12) PRESERVATION OF FRUIT AND VEGETABLES
AT CHILLING TEMPERATURES

Introduction

It has been estimated that in certain areas of the world 50% of available foodstuffs are lost in the period between production and consumption. In warmer and more humid countries the problem is especially large, due in most cases to the lack of infrastructure, which would make efficient methods of preservation possible, and to the insufficiency, or costliness of traditional methods.

The most common destructive agents are rodents, insects, and microorganisms (fungi and bacteria). Man himself, through ignorance and negligence, often handles and distributes foodstuffs poorly, creating conditions which promote physical, chemical or microbiological changes that make them unsatisfactory consumption.

Other factors, related to the culture and development of a people, can contribute to losses of foodstuffs. Every nation is, indeed unique (in ethnicity, economy, climate, agriculture, education, geographic position, eating habits, sanitation conditions, etc.). Food preservation assumes, then, a special importance in developing countries. Food products must be kept sufficiently stable to avoid, or to delay, deterioration.

The problems confronted in food preservation are not simple, for a whole set of biological factors, prior to the start of the chosen preservation method, can later affect losses that occur during treatment, storage, conditioning, transport, and distribution. Hence, one must for the most part take into account the treatments of, and deterioration in, fruits and vegetables before and after harvest, as well as the ante and post mortem treatments and biochemical deterioration undergone by land and sea animals used for food.

Ultimately, the feeding of an endlessly growing world population requires that efforts to increase food production be accompanied by initiatives to reduce, if not eliminate, losses which would otherwise remain considerable at all stages of food distribution and transformation.

A chilled product, which is the subject of this study, is understood to be product cooled to what is called a storage temperature, which remains permanently, everywhere in the product, higher than a critical temperature, below which appear phenomena both undesirable and irreversible. In all cases this temperature is higher than the temperature of initial ice formation (or cryoscopic temperature). Practically, the minimum temperature in refrigeration is 0°C.

In order to insure suitable preservation of refrigerated food, operating instructions for cold rooms should be followed, and the effect of other factors, examined below, must be taken into account.

Storage Life and Quality

The recommendations given in this document are based on the following general principles:
Optimal conditions

The recommended conditions are those most suitable for maximum storage life. These optimal conditions may, in general, be somewhat relaxed if it is intended to keep the produce for a very short period only. Temperatures, lower than those recommended, will not always result in an appreciable increase in storage life and may in the case of storage of certain fruits and vegetables, even lead to a decrease.

Expected or practical storage life

"Expected or practical storage life" depends mainly on storage temperature and does not necessarily mean the maximum period for which the food can be stored without any regard to loss in quality, but is the greatest length of time for which the bulk of the produce may be stored either with maximum commercially acceptable loss of quality and nutritive value or with maximum acceptable wastage by spoilage.

Furthermore, the periods given in the tables are those for which the produce can be kept, while still retaining its quality during subsequent marketing over a normal period and under normal climatic conditions.

Foods intended for immediate use or for further processing can be kept for longer periods under the conditions given, or may be held at higher and sometimes even at lower temperatures.

Initial quality

The recommended conditions (especially the length of storage) are valid for produce, which is perfectly fresh, and of good quality, such as freshly harvested fruits and vegetables, freshly caught fish, newly and hygienically slaughtered meat, bacon after an appropriate curing process, new-laid eggs. It is thus that chilled storage of the perishable foodstuff begins as soon as possible after harvesting or production. Delay in placing the produce in cold store will reduce the time for which it can be kept (beef may be an exception because it is aged) either because deterioration has advanced during the interval, or because the produce has changed in the interim and would be damaged by the conditions recommended. An example of the latter type is that of pears, which should not be cold stored once they have begun to ripen.

