REVIEW OF LITERATURE
2. REVIEW OF LITERATURE

2.1 GENERAL INFORMATION:

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important and widely cultivated vegetables in India and according to FAO (2010), the annual production of tomato in India was 4,800 MT. There is increasing evidence that diet can play an important role in human health by providing important substances that increase the body defense system against several diseases. Tomato is a major contributor of carotenoids (especially lycopene), phenolics, vitamin C and small amounts of vitamin E in daily diets. Results from the epidemiological studies showed that tomatoes and tomato products may have a protective effect against various forms of cancer, especially prostate cancer and cardiovascular diseases. Since tomato is highly perishable it encounters several problems in its transportation, storage and marketing. Owing to lack of information on appropriate post harvest treatments, packaging, temperature etc, the fruits not only lose their quality but also encounter a substantial post harvest loss. In tropical countries a loss of 20-50% between harvesting, transportation and consumption of fresh tomato has been reported by Aworth and Olorunda (1981). Even though some research efforts have helped to increase the production of tomato to some extent, the purpose of obtaining maximum profit will be served only if the increased production is supplemented with the similar efforts to minimize the post harvest losses and enhance the shelf life. In the past, some efforts have been made in this direction by employing certain chemicals/plant growth hormones or controlled atmospheric storage to hasten or delay ripening, to reduce losses and to improve and maintain the colour and quality by slowing down the metabolic activities of the fruit. These chemicals are reported to arrest the growth and spread of micro organisms by reducing the shriveling which ultimately leads to an increased shelf life and maintain the marketability of the fruit for a longer period.

2.2 TOMATO COMPOSITION AND POST HARVEST TREATMENT:

Tomatoes were ranked highest in a comparison of crops and their contribution of nutrients to the diet (Wills, 1981). Tomatoes also provide potassium, iron, phosphorus, and some B vitamins, and are a good source of dietary fiber. Ripe tomatoes are red in color because they contain lycopene, an antioxidant. Lycopene is a pigment synthesized by plants and microorganisms. It has twice the ability as that of beta-carotene and 10 times that of alpha-tocopherol to quench singlet
oxygen, which is a metastable state of molecular oxygen (O\textsubscript{2}) responsible for oxidative reactions (Rao and Agarwal, 1999). Water comprises 90% of the fresh weight of tomato fruit; and the size of the fruit is influenced by the availability of water to the plant. The large amount of water also makes the fruit perishable. As the tomato fruit develops, starch decreases while carbohydrates such as sucrose and reducing sugars increase (Jones, 1999). Sugars are mostly found in ripe fruit; and starches are found mostly in unripe fruit (Wills, 1981). In a ripe tomato, solids form about 5-7% of the fruit. About half of the solids comprise sugars and one eighth is acids. The main sugar in tomatoes is glucose. Citric acid is the main acid in tomato juice; and the pH of fruit is normally between 4.0 and 4.5. The pH of the fruit increases throughout development. Vegetables or fruits with natural coatings of wax have lower respiration rates than fruits without such protective barriers. Transpiration is the movement of water through the cellular tissue of a plant, and eventual evaporation of this water from plant surfaces. This movement of water is driven by the gradient existing between the tissue of the plant and the humidity of the surrounding air (Ben-Yehoshua, 1987). Transpiration serves two purposes: first transpiration contributes to the lowering of the surface temperature of the plant's tissues by evaporation. The second function of transpiration relevant to post harvest is the maintenance of turgidity of the plant's tissues and fruits. As much as 90% of the water moving into a plant can be lost through transpiration. Plants have therefore developed specialized tissue structures for preventing moisture loss. When a fruit is removed from the plant, the replenishing water source, the soil, is cut off and turgor is altered. The speed at which damage from loss of turgidity occurs depends on the characteristics of the commodity, including its rate of respiration, size, and state of maturity. Respiration produces water and heat, both of which directly affect transpiration. The metabolic water produced through respiration remains within the fruits' tissue; however, the carbon dioxide lost to the air through open stomata can result in weight loss of harvested fruits. Heat generated during increased respiration after harvest may also contribute to weight loss of a fruit. The heat lost to the environment contributes to increased evaporation of water. Water losses from transpiration may also be affected by the stage of fruit maturity. In general, climacteric fruits have increased transpiration at very early (pre-climacteric) stages. Increased transpiration also occurs at the beginning of the climacteric phase. Fruits and vegetables have colored pigments. The green colored chlorophyll pigments are contained within the chloroplast. This pigment may also be lost through photo degradation, which occurs when chlorophyll molecules are bleached by light and
oxygen. This process occurs during ripening and senescence. Carotenoids are pigments with colors ranging from yellow to orange red. The important pigments in tomatoes are the lycopene and the beta carotene (Jones, 1999). Texture is imparted by components of plant tissue and its cell walls. The cellular walls are made up of cellulose fibers which are held together by cement like substance called pectin. These cells take up water, which generates a hydrostatic pressure, giving rise to the crisp texture of vegetable and fruit products. After harvest several factors affect the texture of fruit and vegetable products. First, turgor pressure, and hence crisp texture is altered. Turgor pressure change results from decreased transpiration and respiration. Because additional water can not move into the plant cells, and water still is being continually lost from the plant's surface, wilting occurs. Softening of fruits and vegetables is brought about by enzymatic dehydration of the pectin holding adjacent cells together. As the fruit begins to senesce and proceed to an overripe stage, the pectin is being changed into pectic acid by the enzyme pectinase. Pectic acid imparts the characteristic mushy texture to overripe fruit (Whitaker, 1996). Tomato is a short duration crop and it gives high yield; it is important from economic point of view and hence area under its cultivation is increasing day by day. It is not uncommon to hear that farmers in developing countries like India dump cartloads of tomato on the streets. Excess production results in a crash in tomato prices, with prices slumping to 50 paise a kilo (one Canadian cent is equivalent to 42 paise), farmers are left with no choice. Ever since the Agreement on Agriculture of the World Trade Organization began to be debated in the country, increasing agricultural productivity and improving food quality are being considered as the only solution for farmers. There is good scope for increased utilization of tomatoes but this can be obtained only by adopting suitable storage techniques to avoid losses. Simple low cost technologies can be more appropriate for small volume, limited resource commercial operations, for farmers involved in direct marketing, for home gardeners, as well as for handlers in developing countries. Local conditions for small-scale handlers may include labor surpluses, lack of credit for investments in post harvest technology, unreliable electric power supply, lack of transport, storage facilities and/or packaging materials, as well as a host of other constraints. Bruising, moisture loss, chilling injury, compositional changes, over ripening, softening and decay are caused by harvesting at improper maturity, rough handling, inadequate cooling and temperature maintenance and lack of sorting. Utilizing improved post harvest practices often results in reduced food losses, improved overall quality and food safety, and higher profits for growers and marketers (Talukder et al., 2003; Kitinoja
Depending on the market and production area, tomatoes are harvested at stages of maturity ranging from mature-green stage through full-ripe. There are six stages of tomato fruit development during ripening (for red fruited cultivars): mature green, breaker, turning, pink, light-red, and red. Fruit change from green to red, due to the conversion of chloroplasts, which contain chlorophyll to chromoplasts, which have red or yellow carotenoids. Greenhouse-grown tomatoes are generally harvested at various stages of maturity after mature green stage. Losses can occur by improper packing through dropping, compression, vibration and puncture. The fruits are sorted, graded and packed in lidded cartons or plastic crates that can be stacked in a cold room for precooling. Tomatoes are routinely palletized and cooled to 20°C (68°F) for ripening or to 12°C (53.6°F) for storage. Optimal storage temperatures depend on the maturity stage of the tomatoes. Optimal conditions for ripening are 19 to 21°C (66 to 70°F) with 90 to 95% RH. According to Kader (1993) tomatoes are classed as highly perishable crops. Mature-green tomatoes can be stored at 18-22°C at 90-95% RH for 1-3 weeks and firm-ripe ones at 13-15°C at 90-95% RH for 4-7 days. Chilling injury can occur at 7-10°C in ripe fruits and at 13°C in mature green tomatoes, developing poor color and *Alternaria* rot.

