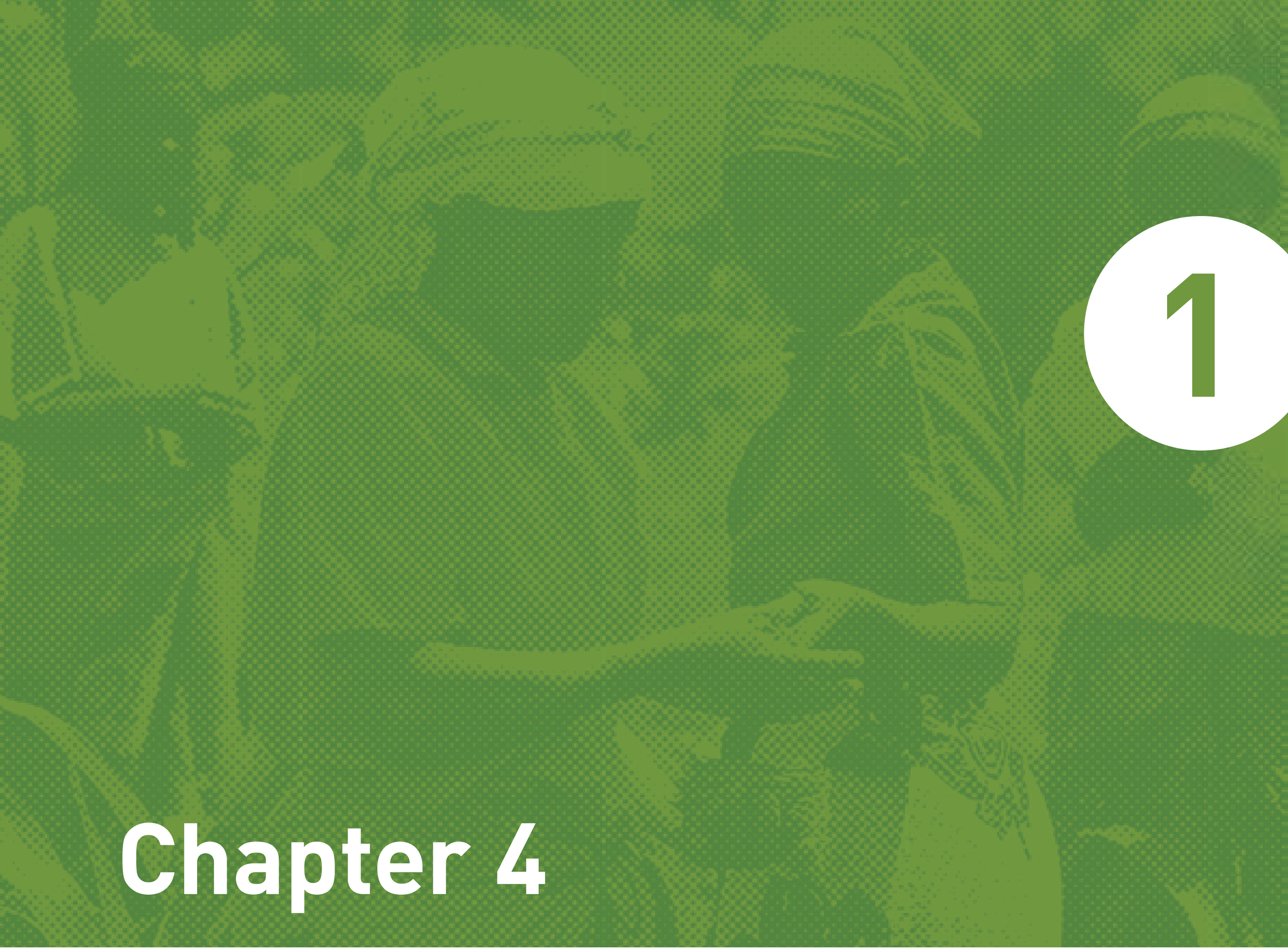


Chapter 4

Handling and preservation of fruit and vegetables

4.1. Importance of different factors for handling and preservation of fruit and vegetables

4.1.1. Objectives of handling and preservation operations

After harvest, the product's properties need to be preserved (cleanliness, appearance, freshness, absence of spots, unit weight, shine, skin colour, etc.) up until the time of consumption.

For regulatory and economic reasons:

1. **Products need to be protected during post-harvest operations**: packaging, consignment and distribution. The aim is to prevent the development of organisms that could pose a threat to consumers' health or alter the commercial quality of products. This constraint is imposed on all products and is key for being competitive in markets and conforming to food safety requirements.
2. **Products need to be stored to improve commercial management**. Storing fruit and vegetables is meant to help ensure supplies for consumers living far from production areas (export market). Products (e.g.: potatoes for human consumption) are also stored sometimes to **stagger the product's availability** to markets and thus to **support prices**.[1]

Products have to be distributed to consumption areas both during and outside of traditional harvest periods. Given the difficulty of controlling this flow of products, the use of intermediate storage is an extremely valuable tool.

This possibility is obviously **highly variable** depending on the fruit or vegetable. The **keeping quality** of each product results from a combination of two of its characteristics:

- natural preservation, which corresponds to the longevity after harvest of the vegetable's life;
- the effectiveness of appropriate techniques that can be used to slow down or prevent product deterioration.