Further requirements are that the produce should be sound and clean, free from any form of mechanical injury, infestation or physiological disorder and without any visible sign of microbiological attack. In some cases (e.g. chilled beef and poultry) particular care must be taken to keep the initial load of spoilage organisms low so as to ensure an adequate storage life. Some kinds of produce should be adequately packed (in wrapping films, boxes, containers, etc.) and for these purposes, the packaging process should be carried out hygienically.

Cooling Down

Generally, regardless of whether the storage of perishable foodstuffs is envisaged for a short or long term, the cooling down period should be as short as possible. An exception is
with the meat of some newly slaughtered animals, e.g. beef and mutton, where some moderation of chilling rate may be required to avoid toughening of muscle as a result of cold shortening. For fruit and vegetables, the environmental temperature should generally be decreased to the final storage temperature within 24 hours; for fish, crustacean and mollusk this time, depending upon the ambient temperature, should be no longer than 2-10 hours. The cooling down of foodstuffs could be carried out either by forced cold air in the storage room or in a special pre-cooling chamber or tunnel or by using vacuum, ice, chilled water, seawater or brine, or by employing cold air and sprayed chilled water at the same time (hydrair cooling).

The foodstuffs should be packed and stacked in such a way that the cooling medium is in as good contact with it as possible; it is difficult to cool quickly large masses of foodstuff.

**Storage Temperature**

Chilled storage of perishable produce is normally carried out at a temperature between -1.5 and +10°C; higher temperatures for some fruits and vegetables are recommended. Detailed information is given in annex.

The foodstuff temperature should be kept as constant as possible for the whole period of storage. For some kinds of produce a variation of about ±1°C may have serious consequences on storage life. For example, the life of Williams pears at −1°C is almost double that at +1°C and the life of many varieties of apples, peaches and plums is about 25 per cent greater at +0.5°C than at +1.5°C. Because of this greater sensitivity to temperature near the freezing point the best storage of those kinds of fruits and vegetables for which storage at low temperature is safe and recommended, requires close control of temperature. This type of close control is also a must for meat and fish.

Thus, when planning conditions for long term storage a temperature difference of no more than 1°C in the circulating air should be aimed at, together with a short-term fluctuation of less than 0.5°C.

Fluctuations in temperature often cause condensation or moisture on stored products, which is undesirable because it may favour the growth of microorganisms, in the case of fruits and vegetables, the growth of mould and the development of decay.

Temperature variations can be minimized if the storage room is well insulated and has adequate refrigeration and if the spread between the temperature of the refrigerant and that of the room to be refrigerated is kept small. Proper stacking, adequate air circulation and appropriate design of the package help to minimize temperature fluctuations.

For the control of temperatures the sensing element of the thermostat should be placed in a carefully chosen location so that the temperature is representative of the average temperature of the room and that there is no risk of freezing the stored products, particularly fruit and vegetables.
Relative Humidity

Most foodstuffs, which are held in cool stores in non-sealed packs, evaporate water more or less freely, depending on the nature of the product, surface per unit volume ratio, the difference between the saturated vapour pressure in equilibrium with the product and the ambient vapour pressure and, finally the air circulation rate. A high relative humidity in the store is generally necessary to prevent excessive loss and secondary effects such as shrivelling or wilting. On the other hand too high values of relative humidity may stimulate the growth of microorganisms. The relative humidity recommended in the tables are those, which have, been found in practice to be sufficiently safe as far as microorganisms are concerned, although some moisture loss has to be accepted. A relative humidity of at least 90% is desirable for most fruits and vegetables. It is usually possible to design stores so that the required humidity will adjust itself naturally at about this level unless there is only a small amount of the fruit in the store.

During the period of discharge, the room is partly empty and the balance between humidity supply from the produce and removal of moisture on the surface of the cooler is modified. Hence the relative humidity is generally lower and shrinkage greater in rooms, which are partly filled.

The relative humidity in the cold room is a function of the relative size of the evaporator of the cooler compared to the amount of heat that must be removed. For a given size and loading of a cold room the larger the evaporator surface the higher the relative humidity. Good insulation also favours high relative humidity.