### 2.3 SALIENT CHARACTERISTICS OF TOMATO:

With a view to characterize the fruit used in this study, its various salient properties such as firmness, titratable acidity, total soluble solids, ascorbic acid etc. were determined at the time of harvest. The parameter pertaining to the physio-chemical characteristics of tomato given in Table 2.1:
Table 2.1: SALIENT CHARACTERISTICS OF TOMATO:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture(%)</td>
<td>94.45</td>
</tr>
<tr>
<td>Protein(%)</td>
<td>14.75</td>
</tr>
<tr>
<td>Fat(%)</td>
<td>1.61</td>
</tr>
<tr>
<td>Ash(%)</td>
<td>7.34</td>
</tr>
<tr>
<td>Fibre(%)</td>
<td>7.58</td>
</tr>
<tr>
<td>Carbohydrates(%)</td>
<td>69.48</td>
</tr>
<tr>
<td>Fruit firmness (kg/cm)</td>
<td>0.62</td>
</tr>
<tr>
<td>Juice content (ml/100 g)</td>
<td>30.86</td>
</tr>
<tr>
<td>Pulp content (gm/100g)</td>
<td>68.47</td>
</tr>
<tr>
<td>Titratable acidity (%)</td>
<td>0.526</td>
</tr>
<tr>
<td>Total soluble solids (ºBrix)</td>
<td>5.26</td>
</tr>
<tr>
<td>Total sugar(%)</td>
<td>25.31</td>
</tr>
<tr>
<td>Reducing sugar(%)</td>
<td>20.58</td>
</tr>
<tr>
<td>Non-reducing sugars(%)</td>
<td>2.60</td>
</tr>
<tr>
<td>Ascorbic acid (mg/100g)</td>
<td>25.24</td>
</tr>
</tbody>
</table>

(FAO, 2010)

2.4 MODIFIED ATMOSPHERE PACKAGING:

Historically, atmospheres surrounding produce have been altered in controlled atmosphere storage facilities where the levels of gases are continually monitored and adjusted to maintain the optimal concentrations. This high degree of atmospheric regulation associated with CA is capital intensive and expensive to operate. Hence it is more appropriate for commodities that are amenable to long-term storage such as apple, cabbage, kiwifruit, and pear (Kader et al., 1989). Modified atmosphere packaging (MAP) of fresh fruits and vegetables refers to the still evolving technique of matching the respiration of the product with the O₂ and CO₂ permeability (or breathability) of packages in order to modify the O₂ and CO₂ concentrations of the atmosphere to desired levels within the package (Beaudry and Lalakul, 1995). Modified atmosphere storage implies a lower degree of control of gas concentrations. Typically, initial atmospheric conditions are established for a temporary period of time, and the interaction of the commodities physiology and the physical environment maintain those conditions within broad limits (Zagory and Kader, 1988). Advances in the design and manufacture of polymeric films with a wide range of gas permeability characteristics have motivated interest in creating modified atmospheres via flexible film packages which result in decreased O₂ and/or
increased CO₂ concentrations inside the package. A modified atmosphere is created naturally in a sealed package, as a direct result of counterbalancing of the O₂ uptake and CO₂ production by the produce with diffusion gases across the membrane (Kader et al., 1989). Eventually, at a given temperature, the two gases approach steady-state when the rate of gas permeation through the package film equals the rate of respiration. The magnitude of the CO₂ increase and O₂ decreases inside the package is largely dependent on gas permeabilities of the film. In order to obtain maximum benefit, such steady-state gas concentrations should correspond to storage optima of the packaged commodity (Exama et al., 1993). Such modified atmosphere packaging could be applied to shipping containers, retail packages containing several intact or sliced commodity units, or retail packages for individual units of the commodity (Kader et al., 1989), and represents considerable costs savings compared to controlled atmosphere facilities. One important goal of MAP is to generate an atmosphere sufficiently low in O₂ or high in CO₂ to influence the metabolism of the product being packaged or the activity of decay-causing organisms resident on that product such that storability and/or shelf life is extended (Beaudry and Lakakul, 1995). MAP can produce all the positive and negative effects of any modified atmosphere. The positive effects of film packaging, independent of the creation of modified O₂ and CO₂ atmosphere can include: (1) maintenance of high relative humidity and reduction of water loss; (2) possible carriers of fungicides or ethylene absorbers (Kader et al., 1989); (3) protection from surface abrasions by avoiding contact between the commodity and the material of the shipping container; (4) possible protection from the deleterious effects of light for commodities such as potatoes and Belgian endive; (5) provision of a barrier to the spread of decay from one unit to another; (6) improved sanitation by reducing contamination of the commodity during handling; and (7) facilitation for brand identification (Zagory and Kader, 1988). Some negative effects include excessive humidity which favors mold growth, and the possibility of off-flavors if CO₂ or O₂ are changed excessively. If atmosphere modification for packaged fruits or vegetables is a goal, knowledge of the effect of packaging on the atmosphere obtained in the package and the effect of the obtained atmosphere on the quality and physiology of the enclosed product is essential. The effects of reduced O₂ and elevated CO₂ on respiration and fruit ripening are additive and can be greater than the effects of either alone (Kader et al., 1989). However, exposure of fresh produce to levels above their
CO₂ tolerance limit may cause physiological damage and off-flavors, and exposure to levels below their O₂ tolerance limit may increase anaerobic respiration and the development of off flavors due to accumulation of ethanol, acetaldehyde and other metabolites (Richardson and Kositttrakun, 1995; Beaudry and Lakakul, 1995; Zagory and Kader, 1988). Benefits of appropriate MAP include reduced rates of nutritional and quality losses. Generally, lower oxygen concentrations during storage result in lower ascorbic acid losses in vegetables (Weichmann, 1986). Ascorbic acid, chlorophyll and moisture retention were greater in broccoli spears packaged in a semipermeable film compared to non-packaged, when they were stored 4 days at 20°C. Packaging and storage temperature of 10°C generally maintained the various qualities attributes of vegetables (green beans, spinach and bell peppers) better than unpackaged conditions and/or a higher storage temperature of 20°C. The degree of benefit differed with vegetables and quality attributes (Watada, 1987). MAP used during simulated prolonged transit (3 days at 15°C + 2 days at 20°C or 14 days at 0.5°C + 2 days at 20°C) allowed the broccoli heads to be kept in high quality, whereas the PVC-film wrapped heads were unsaleable (Aharoni et al., 1985).