[1] For example, for the cultivation of potatoes from seedlings imported from Sahel, all production areas plant between 15 November and the end of December. The large majority of harvests therefore take place between 15 February and the end of March. Based on average yield of 22 tonnes/hectare, huge quantities are placed on the market, which brings down prices in the main production areas (Sikasso, Fouta Djallon, etc.). By storing potatoes, market supply can be regulated and prices stabilised.

4.1.2. General principles

❒ Product spoilage

Food spoilage or rotting is understood to mean any change that causes the food to lose its desired quality and to make it unfit for consumption.

As soon as fruit and vegetables are separated from their natural source of nutritive substances, their quality starts to deteriorate. This is due to a natural process that begins when the biological cycle is interrupted by harvesting. The product is then consumable for only a limited time ranging from a few days to a few weeks, after which it starts to spoil or rot.

In spite of 'ideal' (or recognised as such) conditions for preserving fruit and vegetables, **it is impossible to avoid the ultimate perishability and limited shelf life** of fresh produce.

The following table sums up the risk of loss for certain products (*Source: FAO, based on Kader, A.A. (1993) – see in the annex below the detailed table presenting the shelf life of many products under ideal conditions):*

Relative risk of loss	Potential shelf life	Products
Very high	Less than 2 weeks	Apricot, cherry, mushrooms, spinach, fig, lettuce, green onion, ripe tomatoes
High	2 to 4 weeks	Aubergine, banana, green beans, mango, melon, nectarine, peach, sweet pepper
Moderate	4 to 8 weeks	Carrot, pomegranate, orange, grapefruit, grape
Low	8 to 16 weeks	Garlic, lemon, dry onion, pumpkin
Very low	More than 16 weeks	Seed-fruit, dry fruit and vegetables

There are **several types of deterioration**, which are reviewed below:

1. physical deterioration;
2. physiological ageing;
3. chemical and enzymatic deterioration;
4. deterioration caused by insects, rodents and pathogens;
5. mechanical damage;
6. deterioration caused by spoilage microbes.

❒ Physical, physiological, chemical and enzymatic deterioration

Physical deterioration is caused first and foremost by **dehydration**. **Physiological ageing** occurs as soon as the biological cycle is interrupted by the harvest. The physiological functions of the organ still on the plant do not stop at harvest but are considerably altered.

Chemical and enzymatic deterioration occur mainly when the fruit and vegetables are damaged upon falling or breaking, or **due to cold**. This releases enzymes that trigger chemical reactions. Tomatoes soften, for example, and other types of fruit turn brown.

Banana cells have no defence against cold. When the fruit is kept at excessively low temperatures, the cells burst and release enzymes that cause the fruit to turn brown and soften very quickly.
(Don Glass, 2008 – Moment of science).

Lychee fruit left at ambient temperature deteriorates very quickly.

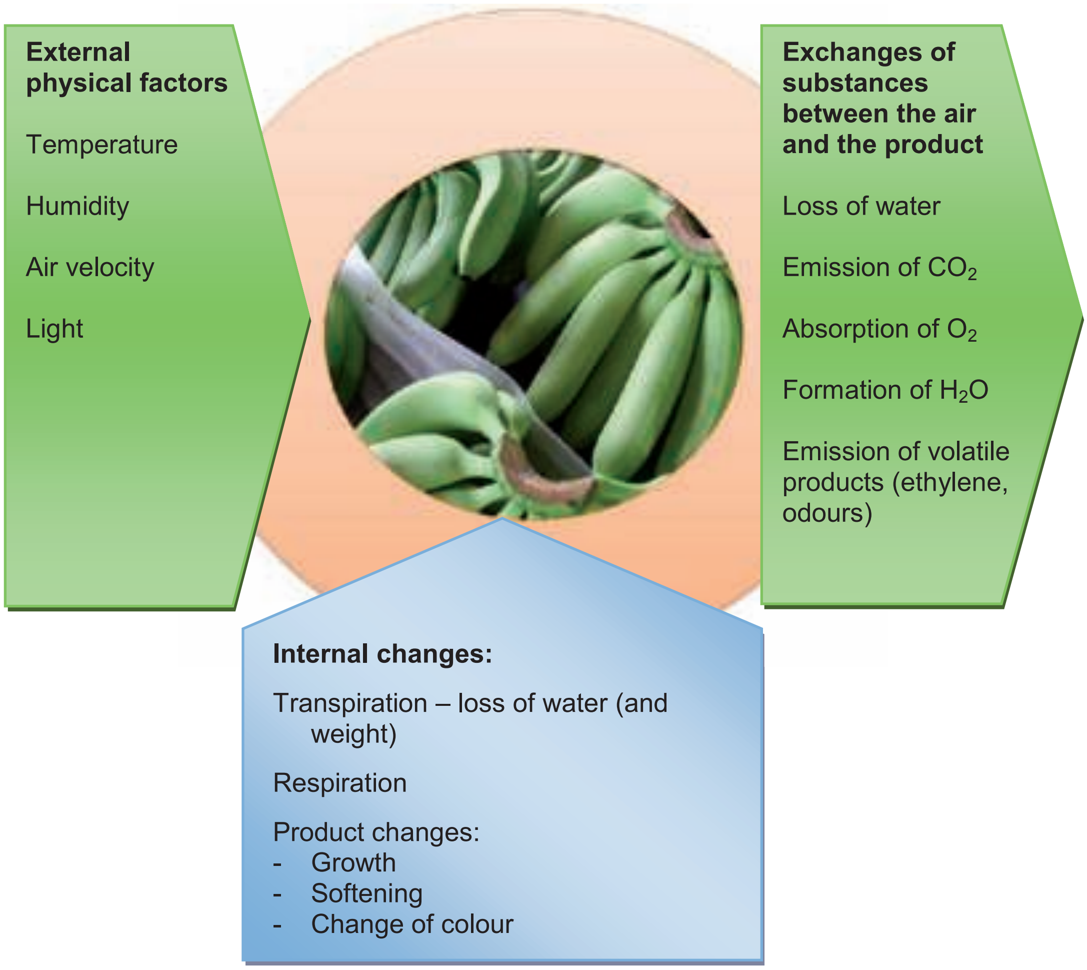
In two or three days, the shell turns brown and then dries out and becomes brittle. The loss of colour is caused by the oxidation of anthocyanic pigments. The fruit is then more likely to burst and becomes susceptible to secondary contamination from fungi.