The relative humidity can be estimated by taking the average temperature difference between air cooler surface temperature and storage temperature. If this difference is small relative humidity is high, and vice versa. The water holding capacity of air increases as the temperature rises, hence air of 90% R. H. at 21°C contains much more water by weight than air of the same relative humidity at 0°C. A rise in temperature will considerably reduce the pressure of the water vapour in the air and increase its drying power. Therefore maintenance of low and uniform temperatures is often the main factor in limiting shrinkage and wilting.

Some vegetables, e.g. broccoli, celery, dill, lettuce, parsley, spinach are particularly subject to wilting and humidity above 90% are desirable for them unless protective packaging or some other measures to restrict water loss are used. A few products, which are cold stored, are relatively dry and precautions may be necessary to prevent uptake of water by them. Some of these, e.g., nuts, dried fruits and fish, are in equilibrium at about 70% relative humidity. If these are held in cold rooms containing no other produce, which evaporates water freely, they will rarely be injured by absorption of water.

Air Circulation

Cooling in cold rooms is accomplished by transferring the heat to an air stream. Heat to be transferred depends on the product temperature, the respiration rate in the case of fruits and vegetables, and the heat entering the storage room by heat transfer through the walls and by air exchange.
During the cooling down period a large heat load must be removed and during the storage period it is important to reduce temperature differences to a minimum. However, some spread of temperature must be accepted in order to allow transfer of heat from the room to the cooler as well as from the produce to the air. Air is the transport vehicle for heat; therefore air circulation needs full consideration.

Airflows and stacking should be arranged so that air travels in the same direction as the corridors between stacks. The maximum allowable airflow around stacks depends on the type and the way that the produce is packaged. Continuous air circulation at a high rate tends to equalize the temperature throughout the room but the higher the air flows the greater the water loss.

The circulation of air by natural convection, or by fan, should be sufficient to maintain a reasonable uniformity of temperature and humidity within the cold store; the free horizontal flow system with high velocities of primary air has shown to be a reasonable efficient solution. The space on top of stacks needed for handling by forklift trucks is adequate for good air circulation. Care has to be taken to provide enough space for the down stream along the wall opposite to the cooler units, and for the return air through the stack; air channels of appropriate width have to be arranged in the main flow direction.

**Ventilation**

Because of economic considerations, ventilation, air change or air renewal (introduction of outside air) should be kept to the minimum. Only clean, uncontaminated and odour free air should be supplied to the cold store. Some ventilation may be essential in the storage of fruits, vegetables and other commodities, such as cheese, which may give off odoriferous products. Often enough air is supplied by infiltration, changes in atmospheric pressure, opening of doors, etc., but for certain foodstuffs, such as citrus, special facilities for ventilation may be necessary. Ventilation is not normally required in the storage of fish and meat. If any fresh air is introduced, it should be directed over the cooler to avoid condensation on the colder surface of the products.

In introducing fresh air, care should be taken to allow for the removal of an equal amount of storage room air. The air renewal or air change rate indicates how many times per hour a volume of fresh air equivalent to the volume of the empty cold room is introduced in the room. Calculation of the reduction of CO$_2$ in the atmosphere in a cold room, required for storage of some products, can be made by taking into account the mass of product, the cold room volume, the respiration rate of the produce at the storage temperature and the maximum concentration of carbon dioxide tolerated by the product.

**Packaging and Stacking**

It is assumed that produce is packaged in the usual way (normal materials or containers, etc.) and that the goods are stacked in such a manner as not to impair circulation of air; an adequate system for air distribution is useless if poor stacking prevents airflow. Air follows the path of least resistance; thus if spacing is irregular, wider spaces get a greater volume of air than narrower ones. If some spaces are partially blocked, dead air zones occur with resultant higher temperatures; no direct contact of goods with the walls or floor (except in jacketed rooms) should be allowed. It is important that the nature of the packages and the way in which they are stacked neither reduce the heat transfer
coefficient nor allow the build-up of an atmosphere, which might be harmful to the produce.