2.5 METHODS OF CREATING MODIFIED ATMOSPHERES:

Atmosphere modification necessitates a film or package through which gas exchange is restricted. Modified atmosphere can be established either passively by the commodity or by initially charging the atmosphere with O₂ and/or CO₂ concentrations expected to be near equilibrium. Commodity-generated or Passive Modification Modified atmospheres are generated through the natural process of respiration of the enclosed product, which reduces O₂ and increases CO₂ under restricted gas exchange through the film barrier. Because the process of respiration is relatively slow, atmospheric modification by these methods can be relatively slow as well, taking several days at low temperatures and much of the benefit of the MA may be lost (Beaudry and Lakakul, 1995; Kader, 1992). Passive modification depends on both the characteristics of the commodity and the packaging film. If the commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O₂ and the production of CO₂ through respiration (Smith et al., 1987). In order to achieve and maintain a satisfactory atmosphere within the package, the gas permeabilities of the selected film must be such that they allow O₂ to enter the package at a rate balanced by the consumption of O₂ by the commodity.
Similarly, CO₂ must be vented from the package to balance the production of CO₂ by the commodity. Furthermore, this atmosphere must be established rapidly and without danger of creation of anoxic conditions or injuriously high levels of CO₂ (Zagory and Kader, 1988). The conditions created and maintained within a package are the net result of the interaction among several factors, both commodity generated and environmental (Zagory and Kader, 1988).

2.6 RESPIRATION AND DIFFUSION CHARACTERISTICS OF THE COMMODITY:

Gas exchange between a plant and its environment includes the following steps: (1) diffusion in the gas phase through the dermal system, (2) diffusion in the gas phase through the intercellular system, (3) exchange of gases between the intercellular atmosphere and the cellular solution (cell sap) or vice versa, which is a function of the distribution and effectiveness of the intercellular spaces and respiratory activity, and (4) diffusion in solution within the cell from centers of CO₂ production to centers of O₂ consumption (Kader, 1987). As a result of respiratory metabolism, CO₂ and C₂H₄ are produced in the mitochondria and cytoplasm, and this local increase in concentration diffuses outside toward the cell-wall surface adjacent to the intercellular space. These gases then move into the intercellular space below the dermal system. From there, CO₂ and C₂H₄ diffuse through the openings in the surface of the commodity to the ambient atmosphere (Burton, 1982). Oxygen diffusion follows a reverse pattern of that for CO₂ and C₂H₄. Oxygen diffuses inside from the ambient air into the centers of consumption inside the cells. In senescent tissues the intercellular spaces may become filled with cellular solution, which impedes O₂ movement and results in anaerobic conditions within the tissue (Kader et al., 1989). Gas diffusion rate within a fruit or vegetable depends on the properties of the gas molecule, the magnitude of the gradient, and the physical properties of the intervening barriers (thickness, surface area, density, and molecular structure). CO₂ moves more readily than O₂. Diffusion of C₂H₄ and CO₂ are similar. Three different routes are available for the exchange of gases between horticultural commodities and their surrounding atmosphere: lenticels and stomata, the cuticle, and the pedicel opening or floral end. In leaves, gas diffusion is regulated by control of stomatal aperture, but most bulky organs have no functional stomata or other active controls of gas exchange (Banks, 1984). Fick's First Law of Diffusion states that the movement or flux of gas in or out of a plant tissue depends on the concentration drop across the barrier involved, the surface area of the barrier, and
the resistance of the barrier to diffusion (Salisbury and Ross, 1992). In turn, the respiration rate of a commodity inside a polymeric film package will depend on the kind of commodity, maturity stage, physical condition, concentrations of O₂, CO₂ and C₂H₄ within the package, commodity quantity in the package, temperature, and possibly light (Kader et al., 1989).

2.7 EQUILIBRIUM GAS CONCENTRATIONS:

There are somewhat different strategies of regulating gas exchange to achieve desired gas concentrations. In one strategy, all the O₂ and CO₂ that move through the package do so through the film itself. After a short period of adjustment, steady-state conditions will be established inside an intact polymeric film package once the appropriate relationship among produce and package variables is achieved. Oxygen inside the package is consumed by the produce as it respires and an approximately equal amount of CO₂ is produced. The second strategy involves the use of perforations (either small holes or patches containing microperforations) for the major route of gas movement (Beaudry and Lakakul, 1995). For both routes of gas exchange, the reduction in O₂ concentration and increase in CO₂ concentration create gradients that, according to Pick's Law, cause O₂ to enter and CO₂ to exit the package. Initially, however, the gradient is small and the flux across the package is not sufficient to replace the O₂ that was consumed or to diffuse out all the CO₂ that was generated. Thus, inside the package, the O₂ content decreases, the CO₂ content increases and new equilibrium concentrations of the gases surrounding the product are established. Steady state (constant) O₂ levels can be achieved in the package when the O₂ uptake by the product is equal to that permeating into the package (Jurin and Karel, 1963). Similarly, steady-state CO₂ levels in the package are achieved when CO₂ production by the product equals CO₂ escape from the package (Geeson et al., 1985; Smith et al., 1987; Beaudry and Lakakul, 1995). Kader et al. (1989) described that oxygen inside the package is consumed by the produce as it respires and an approximately equal amount of CO₂ is produced. The reduction in O₂ concentration and increase in CO₂ concentration creates a gradient causing O₂ to enter and CO₂ to exit the package. Initially, however, the gradient is small and the flux across the package is not sufficient to replace the O₂ that was consumed or to drive out all of the CO₂ that was generated. Therefore, inside the package, the O₂ content decreases and the CO₂ increases. As this modified atmosphere is created inside the package, respiration rate falls in response to the new atmosphere, resulting in less O₂ utilization and less CO₂.
production. Therefore, new equilibrium concentrations of the gases surrounding the fruit are eventually attained (Geeson et al., 1985; Smith et al., 1987). When O₂ consumption equals O₂ diffusion into the package and CO₂ production equals CO₂ diffusion out of the package, steady state equilibrium is achieved (Kader et al., 1989; Beaudry and Lakakul, 1995). They reported that accumulation of CO₂ and C₂H₄ and the depletion of O₂ occurred faster at 10°C than at 5°C, and the equilibrium gas concentrations were different at 10°C than at 5°C. Since modified atmosphere conditions generated within a package may fluctuate slightly, the practical optimal atmosphere should be one that is not too close to an injurious MA (Day, 1993). He suggested that an optimal MAP should minimize respiration rate without danger of physiological damage to the commodity. In addition, different commodities vary widely in their tolerance to different atmospheres. Moreover, the effect of low O₂ and high CO₂ levels on respiration are additive, therefore, optimal concentrations of both gases in combination are difficult to predict without actual measurements in a variety of atmospheres (Zagory and Kader, 1988; Zagory, 1990). However, as a generalization, MAP containing 2 - 5 % O₂ and 3 - 8 % CO₂ has been shown to extend the shelf life of a wide variety of fruits and vegetables (Day, 1988). Day (1993) concluded that determination of the optimal MAP of a particular produce item is complicated because of the numerous variables involved. Thus, if the effect of simultaneous variations in CO₂ and O₂ levels on the quality of a vegetable held at 5°C were to be assessed, then a critical quality parameter would have to be assessed by a trained sensory panel.