Currently, sulphur treatment is the only product available, at an acceptable cost, that helps to preserve the colour of lychee shells during a storage period of 30 days or more (which makes export possible). Sulphur dioxide keeps the pericarp from turning brown by acting on the shell pigments and preventing enzymatic reactions. The sulphuring of fruit presents many disadvantages, however: residues, exposure of workers and so on.

Fruit can also go rancid.[2] **Insects** trigger the same process: they damage fruit and vegetables, which leads to the release of enzymes.

These processes are inevitable but can be delayed by storing agricultural products **in a dry area protected from draughts, at the lowest temperature possible**, and protecting them from pests before, during and after harvest.

The most important functions of the vegetable organs during this period are **transpiration**, **respiration** and **metabolism** of the plant tissues. The storage parameters (temperature, atmosphere, treatment and various types of protection) are chosen to act on these functions to obtain optimal stabilisation.



[2] 'Rancidity' is due to the alteration of fatty substances leading to an unpleasant change in their smell and taste (unpleasant taste upon consumption). It mainly concerns dry fruit and nuts (e.g.: cashews) rich in fats.

- **Transpiration**

Transpiration is a **loss of water through evaporation**. It depends:

- on the one hand, on the organ's morphological characteristics, in particular the structure of the epidermis and of the surface in contact with the air;
- on the other, on the **difference in temperature** between the air and the product, **humidity** and **whether the ambient air is still or in motion**.

These **water losses add up** throughout the storage period and are responsible for a significant deterioration in quality: wilting, softening, alteration of appearance, etc. So it is very important to take this into account.

% of water loss resulting in a harmful change of appearance (Source: Centre Technique Interprofessionnel des Fruits et Légumes (Fruit and Vegetable Inter-branch Technical Centre), France):

Leaf vegetables, asparagus	3 to 4 %
Fruit, fruiting vegetables	5 to 6 %
Root vegetables	7 %

Comparison between green beans kept cool (left) and green beans left exposed to heat during harvest (right). There is a pronounced difference in appearance and colour between the two boxes. The product on the right is no longer marketable (Photo B. Samb).

- **Respiration**

Respiration is a cycle of complex biochemical reactions that is manifested principally in a loss of substrate (sugars, acids) burned to supply energy to the tissues. It absorbs oxygen, emits carbon dioxide and releases heat that must be removed through cooling:

sugars + oxygen = water + carbon dioxide + heat

When respiration is reduced, shelf life is extended.

The exploitation of these biochemical phenomena in holding rooms is the basis of **controlled atmospheres**. This technique was originally developed to extend the shelf life of a number of fruit and vegetables.

Respiration is reduced by lowering the concentration of oxygen in the ambient air and by increasing carbon dioxide concentration. Between 0 and 30°C, the respiration rate increases exponentially. However, even at 0°C, vegetable respiration continues.

Level of respiration of various products:

Very low	Dates, dry fruit, cashews
Low	Citrus fruit, garlic, grapes, kiwis, onions, potatoes, sweet potatoes
Moderate	Bananas, cabbage, carrots, lettuce, mangoes, tomatoes
High	Avocadoes, cauliflower, green beans, strawberries
Very high	Brussels sprouts, green onions, certain beans
Extremely high	Asparagus, broccoli, mushrooms, peas, spinach, sweet corn

- **Product changes**

The metabolism of plant tissues is a set of chemical reactions that characterise a living organism, which are the source of the changes observed during the plant's life and that continue after harvest.

The **'maturation'** of fruit and vegetables results from a complex set of reactions and biochemical and physiological changes that accelerate their development. It leads to the state of full maturity and gives the fruit its organoleptic characteristics.

Maturation improves quality (especially texture and taste) but reduces storage time!

Maturation can be controlled by environmental factors.

Temperature, oxygen, carbon dioxide (CO_2) and ethylene are factors that influence the fruit ripening process.

Maturation is accelerated by the ethylene content of the air. This gas is emitted by the fruit and vegetables themselves.

❒ **Deterioration due to insects, rodents and pathogens**

Insects and rodents cause a great deal of damage, not only by eating away at produce, but also by transmitting micro-organisms found on their hairs or in their excrement. The damaged parts of plants are particularly sensitive to infections from bacteria or mould.

Certain plant pathogens (diseases) can cause post-harvest alteration. The skin of the fruit or vegetable usually provides natural protection against micro-organisms, but **once damaged** after being dropped or receiving a shock, the risk of deterioration increases considerably. Shocks are produced most often when fruit and vegetables are harvested without care and stacked up in piles. The appearance of rot is associated with the production of enzymes that damage the cell walls. As fruit ripens, it becomes more sensitive to shocks and infections, causing spoilage, on the one hand because its production of antifungal components declines and on the other because of damage to cell walls.