Generalization on stacking is difficult with the large variety of containers in use for different commodities, and with the increasing use of pallets, bulk bins and corrugated containers. Special precautions should be taken in stacking containers on pallets so that as much container surface as possible is exposed to circulating air.

The arrangement of the produce packages greatly affects the storage conditions. Stripes should be painted on the floor, indicating the position for pallets and packages and the necessary passageways.

In the free horizontal flow system stacking should be as high as possible and the air stream should reach each packing unit. Stacks up to 9 m high with bulk bins are common for long-term storage. A stack of 3 pallets high is common for boxes and cartons without an auxiliary construction. If pallets are equipped with a supporting frame higher stacks are possible. Pallets should be placed with their openings facing the direction of airflow.

Special packages are necessary for the cold storage of foodstuffs. They must be strong enough to withstand handling in the cold store, protect the produce, allow stable loading, and permit rapid heat removal and adequate air circulation.

Conventional packages consist of wood, plastics, solid carton, corrugated fibreboard or a combination of these materials. They can be constructed with or without lids but should allow horizontal air movement.

Volatile Substances

Because certain produce (such as fish, citrus, apples) give off strong specific doors and other produce (such as eggs, butter, meat) may absorb them very easily, the cold storage operator must be very careful in storing different produce or even different varieties of the same kind of produce in the same store at the same time; ventilation may help here. Even if different foods are not stored in the same room at the same time, the second lot of food may be tainted by doors, which remain from the first lot. This may also apply to odourless volatile substances, such as ethylene, produced by one foodstuff but which are detrimental to another. Therefore, storage rooms should be thoroughly cleaned from time to time and deodorized if necessary.

Hygiene

Cleaning is, of course, also necessary to maintain the cold store in hygienic conditions because microbial growth can be rapid at temperatures above 0°C. In addition to frequent removal of dirt and all food debris, the following points may be noted:

- a) Mould growth appearing on walls and ceilings may be indicative of defective insulation and/or defective moisture vapour barriers. Apart from renewal of the affected areas, only palliative measures, such as frequent disinfection, can be used.

- b) When mould attack occurs on walls, ceilings, ducts, pillars, etc., which are in good physical condition, thorough cleaning and disinfection should be undertaken.
at the first opportunity. This operation should begin with the scrubbing of all affected surfaces with hot water containing a good detergent, followed by rinsing with potable water, then fogging or spraying with a solution containing about 0.3% available chlorine. This should preferably be followed by fumigation of the room with gaseous formaldehyde, which can best be generated by heating paraformaldehyde tablets in special stoves using one gram of tablets for each cubic meter of free air space.

c) Rooms used for chilling and storing meat and fish should have impervious, easily cleaned linings or coatings on floors and walls. Rooms used for the cooling of freshly processed carcasses, should be cleaned and disinfected daily, and other rooms at least weekly.

The use of sawdust, or similar organic material, on the floors of meat storage rooms should be avoided. While it gives an appearance of cleanliness it is a fertile medium for the growth of moulds and bacteria when it becomes moist.

d) Fungicidal additives to wall paints may be useful at high relative humidity in the store.

Condensation

On removal from cold stores care must be taken to prevent condensation on the surface of the cold produce; this will happen when the dew point of the air is higher than the surface temperature of produce or of its packaging material. The package in which the commodity is packed may act as a barrier to condensation on its contents. Tight packages for dried fruits, shelled nuts, canned goods etc., offer good protection. Sometimes a pallet-load of packages can be covered until it warms to above the dew point of the surrounding, thus avoiding heavy condensation. If condensation occurs, steps must be taken to dissipate condensed moisture as soon as possible. This could be done for instance by slow warming up in sufficiently dry air.