2.8 PHYSIOLOGICAL CHANGES:

When a fresh fruits and vegetables are harvested, the processes of life continue in a different way. The plants can no longer add food materials or water, so it has to depend on its stored reserves. When they are exhausted, the fruits or vegetables undergo an ageing process leading to breakdown and deterioration. It will finally become unacceptable as food because of this natural rot. The normal physiological processes leading to deterioration are respiration and transpiration (FAO, 1989). In respiration process the stored starch or sugar is used as long as they last. Carbohydrates are broken down through oxidation which resultantly produces carbon dioxide and water. This process results in the production of heat. When the atmosphere inside is controlled air supply is restricted and the presence of oxygen in the environment falls to about 2 percent or less, fermentation instead of respiration occurs. Fermentation is the process in which sugar is broken down to alcohol and carbon dioxide, and the alcohol causes unpleasant flavors in product
and promotes premature ageing. Poor ventilation of produce leads also to the accumulation of carbon dioxide around the produce. When the concentration of CO₂ gas rises between one and five percent in the surroundings it will soon spoil the produce by causing off flavors, tissues breakdown, failure of fruits and vegetables to ripen and other abnormal physiological conditions will happen. Therefore, adequate ventilation of produce is required. Ripening occurs when the fruits and vegetables are said to be mature. It is followed by ageing (often called senescence) and breakdown of the fruits and vegetables. There are fruits and vegetables which show a rapid rise and fall in respiration rate during ripening and are said to be climacteric, for example tomato and mango. The non-climacteric fruits like pineapple, lime and grape do not show such sharp rise and fall in respiration rate. Ethylene gas is produced in most plant tissues and is an important factor in initiating the ripening process (Irtwange, 2006).

Fresh fruits and vegetables contain 70 to 95% water at the time of harvest. When harvested starts loosing water and cannot be replaced. This resulted in shrinkage weight loss. The high humidity level prevents water loss that may occur due to increased respiration and lowered transpiration. At the time when the fresh product loose 5 to 10 % of its fresh weight, it begins to wilt and becomes unusable. The rate at which water is lost from plant depends on the difference between the water vapor pressure of the plant and the pressure of water vapor in the air. In order to keep water loss from fresh fruits and vegetables as low as possible, it should be kept in moist conditions. Air flow helps to remove heat of respiration but must be controlled to prevent moisture loss (Elazar, 2004). Perishable products should be maintained at RH levels of 90 – 95%. For determination of storage and marketability duration of fruit and vegetables weight loss, decay and rapid deterioration plays a very important role. These factors depend among others on fruit quality and physiological stage and the atmosphere surrounding the fruit. Tomato fruit kept within sealed packages resulted in an atmosphere with high carbon dioxide and low oxygen content. These conditions retained flesh firmness, low acidity and soluble solids concentration and delayed fruit lycopene development. When the tomato fruits are wrapped in 20 micron (PE20) and 50 micron (PE50) polyethylene, 10 micron polyvinylchloride (PVC) or 25 micron polypropylene (PP) compared with unwrapped fruit as a control and evaluated for color, firmness, Weight, Titratable acidity, total soluble solids, decay and sensory attributes. All unwrapped tomatoes were overripe and soft after 30 days. Tomatoes sealed within PE50 and PP film had lowest weight loss and highest soluble solids after 60 days of storage. Tomato fruits of two
varieties were tested for three methods of packaging at two different temperatures of 13 and 24°C for a period of 50 days after harvest. Fruits were tested for weight loss, decay percentage, coloration of fruits, total soluble solids and titratable acidity and vitamin C content. Storage at 13°C was more favorable for prolonged shelf life and increasing vitamin C content, but storage at 24°C was the best for ripening and good red color of fruits (Mustafa and Mughrabi, 1994). The post harvest losses in terms of quality and quantity of food are major problem all over the world. Therefore, post harvest technology has been given more attention by all developed and developing countries. They all have identified that most of these losses are due to the poor post harvest handling. Rough handling in the field, improper packaging, careless loading and unloading during transportation and poor storage facilities are major factors responsible for both quality and quantity losses. These losses cannot be completely eliminated but can be reduces to a certain extent by employing better handling methods or post harvest treatments. Post harvest losses for tomato are rarely reported in developing Asian countries. It means that studies have not been conducted frequently to estimate losses. However, frequent systematic studies are necessary for estimating post harvest losses in order to identify the weaknesses of the handling system and provide necessary improvements. Post harvest losses of tomatoes ranged from 20 to 50% in developing countries as shown in Table 2.2 (FAO, 2010).

Table 2.2  POST HARVEST LOSSES OF VEGETABLES/ TOMATOES IN DIFFERENT COUNTRIES.