❒ **Deterioration due to production, harvest, transport and storage conditions**

Cultivation conditions are key in terms of the microbial flora present upon harvest of the product. Exposed surfaces are contaminated by soil, water, air, waste water, animals, insects, and then by contact with harvesting equipment. Pre-harvest fungal colonisation is usually the main cause of post-harvest rot.

Certain fungi can penetrate the intact cuticle of leaves, stems and fruit. Other harmful organisms penetrate the fruit through mechanically caused injuries that occur during harvest, handling and packing or through natural openings in the cuticle, and attack the internal tissues.

Post-harvest changes can take the following forms: rot due to brown, blue, pink or grey moulds; superficial growth of moulds; tissue blackening (anthracnose); sour rot; stem end rot, rot due to yeasts and other forms of rot. Spoilage is also favoured by high temperatures and high humidity after harvest.

Poor harvest and handling conditions result in product spoilage. **Harvest and transport conditions should therefore be such as to avoid accelerating the deterioration of products.** Fruit and vegetables must be handled **very gently** to avoid causing injuries that can contribute to physiological damage or the penetration of pathogens or moulds.

It is important to start with quality products for packing and preservation. The fruit or vegetable lot cannot contain damaged or diseased products. It is preferable to **sort products** as soon as they are harvested (preferably in a shady area) and before storage, to keep from introducing rotten or parasite-infested products into the storage station.

If possible, fruit and vegetable collection, transport and storage should take place at a low temperature (e.g.: for **green beans, tomatoes**, etc.). These products must be **placed in the shade** as quickly as possible.

Providing a shady spot for the harvested products cannot be improvised and does not override the need to comply with minimum hygiene standards, such as keeping products off the ground.

Well ventilated sheds that can be built at the place of harvest, using light materials, so that harvested products can be brought into the shade quickly and thus retain their freshness, are valuable assets for quality.

Sheds offer shade and limit water loss from products. To be effective, they must be placed as close as possible to fields being harvested.

Products should not remain in sheds for long periods. However, workers can perform an initial sorting of the harvest in such sheds, taking only those that can be validly processed to the packing station.

Sorting and weighing operations must be performed quickly and in a shaded area from beginning to end. It is important to observe minimum hygiene conditions during this initial sorting.

When the packing station is located at a distance from the production and harvest area, it is possible to keep the products in cool storage by building 'cold chambers' out of light materials.
Products can then be stored for several hours before transport.

This small 'storehouse' has double walls made of two rows of wire-mesh between which charcoal is stacked. The wire-mesh and the charcoal must let air pass freely. The charcoal is watered abundantly and regularly to keep it saturated. The warm air goes through the walls. As the water that trickles down the walls evaporates, the temperature drops in the shed (evaporation removes heat from the water).

This system requires availability of water at the site, but it does not use electricity.

The roof is made of straw rather than sheet metal, which is much more resistant to bad weather but offers much less insulation than straw. The straw should be kept dry to keep it from rotting.

(Photos B. Schiffers)

The **means of transport**, condition of transport material, loading method and transport and storage practices play a role in successful product conservation. The '**containers'** (bins, crates, etc.) used are also important factors. If the recommended temperature and relative humidity are not maintained, product quality will decline. The 'cold chain' must be maintained during transport of products between processing and storage areas.

*Like cold chambers, refrigerated vehicles must also be fitted with **(calibrated) temperature regulation and control systems** .*

*During loading, products should be stacked carefully to avoid crushing and to ensure **good circulation of the chilled air** (the loading capacity should not be entirely used).*

4.1.3. Storage conditions

❐ **Importance of temperature and humidity on deterioration**

Storage conditions during harvest, transport and storage have a significant impact on the quality of foods brought to market.

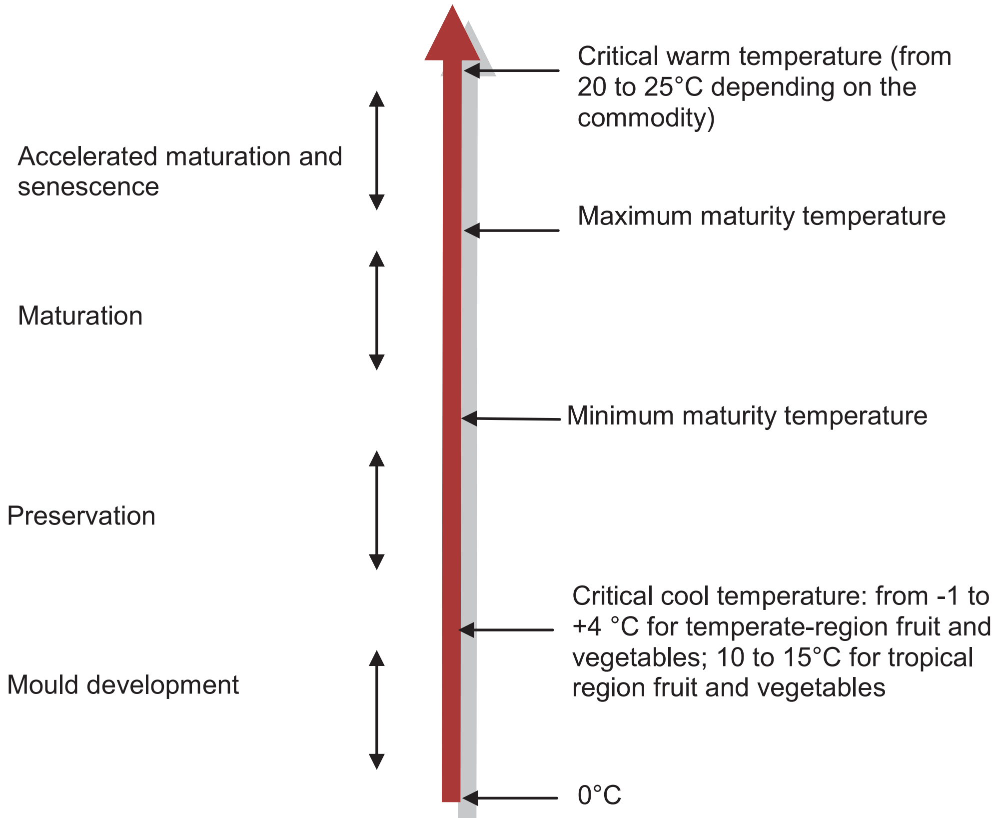
Harvest, transport and storage installations must be designed to ensure maintenance of the cold chain and to **prevent damage** resulting from:

- the heat of outside air;
- heat released from product respiration;
- the accumulation of ethylene due to product maturation;
- the loss of heat in very cold temperatures;

- excess cold due to the functioning of the refrigerating installation.

It is important for the stability of physiological and organoleptic properties **to know the optimal temperature and humidity conditions for each product**.

Temperature plays a key role in product handling and preservation:



Optimal control of temperature and relative humidity is therefore essential. However, while very high humidity (sometimes over 95 %) has to be maintained, **the 'dew point'**[3] **must not be reached,** because this could result in **condensation and dampen** the stored products, creating conditions for infections to develop. Sophisticated storage installations, which ensure precise temperature and humidity control, significantly increase the shelf life of fruit and vegetables.

Most vegetables should ideally be stored at a temperature of 0°C.
The lower the temperatures, the longer the vegetables can be stored. Low temperatures slow down the metabolic activity of vegetables. An increase in temperature also affects **products' nutritional value**. Vitamins, for instance, are not resistant to high temperatures.

[3] When humid air cools, the *dew point temperature* corresponds to the appearance of water in a liquid phase. When the dew point is reached, water in the air condenses: drops form and settle on surfaces, which appear to be wet. The dew point can be measured with a condensing hygrometer (dew-point hygrometer).

Most vegetables have a **high transpiration rate**. Plant cells are relatively impermeable but always let a certain amount of water escape **in the form of vapour**. **If the air is dry, vegetables can lose water quickly, soften, shrivel and become unmarketable**. Maintaining a high relative humidity during storage helps to keep transpiration to a minimum.

Storage at close to 100 % humidity nevertheless requires **perfect temperature uniformity** inside the warehouse. If colder areas exist, water will condense and settle on vegetables, contributing to the development of diseases.

Example of optimal storage conditions:

For optimal preservation of **green beans**:

- Maintain a temperature of between 5.0 and 7.5 °C.
- Ensure the highest possible rate of humidity (at least 95 % relative humidity within the building).
- Store the green beans in the dark, protected from moulds and attack by insects and/or rodents.

The closer the storage conditions can be kept to these optimal values, the better/longer the preservation.

❒ Importance of ventilation

Ventilation plays a major role because it helps to ensure uniform temperature and same relative humidity inside the warehouse. As stored volume increases, ventilation becomes more essential. **Air must circulate** not only around but also within the stacks of vegetables, whether they are stored in bulk or in boxes.

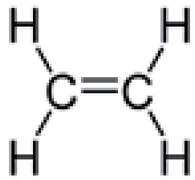
Good ventilation is needed throughout the storage period, both at the start when the temperature of the harvested products is lowered, and subsequently when the temperature has been stabilised. It should be kept in mind that, even at a low temperature, vegetables continue the respiration process and produce heat. This heat has to be removed. Proper circulation of air is also essential in conditions of high relative humidity to **avoid condensation problems**.

❒ Physiological compatibility of stored products

Products stored together must be able to tolerate the same temperature, same relative humidity and the **same level of ethylene in the storage environment**.

Products that emit a lot of ethylene (such as ripe bananas, apples and cantaloupes) **can stimulate physiological changes** in products that are sensitive to ethylene (such as lettuce, cucumbers, carrots, potatoes and sweet potatoes) and cause undesirable changes in colour, taste and texture (see in an annex to this chapter the *'Compatibility groups for storage of fruit and vegetables'*).

What role does ethylene play in the maturation and conservation of fruit and vegetables?



Ethylene (CH2 = CH2) affects virtually every aspect of plant growth and development.

Maturation and alteration in tomatoes, three weeks after the start of ripening. Left, ethylene inhibition – Right, absence of inhibition

Without ethylene *With ethylene*

Ethylene stimulates the lengthening of plant stems, leafstalks, roots and flower structures. As a general rule, ethylene delays or prevents flowering. For pineapple, however, it stimulates flowering. Producers therefore apply a treatment using products that produce ethylene for a uniform flowering of pineapples in fields.

A direct proportional relationship has been established between the rate of inhibition of ethylene production and the length of delayed fruit maturation. To avoid overly rapid maturation and withering of fruit during storage and/or transport, **it is vital to avoid an accumulation of this gas in cold storage rooms or containers!**

4.1.4. Conditions for alteration by micro-organisms

❒ **Conditions that contribute to the development of micro-organisms**[4]

There are three types of micro-organisms **that cause products to spoil**: **bacteria**, **moulds** and **yeast**.