Condensation is harmful to goods as it stimulates the growth of micro organisms. Many packaging materials, such as cartons, will also suffer in rigidity.

Fruits and Vegetables

Introduction

Fruits and vegetables are fundamentally different from most other produce, which is cold stored in the fresh (unfrozen) state, in that they are living. They respire; thus suitable ventilation must be provided. During cold storage, they undergo characteristic changes, of senescence, and of ripening of fruits. Like all living material, fruits and vegetables vary greatly from one species to another, from one cultivar to another, and between individual examples of the same cultivar. This latter is due to some extent to different cultural conditions - climate, fertilizers, irrigation, spraying, etc. Thus the information, in the tables which follow, is not true for every case; each user should adapt it to the product and region involved.
There has been an attempt to avoid giving too optimistic storage periods, in the tables, since the objective is not just to keep the produce alive, but also to keep it in a satisfactory commercial condition.

**All Fruits and Vegetables Do Not Tolerate Cold Storage Equally**

The ability to withstand cold storage varies according to species and cultivars and the choice of these is very important; late varieties are usually best. Differences in the rate of loss of water (thus of shrivelling), in incidence of physiological damage (caused by chilling and not microbial), in fungal attack, in the ability to withstand rough handling, etc., are some of those to be considered.

A second factor, which is important in determining if a given product will tolerate cold storage, is the stage of development at the beginning of storage (use of indicators of degree of maturity of fruits).

Finally, notice must be taken of any pre-storage treatments, in the field or orchard, and of steps taken at the time of harvest, packaging, rapidity of transport to the cold store, etc.

**Practical Operations Before Cold Storage**

**Packaging**

Packages (boxes, crates, cartons, etc.) play a protective role against mechanical handling, dust, insects, infection by fungi, and they can also diminish the rate of loss of water, or hinder gaseous exchange and thus modify the composition of the atmosphere around the produce. The use of plastic films of various sorts is the most important recent step in packaging (box liners, gastight or perforated bags, pallet covers). Pre-packaging, which is maintained up to the point of consumption has in particular the advantage of maintaining a high relative humidity around the produce, and thus to preserve their appearance and freshness; weight loss is reduced and the commercial life is increased (carrots, radish, lettuce, etc.). Perforated packages (for apples and pears) allow a certain amount of ventilation, limiting the risk of fermentation and accumulation of carbon dioxide (CO$_2$) and ethylene.

Fluctuations of temperature lead to condensation of water inside the package or on the plastic cover (berries). Too high a relative humidity may unfortunately favour microbial development, due to presence of liquid water; the use of a fungicide (which must be one approved in the country), or the presence of calcium chloride as an absorbent of water may then be useful.

**Various prophylactic measures**

Washing (e.g. of carrots) may be recommended for some vegetables. The use of fungicides is limited by regulations, which vary widely from one country to another, and this must therefore be taken into account. Superficial scald of apples may be prevented by a chemical treatment, with diphenylamine, or ethoxyquin. The risk of sprouting of potatoes or onions may also be reduced by suitable chemical treatments or by irradiation, provided that local regulations permit. Finally, hot water may sometimes have a protective role (e.g. for papaws). A covering of wax has been recommended for some special cases.
(citrus, turnips, cucumbers, and tomatoes), and fungicides are sometimes incorporated in
the wax.

Pre-cooling

As long as the temperature remains high, transpiration, respiration and the various
metabolic processes in the fruits and vegetables will be intense, thus, in general, leading to
very rapid changes. Thus it is necessary to cool the produce as rapidly as possible; this
reduces loss of water and slows down or inhibits development of micro organisms. Once
cooled, the produce must be continuously held at low temperature.