<table>
<thead>
<tr>
<th>Country</th>
<th>Loss in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>20 – 50 (Tomatoes)</td>
</tr>
<tr>
<td>Japan</td>
<td>10 (Tomatoes)</td>
</tr>
<tr>
<td>Nepal</td>
<td>27 (Vegetables)</td>
</tr>
<tr>
<td>Pakistan</td>
<td>21 – 37 (Vegetables)</td>
</tr>
<tr>
<td>Philippines</td>
<td>22 – 32 (Tomatoes)</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>45 (Vegetables)</td>
</tr>
<tr>
<td>Thailand</td>
<td>20 (Thailand)</td>
</tr>
<tr>
<td>USA</td>
<td>12 (Tomatoes)</td>
</tr>
</tbody>
</table>

(FAO, 2010)
2.9 PHYSICO-CHEMICAL CHANGES ASSOCIATED WITH RIPENING AND SENESCENCE:

Ripening refers to changes in physical, physiological, biochemical and sensory traits of harvested fruits which render them acceptable to eat by consumers (Biale, 1975 and Matto et al., 1975).

2.9.1 PHYSIOLOGICAL LOSS IN WEIGHT:

Early Pear type and S-12 cultivars of tomato had 55 and 33 per cent loss in physiological weight, respectively harvested at red ripe stage after seven days of storage at room temperature. While, minimum loss of 23 and 46 per cent, respectively were observed when harvested at breaker stage (Kaur et al., 1977). A minimum loss in weight was reported in tomatoes harvested at turning stage when compared to those harvested at red ripe stage after 12 days of storage (Gaur and Bajpai, 1982). Tomatoes stored at room temperature recorded a maximum weight loss as compared to those packed in polyethylene bags due to higher rate of transpiration and water loss (Lingaiah, 1982).

Weight loss of the plastic film packed fruit was lower and linearly increased throughout storage. For unwrapped fruit weight losses were higher but also linear over the first 40 days, then the rate highly increased. It could be due to senescence or more desiccation of tomatoes. There was not significant difference in weight loss value of tomatoes sealed with PE20 and PVC. Weight loss of fruit sealed in different films indicated that their weight losses were related to film permeability (Batu and Thompson, 1998). Weight loss of the fruits with respect to harvesting methods and calcium chloride treatments were studied. Harvesting method did not influence the weight loss of tomato. Physiological weight loss after 10 days of storage ranged from 15.07 to 15.27%. On the other hand, calcium chloride treatment significantly influenced the physiological weight loss of the fruits right after second days of storage and subsequently afterwards. After two days of storage, controlled fruits exhibited 4.2% weight loss which was significantly higher than calcium treated fruits (Bhattarai and Gautam, 2006).

2.9.2 TOTAL SOLUBLE SOLIDS:

Total soluble solids increased throughout the fruit development in tomato (Boe et al., 1967). In cultivars like Best of All and Large Red, TSS increased from mature green to red ripe stage but in cv. Sioux, it decreased at red ripe stage (Saimbhi, 1969). Similar reports were made in cv. Kuber. An increase in TSS from 5.2 to 5.9 per cent and 5.8 to 5.9 per cent was noted after eight days of storage in
fruits harvested at turning and pink stage respectively, but there was a decline in TSS from 6.6 to 4.3 when the fruits were harvested at red ripe stage (Gaur and Bajpai, 1982). The increase in TSS upto 8 days of storage was observed in tomatoes harvested at mature green stage, but this increase varied with cultivars (Bhatnagar et al., 1980). Siddiqui et al. (1986) reported that no definite trend was observed in total soluble solid contents of tomato with advancement of maturity except in SG-12 and Pusa Hybrid-1 where TSS progressively increased from green mature to red ripe stage. Maximum TSS content was reported in Marglobe (5.75%) followed by Roma (5.70%); whereas, it was minimum in Pusa Ruby (4.85%) after 12 days of storage (Syamal, 1991).

2.9.3 TITRATABLE ACIDITY:

Titratable acidity was found to be maximum at pink stage of tomato fruit (Sands, 1950). Tomatoes had a maximum acid percentage at immature stage and increased at colour initiation, then decreased rapidly as ripening progressed (Winsor et al., 1962). Maximum citric acid content was reported at breaker stage (0.41%) and it decreased with ripening to 0.28 per cent at red ripe stage in field ripened cv. V.R. Moscow (Boe et al., 1967). With an increase in the degree of ripeness, a decrease in acidity was observed in all the tomato varieties under study. Sabour Prabha showed highest acidity (2%) at firm ripe stage and lowest (1.92%) at soft ripe stage (Singh et al. 1983). Tomato cv. Kuber had a decreasing trend in the titratable acidity. At turning stage, a maximum acidity of 0.67 per cent was noted which reduced to 0.43 per cent after 12 days of storage. In pink and red ripe stages, acidity decreased from 0.56 to 0.39 per cent and from 0.34 to 0.26 per cent, respectively after 12 days of storage at room temperature (Gaur and Bajpai, 1982).

2.9.4 ASCORBIC ACID CONTENT:

Ascorbic acid content of field grown tomatoes increased to a maximum level when the fruits turned almost red (Markakis et al., 1974). Maximum concentration of ascorbic acid (20.03 and 13.81 mg/100 g) was reported in cultivar S-12 and Early Pear type, respectively during initial stage of storage. Maximum ascorbic acid content in turning stage fruits was noticed during subsequent storage (Kaur et al., 1977). Ascorbic acid content was higher in firm ripe tomato fruits but varied among the cultivars ranging between 18.44 to 23.28 mg/100 g. In soft ripe fruits, the ascorbic acid content decreased (16.48 to 21.72 mg/100 g) in all the cultivars. A progressive increase in ascorbic acid content from green mature to red ripe stage was noticed in tomato fruits and it varied with cultivars, with Pant T-3, Pant 2466-27
and Pusa Hybrid-1 having maximum ascorbic acid content at red ripe stage and SG-12 and MTH-1 at yellow colour stage and then showed a decline at red ripe stage (Siddiqui et al., 1986). Sowinska and Kornobis (1966) also found highest ascorbic acid content in firm red tomato fruits. While Gaur and Bajpai, (1982) found maximum ascorbic acid content at red ripe stage as compared to turning and pink stage, and it decreased during storage.