- ***Bacteria***: bacteria develop on almost all types of fresh food that are not too acid: meat, fish, milk and vegetables.[5]

- ***Moulds***: moulds are often quite visible because they form fine filaments or a solid mass that can be easily distinguished. **They cause a pronounced change in the taste of products**. Moulds develop best at low temperatures and in an acid environment.

Certain moulds produce toxic substances (mycotoxins), especially in damp grains such as groundnuts, maize and soy, or on vegetables.

- ***Yeast***: yeast also causes food to spoil. It prefers low temperatures and acid products.

Development of these micro-organisms requires certain conditions. They cannot survive without the following elements:

1. **water** in sufficient amounts (this point will be developed below);
2. **oxygen** (except for certain 'anaerobic' micro-organisms that develop without oxygen, such as bacteria of the *Clostridium* genus);
3. an appropriate **acidity** (pH: the higher a product's acidity, the lower its pH);
4. **nutritive substances** (e.g.: sugars, proteins, fats, minerals and vitamins): micro-organisms need but rarely lack nutritive substances since they are found in all foods;
5. an appropriate **temperature.** On average, the temperature should lie between 5 and 65°C for micro-organisms to develop (the number of bacteria in a foodstuff

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4 See also chapter 3 of this handbook.

5 Sometimes the negative effects of bacteria are very clear (e.g.: sticky meat, formation of gas, rotten smell). However, food deterioration is not always obvious and the presence of certain bacteria does not necessarily result in a change in taste or appearance. Spoiled food should never be eaten in any case because there is always a risk of contamination or food poisoning (toxic waste secreted by bacteria).

can double every 15 to 20 minutes in temperature and humidity conditions close to those of the ambient air).

As we can see, there is a **connection between a product's characteristics and possible contamination by these micro-organisms**. For instance, micro-organisms cannot develop when there is very little, or no, water (this is the case for dried fruit and vegetables). Another example: the slightly higher acidity of damaged fruit contributes to the development of yeast and mould.

Most micro-organisms need oxygen. In the absence of sufficient oxygen, it is difficult for them to survive and even more difficult to reproduce. There are always a few that manage to survive, however, and as soon as the oxygen level increases, they start developing and reproducing again. Some types of micro-organisms proliferate even in an oxygen-poor environment.

❒ **Influence of cold on the development of micro-organisms**

The development of micro-organisms is also significantly **slowed at temperatures of 0 to 5°C** (in a cold chamber, for example), making it possible to store food for several days. *Listeria*, the bacteria that cause listeriosis (a serious illness), multiply at temperatures of 3 to 8°C, resulting in problems for prolonged food storage.

A contaminated product does not improve simply because it is refrigerated.

At a temperature below 0°C, **microbial development stops completely, but micro-organisms are still alive**.

They resume their activity once the temperature goes back above 0°C.

Microorganism multiplication is merely slowed or halted by cold. Therefore, a cold storage room must:

- be washed and disinfected regularly because a product carrying bacteria can contaminate the entire installation;
- not be filled too completely, to allow circulation of the chilled air;
- allow for a separation of products to avoid cross-contamination;
- be checked regularly to ensure that the internal temperature corresponds to product preservation recommendations;
- allow for each product to be stored at its ideal storage temperature.

As a general rule, fruit and vegetables must always be stored at cool temperatures (observing the temperatures recommended on the label or packaging[6]).

❒ **Influence of high temperatures on the development of micro-organisms**

One of the most widely used and most effective methods of preserving fruit and vegetables is to prepare them and place them in airtight containers that are then heated.

6 A food must never be refrozen. Any food, even a vegetable, that has been thawed and then refrozen should never be eaten (freezing temperature is -18°C).

Under the effect of the heat, the micro-organisms are gradually eliminated, but **not all at the same time**!

A high temperature kills micro-organisms and neutralises enzymes. At a temperature above 65°C, most micro-organisms have difficulty surviving. *Salmonella*, a major cause of food poisoning, is destroyed at a temperature of 65°C maintained for 15 minutes or at 80°C for 10 minutes. Any remaining spores cannot develop into bacteria and the food will be protected from all external microbial contamination. Certain micro-organisms, however, are unfortunately more heat-resistant: *Clostridium* and *Staphyloccus* can continue to multiply and damage food by producing toxic substances. *Clostridium* sometimes causes botulism and can be fatal. This bacterium has a harder time developing in acid products like fruit (pH < 4.5).

It is thus hard to achieve absolute safety, but lengthening heating time and increasing temperature help bring us closer to the goal. Techniques used to eliminate infectious organisms through heating include **pasteurisation** and **sterilisation**:

- Micro-organisms **die at boiling temperature** provided it is maintained long enough, namely around 10 minutes. If the temperature remains below 100°C, it has to be maintained longer to bring about a significant reduction in the number of micro-organisms present (e.g.: **'pasteurisation'**[7] **process**).

- Certain bacteria (*Bacillus* and *Clostridium* genera) produce a type of 'seed' known as a **spore**, **which survives at a temperature of 100°C, even after the death of the bacteria**. As soon as the temperature drops, new bacteria are formed from the spores. **To eliminate spores, they must be exposed to a temperature of at least 121°C** : this process is known as **'sterilisation'**.