The main methods of pre-cooling are: by vacuum, hydro cooling by immersion or
spraying with cold water, blast cooling in a current of cold air, or a combination of hydro
cooling and blast cooling (hydrair cooling), using a current of air containing a fine mist of
water, and finally cooling by contact with ice. Vacuum cooling is mainly used for leaf
vegetables such as spinach, lettuce, celery, parsley, etc. If the produce is wetted, it can
also be used for artichokes, asparagus, broccoli, and leeks. Hydro cooling is suitable for
melons, peaches, cherries, sweet corn, etc. Blast cooling is used for many products, e.g.
strawberries, grapes, cauliflower, etc. Cooling by broken ice, in contact with the produce,
or on top of the containers (top icing) is used mainly for lettuce, spinach, radishes, celery
and cantaloupe melons.

Storage Conditions

The containers of produce should be stowed in the chamber in such a way that a suitable
movement of air takes place between them and even through them. This is particularly
important if the produce produces much heat, e.g. asparagus, or peas.

Storage of different kinds of produce in the same room is possible if they all tolerate the
same temperature or if they do not influence each other, either by tainting or accelerating
ripening. Fats should never be stored in the same room as fruits, onions, potatoes, etc.

The principal parameters of the conditions in the cold store are the temperature of the air,
its humidity, the composition of the atmosphere, the speed of movement of the air and the
amount of ventilation, as well as the surface temperature of the evaporator. Produce may
be stored either in air, or in an atmosphere of different composition, i.e. "controlled"
(C.A.) or "modified" atmosphere.

Storage in air

The biological activity of the produce depends on its temperature, not on that of the air,
measured at a certain point in the room. The initial rate of cooling is important, and should
be as rapid as possible. The temperature of the produce should then be kept constant, any
fluctuation increasing rate of loss of water.

All fruits and vegetables do not demand the same storage temperature, the choice of which
is therefore important. Tropical or sub-tropical produce generally develops physiological
injury (internal or external browning, superficial spots, failure to ripen, all coming under
the heading of "chilling injury"), at temperature near to 0°C; the same is true for green
beans, and some cultivars of apple (see attached tables).

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Thus if one needs to keep a wide range of fruits and vegetables in a few chambers, they must be separated into suitable groups, e.g. at 0°C: apples, pears, stone fruits, grapes, berries, green beans, roots; at 7°C: oranges, mandarins, ripe pineapples, coloured tomatoes, cucumbers, green beans, papaws, avocados; at 12°C: more sensitive produce such as lemons, grapefruit, bananas, green pineapples, green tomatoes, mangoes, etc. In such cases, storage may be reasonably long, but if everything has to go into one room, say at 5°C, then it is clear that the relationship time: temperature becomes important, certain produce tolerating such a temperature for only very brief periods. The tables, which follow, give information suitable for the longest possible duration of storage. If the desired storage period is short, however, the temperature could well be moderately higher or lower, with no great undesirable effect. Short storage at 5°C to 7°C has the advantage that there is not much surface condensation on return to ordinary temperatures.

Broadly speaking, temperature and duration of storage are linked exponentially, the duration decreasing rapidly as the temperature rises from the lowest limits; thus strict attention must be paid to maintaining constant low temperatures, and sometimes to avoiding risk of freezing.

The expected or practical commercial storage life is limited by loss of quality (appearance, flavour, firmness, scent, physiological injury, and microbial attack). This storage life, which depends essentially on temperature, varies widely according to the initial stage of maturity of the produce, their freshness, and the extent of microbial infection.

It may be asked to what extent the optimum conditions of storage are fulfilled by maintaining the same temperature for the whole of the storage period. In fact, there has been considerable interest for some time in variable storage conditions, which could, in particular, be useful in avoidance of physiological injury. Examples are apples warmed to 15°C for 5 days, during storage at 0°C; Golden Delicious apples treated at 7°C before storage at 0°C; progressive cooling of bananas, etc. It is also known that, e.g., William's pears do not ripen at –1°C and that they must be ripened afterwards at 15-18°C. Finally, some Passe Crassane pears do not develop good quality at 18°C if they have not previously been kept at 0°C (at a constant temperature of 4°C they ripen perfectly).