2.10 EFFECT OF POLYETHYLENE PACKAGING ON QUALITY PARAMETERS:

Tomatoes harvested at breaker stage and packed in 300 gauge polyethylene bags with three vents recorded minimum changes in moisture, total soluble solids, acidity and sugars than the control fruits. The organoleptic score was high in above acceptable limits for these fruits with a shelf life of 42 days (Naik et al., 1993). Minimum weight loss of 77.5 g was recorded for tomatoes packed in black polyethylene bags. While, a maximum weight loss of 224.16 g occurred for unpacked fruits. The best colour retention and firmness was noted in black polyethylene bags (Badshah et al., 1997). Banana cv. Magrabi wrapped in polyethylene stored for one month had acceptable quality parameters as determined by TSS, moisture content, acidity, reducing sugars, total sugars and organoleptic traits, but the control fruits were distorted in shape and decayed after storage (Elzayat, 1996). Polyethylene bagging + KMnO₄ of custard apples was the best for reducing fruit spoilage and physiological loss in weight. These fruits retained the natural colour with increased storage life compared to other treatments. Brown paper wrapping was also effective in reducing ripening with a decrease in titratable acidity and ascorbic acid content (Bhadra and Sen, 1999). Mandarin fruits stored in polyethylene bags had the lowest physiological loss in weight (4.0%) compared to other treatments (Rana et al., 2002). Chilli cv. Pusa Jwala packed in 100 guaze polyethylene had the lowest PLW (5.5%) on 25th day of storage, but highest ascorbic acid content was in fruits packed with 30 guage polyethylene. Respiration rate decreased in polyethylene packed fruits (Brar et al., 2000). Oranges packed in LDPE or HDPE unperforated bags and stored at 28-35°C for 15 days had the lowest weight loss and pH and highest TSS than the perforated bags (Efuuvwevwere et al., 1991).

2.11 BASIC PRINCIPLES OF MODIFIED ATMOSPHERE PACKAGING:

Modified atmosphere packaging (MAP) of fresh fruits and vegetables refers to the still evolving technique of matching the respiration of the product with the O₂ and CO₂ permeability (breathability) of packages in order to modify the O₂ and CO₂ concentrations of the atmosphere to desired levels within the package (Beaudry and
One important goal of MAP is to generate an atmosphere sufficiently low in O₂ or high in CO₂ to influence the metabolism of the product being packaged or the activity of decay causing organisms resident on that product such that storage life is prolonged. In addition to atmosphere modification, a sealed package vastly conserves and improves moisture retention which, probably more than O₂ and CO₂ modification helps preserve food quality (Beaudry and Lakakul, 1995). Moreover, maintaining a product in a container sealed off from the external environment helps ensure conditions to reduce exposure to airborne pathogens (plant and human) compared to uncovered produce. During the past 50 years, uses of controlled atmosphere and modified atmosphere packaging to supplement, not substitute for temperature and relative humidity management, has increased steadily and contributed significantly to extending the storage life and maintaining quality of several fruits and vegetables (Kader, 1995). This trend is expected to continue as technological advances are made in attaining and maintaining CA and MAP during transport, storage and marketing of fresh produce. MAP can facilitate maintenance of the desired atmosphere during the entire postharvest handling time between harvest and use. However, temperature abuse conditions or wrong film choices may create highly unfavorable atmospheres, leading to losses. Recent advances in the design and manufacture of polymeric films with a wide range of gas diffusion characteristics have stimulated renewed interest and increased the use of flexible plastic film for MAP of fresh produce (Kader, 1989; Riquelme et al., 1997). Furthermore, microperforation technology in which the film is perforated with consistent, minute holes can potentially open up new applications in fresh produce packaging technology, particularly for high respiring produce (Frey, 1997). Incorporation of the microperforation technology and passive modified atmosphere effectively extend the shelf life of fresh produce. In addition, increased availability of various absorbers and adsorbers of O₂, CO₂, C₂H₄ and water vapor provide possible additional tools for manipulating the microenvironment within MAP units.

2.11.1 BENEFICIAL AND DETRIMENTAL EFFECT OF MAP:
2.11.1.1 BENEFICIAL EFFECTS:

MAP is capable of extending the storage life of fresh produce by 1.5 to 4 fold under refrigeration depending on the commodity (Zagory and Kader, 1988; Day 1989). Incorporation of MAP and low temperature management can further increase storage life of fresh produce. Generally, the effect of reduced O₂ and/ or elevated CO₂ on reducing the respiration rate has been assumed to be the primary reason for the beneficial effects of MAP on fresh produce (Kader et al., 1989; Kader 1995;
MAP conditions can effectively reduce or inhibit \( C_2H_4 \)-induced senescence and physiological disorders in harvested fruits and vegetables (Riquelme et al., 1997). Prevention of ripening and associated changes in fruits is one of the main benefits of MAP (Kader, 1980). Oxygen concentration has to be less than 8 % to have a significant effect on fruit ripening and the lower the \( O_2 \) concentration, the greater the effect (Kader, 1989). Elevated \( CO_2 \) levels above 1% also retard fruit ripening and their effects are additive to those of reduced \( O_2 \) atmospheres. For some commodities which can tolerate high \( CO_2 \), \( CO_2 > 12 \% \) has shown added effectiveness in control of same fungal pathogens (El - Goorani and Sommer, 1981) and this has led to commercialization of MAP. Cherries, strawberries, blueberries and several other small fruits have been shown to benefit from high \( CO_2 \) treatments. In addition, the effects of MAP on delay or inhibition of ripening are greater at higher temperature. Therefore, use of MAP may provide handling of ripening climacteric fruits at temperatures higher than their optimum holding temperature so that chilling-sensitive fruits could benefit by avoiding their exposure to chilling temperatures.

Kader (1989) indicated that MAP conditions reduce respiration rates provided that the levels of \( O_2 \) and \( CO_2 \) are within the range that is tolerated by the commodity. This, combined with decreased \( C_2H_4 \) production and reduced sensitivity to \( C_2H_4 \) action, results in delayed senescence as indicated by retention of chlorophyll, textural quality (decreased lignification), and sensory quality of non-fruit vegetables. The incidence and severity of certain physiological disorders which are induced by \( C_2H_4 \) and chilling injury of some commodities can be reduced under low \( O_2 \) and high \( CO_2 \) concentrations. El - Goorani and Sommer (1981) concluded that delaying senescence by MAP reduces susceptibility of fruits and vegetables to pathogens. Therefore, use of some postharvest fungicides and fumigants can be reduced or eliminated in those cases where MAP provides adequate control of pathogens. Oxygen level below 1 % and/or \( CO_2 \) level above 10 % are needed to significantly suppress fungal growth (El - Goorani and Sommer, 1981). Moreover, elevated \( CO_2 \) levels (10 to 15%) can be used to provide fungistatic effects on commodities that can tolerate such high \( CO_2 \) levels. MAP conditions can facilitate picking and marketing more mature or riper (better flavored) fruits by slowing down their postharvest deterioration rate to permit transport and distribution (Kader, 1995).