❒ **Influence of the substratum on the development of micro-organisms**

As a rule, the type of product stored does not have a significant impact on the capacity of micro-organisms to colonise the substratum (because they find the elements they need in sufficient quantities).

[7] Pasteurisation is a gentle treatment that only slightly alters the taste and nutritive value of food. It neutralises enzymes and destroys most but not all bacteria, which is why pasteurised products spoil more quickly than sterilised products. To prevent spore-producing micro-organisms from multiplying, products must be stored at temperatures below 20°C. Often a large amount of sugar is added to extend the shelf life of fruit. They can then be consumed for months. The greater the amount of acid or sugar in a pasteurised product, the longer its shelf life, because the remaining micro-organisms will not be able to develop. Fruit juices must be pasteurised at temperatures of 60 to 95°C.

In the case of fruit and vegetables, however, there can be host **specificity for parasite species**: *Penicillium expansum* on apple (and other pome fruit species), *Penicillium digitatum* on lemon, *Phytophthora infestans* on potato, *Trachysphaera fructigena* on banana (photo), etc.

Fruit has natural defence mechanisms: a thick skin and natural antimicrobial substances (essential oils, anthocyanins, benzoic acid, benzaldehyde, etc.) and/or organic acids (such as malic, tartaric and citric acids) that contribute to the acidity of fruit and vegetables by maintaining pH at < 4.6. Some types of fruit, however, including bananas, melons, figs and papaya, have a high pH. A low pH and the nature of the organic acid in itself determine the development of certain micro-organisms that tolerate acidity (essentially moulds).

❒ **Influence of concentrations of oxygen and carbon dioxide on the development of micro-organisms**

Moulds are **aerobic organisms**: they need oxygen to develop. However, a number of moulds tolerate low concentrations of oxygen and/or high concentrations of carbon dioxide to different extents. The association of these two factors that tend to restrict gaseous composition in O_2 and to increase the concentration of CO_2 can have a restricting and selective effect on the development of mycotoxins.

A few species **tolerate the total absence of oxygen**. Examples include the mould *Byssochlamys nivea*, whose sporulating lesions are relatively resistant to the thermal shock of pasteurisation (leading to real risks for the preservation of fruit juices), and bacteria of the *Clostridium* (risk of botulism in case of contamination by *C. botulinum*) genus.

4.1.5. Importance of water for product preservation

Vegetables, and fruit even more so, generally have high water content (up to 85 or even 90 % water). This 'moisture' encourages the development of moulds. Their spores can germinate from a given degree of relative humidity of the ambient air resulting from evaporation of water from stored products. The mycelium then has to find 'available water' to continue its growth.

Water in a product is **more or less available**, and specialists use terms such as 'free water' and 'bound water' to express this concept. The use of drying processes is determined by these different types of water.

❒ Free water

Free water is found in the product but is not bound to the components of the fruit/vegetable (sugars, proteins and vitamins). This water behaves like pure water and consequently **evaporates easily**. This water makes the product highly perishable because it is **accessible to micro-organisms** and it contributes to the biochemical and physico-chemical reactions that are the source of physiological ageing.

❒ Bound water

Unlike free water, bound water is relatively fixed to product components through adsorption. It therefore **does not evaporate as readily**. It is also **less accessible to micro-organisms** and to biochemical and physico-chemical reactions.

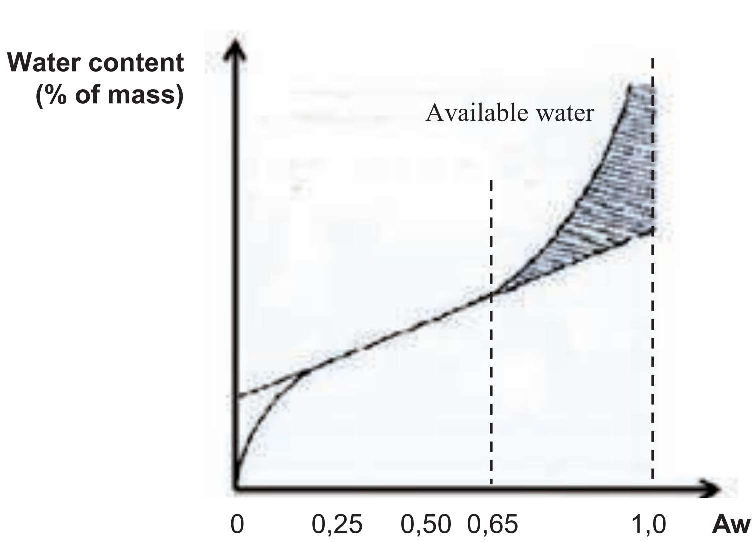
❒ Water activity (Aw)

The availability of water therefore varies in terms of the water content (%) of fruit and vegetables and their biochemical composition. It is quantified in terms of so-called '*water activity*', abbreviated as A*w*.

In very hydrated foods, such as fruit and most fresh vegetables, a very large part of water is in the form of free water (at surface level or in pockets), and another part is weakly absorbed, retained by capillary action in the fruit tissues.

'Available water' is measured by establishing a **sorption curve** for the product in question: this curve describes the relation between water activity (Aw) and the product's water content.

Example of sorption curve for a given product:



Water activity is defined in relation to a reference state, which is that of **pure water, for which water activity is equal to 1**. It corresponds to the ratio of vapour pressure of the food compared to vapour pressure of pure water at the same temperature. The value of

Aw ranges from 0 (dry product in which all water is bound to the food and thus lacks reaction qualities) to **1** (all the water is free).

