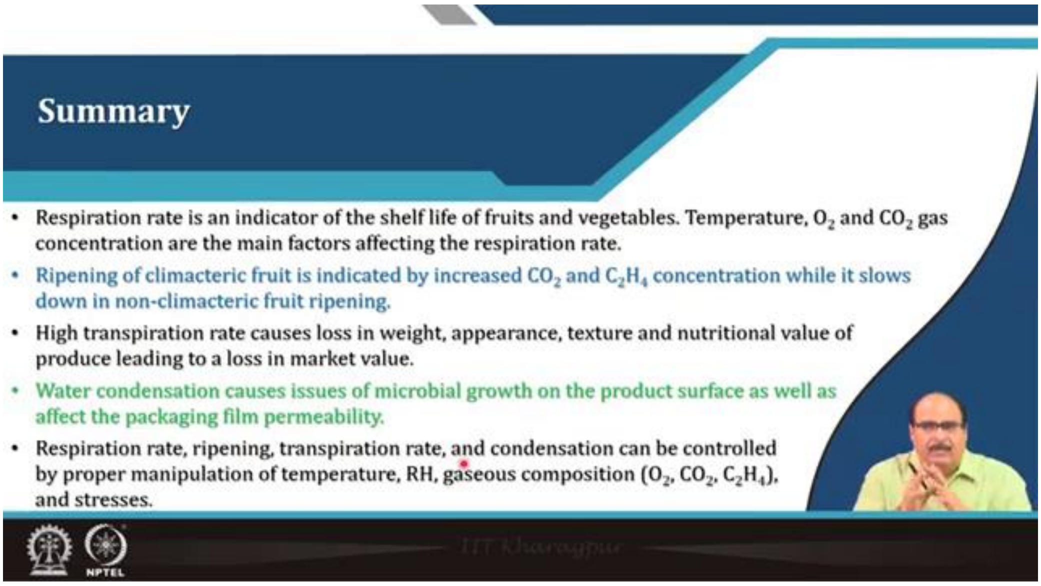
Condensation inner surface of the packaging film

Whenever the packaging material has lower water vapor transmission rate than the product transpiration rate, water molecules evaporated from the product will remain in the package, enhancing the water vapor pressure inside the packet and leading to the water condensation.



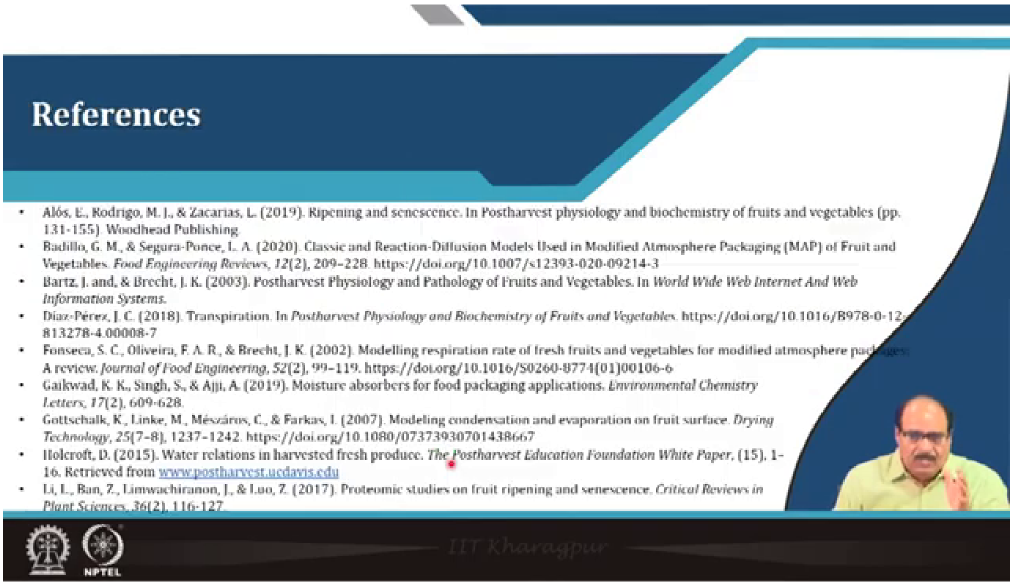
Remedies for minimizing the condensation

Condensation can be minimized by storing the produce at a very stable temperature, maintaining a continuous cold chain, temperature conditioning of packing material, especially plastic bags, so that they are at the same temperature as the produce prior to packaging, packaging in a cold room, which usually always is not practical. In this case, equilibrium humidity packaging will be beneficial. Cooling decay-sensitive produce to above the dewpoint temperature until they are packed and then cooling to the desired storage temperature is another way to minimize the condensation. Faster warming of the cold fruit can reduce the length of time, the produce is wet and therefore decrease the condition for disease development.



Summary

The respiration rate is an indicator of the shelf life of fruits and vegetables. Temperature, O_2, CO_2 gas concentrations are the main factors affecting the rate of respiration. Ripening of climate food is indicated by increased CO_2 and ethylene (C_2H_4) concentration, while it slows down in climate fruit ripening. High transpiration rate causes loss in weight, appearance, texture, nutritional value of the product leading to the loss of the market value. Water condensation causes issues of microbial growth on the product surfaces as well as affect the packaging film permeability. Respiration rate, ripening, transpiration rate and condensation rates can be controlled by proper manipulation of the temperature, relative humidity (RH), gaseous concentration, gaseous composition (O_2, CO_2, C_2H_4) and the stresses on the commodity.



These are the references for further study. Thank you.