### 2.11.1.2 DETRIMENTAL EFFECTS:

Exposure of fresh fruits and vegetables to \( O_2 \) levels below their tolerance limits or to \( CO_2 \) levels above their tolerance limits may increase anaerobic respiration
and the consequent accumulation of ethanol and acetaldehyde and other metabolites causing off-flavors (Kader et al., 1989; Richardson and Kosittrakun, 1995). In addition, anoxic modified atmosphere conditions can favor the growth of facultative anaerobes and obligate anaerobes compared to aerobic spoilage organisms. Fruits present few public health risks due to their relatively low pH (Church and Parsons, 1995). However, a risk does exit with vegetables from both mesophilic and psychrotrophic pathogens in both ambient and chilled stored products (Church and Parsons, 1995). The possibility of potentially fatal toxigenesis by psychrotrophic (Clostridium botulinum) theoretically exists in anaerobic atmosphere caused by O₂ depletion arising from either the use of incorrect packaging material (Day, 1993 as cited by Church and Parsons, 1995) or temperature abuse (O’Beirne, 1990). There is little evidence of a real threat in practical usage (Church and Parsons, 1995) because O₂ levels don’t become zero. However, accumulation of C. botulinum toxin without sensory indication has not been demonstrated in vegetable products (Zagory and Kader, 1988).

2.12 EFFECT OF MODIFIED ATMOSPHERE PACKAGING ON PHYSICO-CHEMICAL PARAMETERS:

Modified Atmosphere Packaging (MAP) helps to extend the storage life of many types of perishable produce by reducing the rates of respiration and the metabolic processes associated with ripening or senescence (Kader et al., 1989). The use of polythene film having a differential permeability rates for O₂ and CO₂ reduces the moisture loss and restricts ventilation, resulting in the build up of carbon dioxide and a reduction of available oxygen creating a modified atmospheric condition. A modified atmosphere of 3 per cent O₂ and 1 per cent CO₂ has been reported optimum for avoiding injuries due to anoxia and CO₂ and maintaining the quality attributes (Kader and Morris, 1974). However, Pan and Bhowmik (1989) reported that mature green tomato fruits can tolerate 3 per cent O₂ and 5 per cent CO₂.

2.12.1 RESPIRATION:

Storing of whole and fresh-cut tomatoes in MAP at 2°C significantly reduced the CO₂ production rates. The respiration rate of whole tomatoes at 2°C was half as that at 10°C and no chilling injury disorders were observed (Artes et al., 1999). Controlled atmosphere storage of tomatoes delayed the onset of climacteric stage and slowed down the rate of respiration. During first 3 weeks of storage, respiration rate of tomatoes were reduced to about 10 per cent of normal respiration (Bhowmik
When bell pepper fruits were stored in low O₂ atmosphere, CO₂ production rates were 38 per cent lower than the air stored samples (Rahman et al., 1993). Bussel et al. (1975) also reported a reduced respiration rate of bell pepper fruits sealed in modified atmosphere packages. Similar results were exhibited by pear fruits kept under elevated CO₂ concentrations. The presence of 10 per cent CO₂ resulted in a significant reduction in the rate of O₂ uptake and in the curtailment of the climacteric respiratory rise of pear fruits (Kerbel et al., 1988). Low O₂ and high CO₂ atmospheres (3%O₂ + 20%CO₂) prevented the total carotenoid and lycopene biosynthesis and α and beta-galactosidase activity in tomatoes. The chlorophyll degradation and loss of firmness was slowed down (Gabriel et al., 1999). Modified atmosphere packaging provided good quality tomato slices with a shelf life of 2 weeks at 5°C (Hong and Gross, 2001). Mature green tomatoes packed in MAP had a built in atmosphere of 4 per cent O₂ and 5 per cent CO₂ and delayed the fruit ripening. These fruits had a low rate of physiological loss in weight and better overall quality than control (Onwuzulu et al., 1995). Tomatoes packed with several polyvinylchloride (PVC) films or with K-resin had a slow rate of colour change than control, but continued to ripe normally after the packs were perforated and transferred to 20°C. The aroma, flavour and texture of these fruits were slightly better than control fruits (Geeson et al., 1985). Controlled atmosphere storage of tomatoes with high per cent relative humidity (98%) greatly reduced the weight loss, colour development was slowed, spoilage was reduced significantly and the shelf life was increased as compared to control (Bhowmik and Pan, 1992). Modified atmosphere packs sealed with breaker tomatoes delayed the changes in acidity, soluble solids, texture and colour. It also resulted in a substantial reduction in fruit weight loss and spoilage (Nakhasi et al., 1991). Tomatoes enclosed in polyethylene bags and kept at low temperature resulted in the build up of modified atmospheres and extended the ripening time, improved firmness and maintained quality in terms of appearance and taste (Hobson, 1981). Low oxygen atmospheres (1% O₂ and 99% N₂) inhibited the ripening and increased the storage life of tomatoes to 87 days at 55°F. It inhibited the degradation of chlorophyll and starch, synthesis of lycopene, Beta-carotene and soluble sugars (Salunkhe and Wu, 1973). Tomato fruits stored under low oxygen concentration (1%) remained firm and green throughout the storage period, whereas, fruits stored in air were soft and developed characteristic red colour (Kapotis et al., 2004). Colour development in mature green tomatoes was prevented by storing the fruits in 5 per cent O₂, 5 per cent CO₂ and 90 per cent N₂ atmospheres (Goodenough et al., 1982). Controlled atmosphere storage of sucrose polyester
coated and uncoated tomatoes at 12°C significantly reduced the weight loss. The fruits had a higher titratable acidity and low TSS. Loss of ascorbic acid content was slower and lycopene synthesis was delayed in addition to increase in the storage life to 40 days (Tasdelen and Bayindirli, 1998).

2.12.2 EFFECT OF HEAT TREATMENT ON QUALITY PARAMETERS:

2.12.2.1 HOT WATER TREATMENT:

Mature green tomatoes immersed in water at 40°C for 15 min and stored for 21 days at 5°C followed by 12 days at 20°C exhibited lowest incidence of chilling injury and were firmer. These fruits ripened normally at 20°C characterized by climacteric ripening. Complete disappearance of chlorophyll followed by lycopene synthesis was observed after 9 days at 20°C indicating normal ripening (Nagetey et al., 1999). Hot water dips (39°C for 90 min) of mature green cherry tomato fruits and subsequent storage in MAP substantially delayed the colour development (Ali et al., 2004). Valencia oranges receiving a hot water immersion treatment of 25°C for 42 min lost less moisture and remained firmer during storage at 0°C for 5 weeks followed by one week at 21°C. Heat treated fruits showed enhanced colour development and reduced acidity. Hot water dips at 47-53°C for 1-3 min significantly reduced the chilling injury of ‘Eureka’ lemons stored at 1°C for 28 or 42 days. The rate of fruit weight loss during 7 days at 20°C was significantly lower in the treated fruits than control. Dipping green bell peppers in water at 53°C for 4 min and storing with film packing reduced the chilling injury and decay after 14 and 28 days of storage (Gonzalez et al., 2000). Pre-storage dipping of late-crop cactus pear fruit in water at 55°C for 5 min was effective in improving the quality of fruits during marketing. The treatment was effective in reducing cold injury and decay and in maintaining the fruit appearance throughout the. Hot water dip treatments at 45°C for 10 and 20 min of ‘Fuyu’ permission fruits enhanced the visual quality. Carotene and lycopene content increased at the end of storage. Decay, skin blackening was significantly lower and the respiration rates decreased with storage time.