The relative humidity of the atmosphere has an important rôle in maintaining the quality of stored produce. Too dry an atmosphere leads to rapid shrivelling; too humid will retain (or even increase) turgescence and reduce water loss, but may favour spread of microorganisms, which could be controlled by certain fungicides if these are permitted. The present tendency is to increase the humidity of the atmosphere for certain vegetables (cabbage, carrots, etc.) Such high humidity, near to saturation, may be obtained inside polyethylene bags. On the scale of a cold room, they necessitate a cold source very close indeed to the air temperature, or the use of a special "jacket" system. To reduce condensation on return to ordinary temperatures (very necessary for small fruits, for example), the temperature may be allowed to rise gradually, controlling the operation by assistance provided by psychometric tables.

In order to maintain homogeneous conditions among the packages, a suitable circulation of air should be maintained throughout the storage. The atmosphere composition is modified by the respiration of the produce, and by the release of ethylene and other volatile substances. Accidents may occur, such as brownheart of apples (excess CO₂),
fermentation (too low a concentration of oxygen), accelerated ripening (excess ethylene) or undesirable growth (in vegetables, due to ethylene). Thus ventilation with fresh air is needed.

In the special case of storage of grapes, the danger of development of the fungus *Botrytis* has led to the practice of injecting sulphur dioxide (SO\(_2\)), or of provision of a compound, such as a metabisulphite, which liberates SO\(_2\).

**Controlled (C.A.) or modified atmosphere (M.A.) storage**

Among the processes, which give a favourable effect, additive to that of low temperature, should be included C.A. storage. This consists of reduction of the concentration of oxygen and/or increase in the concentration of CO\(_2\) around the produce.

Several types of atmosphere are used, with intermediate variability:

1. The sum of the concentrations of CO\(_2\) and O\(_2\) is 21 %, as in air;
2. The sum of the two concentrations is below 21 % (e.g. 2, 4);
3. The oxygen remains very high, and CO\(_2\) is very low or absent (carrots, oranges);
4. CO\(_2\) is added, in high concentration, to air (chestnuts).

Either the concentrations are rigorously controlled and kept as constant as possible (controlled atmosphere, properly speaking), or they may be modified in a less strict fashion to provide a more favourable atmosphere ("modified atmosphere") used in transport.

The rooms used must be as gas-tight as possible, with impermeable wall finishes. Regulation of the desired atmosphere needs special equipment (chemical absorption of CO\(_2\), reduction of concentration of oxygen in a catalytic burner, selective diffusion of the gases across a plastic film diffuser, etc.).

On the small scale, C.A. storage may be obtained by utilizing the selective permeability to gases of sealed plastic bags.

Reduction of oxygen concentration slows down all oxidative metabolisms (respiration), but if carried too far risks appearance of fermentation (ethyl alcohol, acetaldehyde, etc.). It slows down the ripening of fruits, their coloration, softening, and also senescence. Increase in CO\(_2\) slows down respiration, and, with cooling, reinforces the effect of decreased oxygen concentration. The separate effects of these three factors add, in a not well-defined fashion, but one, which favours longer storage. Some produce, it must be noted, are especially intolerant, e.g. lettuce (to reduction of oxygen), oranges and lettuce (to excess CO\(_2\)), while others are very tolerant (seeds to absence of oxygen, cherries to CO\(_2\), etc.).

There are two recent modifications, favouring better storage, viz.: hypobary, or reduction of pressure, or momentary exposure to atmospheres rich in oxygen, CO\(_2\) or nitrogen, e.g. a rich oxygen atmosphere; against scald. Hypobaric storage involves both renewal of the air and the maintenance of a low pressure; the control of oxygen is easy, but it is difficult to control humidity. Favourable produce includes cabbage, avocado, strawberry, peach, and cherry.
Ripening of Fruits After Storage, and Their Shelf Life at Ordinary Temperatures
(Post-Storage Life)

Pears, plums and peaches do not ripen at 0°C; at the end of the permissible storage life, they will ripen if the temperature is sufficiently increased. The optimum temperature and the duration of the ripening depend on the length of storage at low temperature. It may be sufficient to allow the temperature to rise by a few degrees, without using extra heat; e.g. Passe Crassane pears stored at 4°C, in place of 0°C. Post storage ripening is usually useless for apples. If fruit has been harvested too early, or stored too long, additives may be required, e.g. bananas and tomatoes may need ethylene; Golden Delicious apples may need to be exposed to 50% O\textsubscript{2} plus 0.1% ethylene, at ordinary temperatures, to develop a yellow colour.

Shelf life after storage is clearly very important, but it is hardly ever mentioned in storage tables because of its extreme variability, depending on the state at harvest, conditions of storage, and state on removal from storage.

Storage Disorders

The most important disorders, apart from shrivel (too dry an atmosphere), freezing (too low a temperature), and tainting by incompatible produce, are microbial development and physiological injury.

Microbial damage may be caused by bacteria (carrots, lettuce), but it is more often due to fungi (yeast, and filamentous fungi such as *Penicillium*, *Batrytis*, *Mucor*, etc.). Infection may spread easily from damaged organ to neighbouring organs, due to abundance of spores, especially if conditions are warm and humid, and if the produce is senescent, mechanically damaged, rich in sugar, etc. Protective fungicides, such as SO\textsubscript{2} and TBZ, sodium orthophenylphenate, benomyl, exist but their use is limited by national regulations.

Physiological injury is very common. This may consist of superficial dark blemishes (scald, e.g.), sunken (pitting of citrus) or not, of internal browning (a common low temperature injury to apples), of storage flavours. Inability of fruits to ripen, or undesirable growth of celery, cauliflower, potatoes, onions, are all physiological injuries. Usually, the cause is an unfavourable temperature of storage, or too long storage at the recommended temperature. Many examples are given in the following tables. Further, other factors may lead to injury, such as absence of oxygen (fermented taste), excess of CO\textsubscript{2} (brownheart of apples), presence of ethylene (growth phenomena), presence of certain aromatic substances, humidity, etc. Injury may be induced by such factors but may not be immediately visible, e.g. scald. The several cultivars of one species may be unequally liable to injury, e.g. internal browning of apples.

How these injuries arise, closely linked to metabolic disturbances, is not yet clearly understood, despite serious work (\(\alpha\)-famesene and scald; alteration of membrane lipids by cold). But in some cases, very useful prophylactic measures may be taken: storage of certain cultivars rather than others, treatments on the plant or after harvest (scald), storage in favourable temperature and ventilation conditions, or in C.A.
In the case of very long storage, it is prudent to remove small samples of fruits or vegetables from the store at intervals and to see how they behave at ordinary temperatures. In this way one may avoid overlong storage, which is already becoming dangerous.

**Pre-packaging**

Pre-packaged fresh produce should only be stored for very short periods and thus, strictly, is outside the terms of these recommendations. However the practice of pre-packaging just before sale is growing, and it is necessary to point out that it has set problems, which are not yet completely solved. At present, it is probably safer not to use plastic containers or bags, which are completely sealed, but to have sufficient perforations in the plastic; otherwise increased losses may appear from mould attack, due to high humidity in the package, if fungicidal treatment has not been applied, or from too high concentrations of carbon dioxide and other products of metabolism. The use of box liners, for instance, for apples and pears may be useful. Concerning details appropriate authorities should be consulted.

**Conclusion**

After produce is harvested, growers must follow proper management techniques and procedures given in this document to offer a fresh and good-looking product to the wholesaler, retailer and consumer, and to get the maximum return on their investment. Proper management and handling practices require a reduction in produce temperature to maintain quality and market value.

**References**