2.12.2.2 HOT AIR TREATMENT:

Rapsody’ tomato fruit exposed to 34°C for 24 h in air and stored at 10°C for 30 days developed the best colour when ripened and had the least chlorophyll and highest lycopene content (Yahia et al., 2003). Intermittent warming of tomato fruits at 20°C for one day at 7 days interval reduced the fruit titratable acidity, but no significant differences were observed in soluble solid content. Fruits with good quality and shelf life were obtained following 3 cycles of intermittent warming at 6°C
Heat treatment of 33°C for 5 days was able to lower the respiration rate and decrease the chilling injury in tomato fruits (Artes et al., 1998). Heat treatment of 30°C for 60 min had a reduced chilling injury and maintained best fruit quality. Heat treatment of strawberries cv. Selva at 45°C for 3 h and stored at 0°C for 0, 7 or 14 days delayed the red colour development. Lower weight loss, acidity and decay were recorded in these fruits than control. The fruits remained firmer after 7 days of cold storage. ‘Anna’ and ‘Granny Smith’ apples held at 38°C for 14 days and then stored at 0°C were firmer than control upon removal from storage. These fruits softened more slowly during their storage at 17°C. Skin yellowing and loss of acidity was prevented (Klieber et al., 1990).

2.12.3 QUALITY EVALUATION BY COLOR MEASUREMENT OF TOMATO:

One of the quality factors of fresh tomatoes for consumer preference and most practical and successful techniques for nondestructive quality evaluation is the measurement of color. Classification of color and ripening stages have been done for years in many developed countries but Minolta color values still were not determined. Skin color of fruits such as tomato has a strong effect on consumer acceptability of product. Variation in color readings between maximum and minimum values increased during ripening of tomatoes and is most variable at the pink stage of maturity (Ali, 2004). Tomato changes its color rapidly over the first 10 days of storage and then at slower rate over the next 20 days and remained the same color after that. However, after 30 days all fruits reached their maximum red color and although the film the film wrapped fruits tended to be less red than the unwrapped fruits. Lycopene constitute the main red pigments of tomatoes and their concentrations increase steadily through ripening. Formation of lycopene was dependent upon the presence of O₂. Its formation was inhibited by low O₂ atmosphere storage. The lower the O₂ concentration, longer the inhibition. At 1% O₂ and 99% N₂ storage the formation was completely inhibited for 50 days (Ali and Thompson, 1998).

2.12.4 QUALITY EVALUATION BY TEXTURE:

Cold storage in controlled atmosphere (CA) will inhibit ripening and texture change to a greater extent than is possible in air alone. There are three ways in which controlled atmosphere can influence fruit texture: first, a positive effect of CO₂
on tissue strength; second, a general inhibition of metabolic processes which often minimize texture change over long periods of storage; and third, a deterioration in quality and texture associated with use of injurious atmospheres. Changes in the texture of most fruits involve softening whereas vegetables usually involve toughening.

The influence of modified atmosphere storage on the texture of vegetables varies with the commodity (Weichmann, 1986). The texture of green beans was not changed by storage in 0 to 10% CO₂ with 2% O₂ for 1 or 2 weeks at 7°C. The same result was also found in green beans stored in 0 - 30% CO₂ in air for 24 hr at 27°C. In addition, no textural changes were demonstrated in raw broccoli stored in 0 – 20% CO₂ with 2, 5, 10 or 20% O₂ for 14 days at 1 or 7°C. However, broccoli stored in high CO₂ was softer (after cooking). It was also found that 10% or more CO₂ prevented toughening of broccoli and as a result, tissue became tenderer when cooked than it was at the time of harvest. He pointed out that this tenderization may be a direct result of CO₂ mediated decrease in tissue pH. The same result was also found in cauliflowers and asparagus. In asparagus, tenderness of the cooked asparagus spear increased at CO₂ concentrations of 3 - 30% with an optimum at 15%. Reduced O₂ had little effect on tenderness of asparagus or broccoli. A rapid and direct influence of CO₂ on tissue strength has only been reported in strawberry (Smith, 1992). Firmness was enhanced by storage in elevated CO₂ concentration in strawberry. The maximum firmness enhancement was generally achieved at 15 - 20% CO₂ when storage temperature was 0°C. Plocharski (1982) suggested that CO₂ was responsible for the induction of change in pectic substances. However Smith (1992) did not verify this. The effect of CO₂ on increased firmness has not been published in other fruits, which also point out that strawberry has a unique interaction with CO₂. Alternatively, in other fruits, the effect may have been too small to detect with the devices used or the experiment not held long enough. The mechanism of modified atmosphere effect on texture of fresh fruits and vegetables is not fully understood and merits further investigation (Kader, 1986).

2.13 OTHER FRUITS AND VEGETABLES:

Controlled atmosphere storage of ‘ginger gold’ apples maintained the firmness and quality based on measurements of total soluble solids and titratable acidity for several months (Barden and Mitcham, 1997). Storage of ‘Kent’ mangoes in 10 per cent CO₂ + 5 per cent O₂ at 12°C increased the post harvest shelf life to 29 days i.e., 8 days more than control. Tommy Atkins mangoes stored in 5 per cent CO₂ and 5 per cent O₂ had a storage life of 31 days. MAP storage of paw-paw fruits at
moderately low temperature (15°C) was effective in retarding the textural changes and firmness loss, while, the colour development was significantly delayed. ‘Chiripa’ peaches stored in controlled atmospheres of 1 Kpa O₂ + 3 Kpa CO₂ showed the highest firmness, titratable acidity and reduced the occurrence of decay as compared to cold stored fruits after 20 days of storage (Brackmann et al., 2000). Pear fruits kept under elevated CO₂ concentrations (air + 10% CO₂) remained firmer and greener than the fruits stored in air (Kerbel et al., 1999). Modified atmosphere storage (6% O₂ + 14% CO₂) of fresh-cut kohlrabi at 0°C for 14 days enhanced the chemical attributes in terms of soluble solid content, pH, titratable acidity and the sensory attributes such as visual appearance, aroma, flavour and texture. These dices had a quality higher than acceptable showing no chilling injury symptoms and decay (Escalona et al., 2003). Controlled atmosphere storage having a gas composition of 1 per cent or 2 per cent O₂ and 2 or 4 per cent CO₂ prevented the black stem development of celery during a storage period of 10 weeks. Maintenance of quality was best achieved by improved visual colour, appearance, flavour and increased marketability (Smith and Reyes, 1988).