Aw < 0.25	Tightly bound water, also called 'constitution' water. This water is practically not available as a solvent or reagent. It corresponds to a mono-molecular layer of water on the dry material.
0.25 < Aw < 0.65	Loosely bound water, but not very available.
Aw > 0.65	Corresponds to 'free' water or 'liquid water'. It is held only weakly on the surface of the dry substratum and is available as a solvent or reactant. This is the only form in which can water be used by micro-organisms and can allow enzymatic reactions.

It has been observed that the behaviour of fungi that infest food and can produce mycotoxins varies depending on water availability: some species have a preference for very moist environments (e.g.: *Aspergillus restrictus*), others prefer water but not to excess (e.g.: *Aspergillus flavus, A. nidulans*, etc.) and still others prefer a barely moist or even dry medium (e.g.: *Fusarium* spp., Mucorales, etc.).

At an Aw value of < 0.60 - 0.65, moulds no longer develop!

Every type of food has its own sorption curve, which explains why there are **different water content levels corresponding to maximum Aw (0.65) required for proper preservation**: for example, water content for proper preservation is around 14 g of water for 100 g of dried mango.

4.1.6. Other factors to be considered

Several other factors have to be taken into consideration in connection with product shelf life.

A food's keeping quality also depends on:

- **appropriate agronomy,** and in particular irrigation and fertilisation arrangements, which play a role in maturity and physiological state at harvest;
- the **variety of the produce**: there are large differences in the shelf life of certain varieties of vegetables (ex.: onions). Shelf life is often tied to the cultivar used and long-term keeping quality for some species can vary widely from one cultivar to the next. Some cultivars are adapted to longer-term storage, allowing transport by boat rather than by air.
- **atmospheric conditions at the time of harvest** or prior to harvest (products can absorb large quantities of water very quickly if it rains);
- the physiological state of the fruit or vegetables at harvest. **Immature vegetables** have a higher respiration rate than mature vegetables, making it important to keep only vegetables that have matured in the field for longer-term storage. The species

best suited to long storage periods, such as onions and potatoes, have a low respiration rate.

The use-by date for food must be scrupulously respected. The use-by date is the date on which a product must no longer be used for reasons of safety or effectiveness.[8] For packaged products, if the package is damaged or if the product has come out of the package, the use-by date is brought forward considerably. In all cases, the storage conditions indicated on the package must be observed. In the absence of information on storage conditions for a perishable product, it is preferable to recommend its storage at low humidity, at a sufficiently low temperature and protected from light.

8 The risk of consumption after the use-by date is variable. A risk has been clearly established for meat, poultry and eggs. In other cases, it can affect the product's taste without presenting a health hazard. However, it seems wiser to adopt a firm position and to recommend scrupulous respect for these dates, even for products like fresh fruit and vegetables which in theory present less risk in case of consumption after the use-by date.

4.2. Use of cooling to preserve certain products

4.2.1. The usefulness of cooling and of temperature limits

Fruit and vegetable respiration **releases energy** in the form of heat. The quantity or respiratory intensity of this energy varies depending on the product type and variety, its degree of ripening, extent of injuries and temperature. Furthermore, most products deteriorate quickly if **'field heat'** is not eliminated before they are loaded for transport.

The temperature of the fruit or vegetable has the greatest impact on respiratory activity. Prompt, quick and uniform cooling upon harvest, in other words elimination of field heat, is crucial to reduce respiratory intensity. Cooling slows the deterioration process and gives the product a longer shelf life. The empirical rule is that, for every hour of delayed cooling, product shelf life is reduced by one day. This rule is not valid for all crops, but it applies mainly to highly perishable crops harvested in high heat.

Lowering the temperature of the fruit or vegetable also reduces the rate of ethylene production, dehydration, the multiplication of micro-organisms and deterioration from injuries.

Longer shelf life for fruit and vegetables is basically associated with the temperature levels within which they can be stored satisfactorily:

- The **lowest temperature limit** possible is the product freezing point (not always 0°C), below which the plant cells are destroyed (and enzymes released). Since most products are vulnerable to damage caused by refrigeration, care should be taken **not to pre-cool or to store products below the recommended temperature**. Often the effects of such accidents do not appear until the retail sale stage. These include the failure to ripen normally, rot, shrivelling and discoloration of fruit and vegetables.

- The **upper limit** is less well defined and corresponds to each product's specific sensitivity to the increase in temperature, relative to the shelf-life target.

4.2.2. Why pre-cool products?

In a cold chamber, products are stored in cold premises and **cool slowly but not uniformly**, mainly under the effect of conduction and also by natural convective contact with the cooled air. Most products deteriorate quickly if field heat is not eliminated rapidly. In most cold chambers, the **temperature rises every time a new lot of warm fruit and vegetables is added**. If this warming is significant due to insufficient capacity of the refrigerating unit, the other fruit and vegetables stored in the chamber become warmer and transpire.

Pre-cooling to remove the heat is meant to bring the product as quickly as possible to recommended storage temperature and relative humidity.

Pre-cooling must take place **as soon as possible** after harvest and transport of the products to the packaging station. This operation is crucial to maintain the quality of fruit and vegetables.

Pre-cooling lengthens the product's shelf life by reducing:

- field heat;
- respiration rate (heat released by the product);
- ripening speed;
- loss of humidity (the product shrivels and wilts);
- production of ethylene (maturation gas emitted by the product);
- the spread of decomposition.

Important considerations

1. To reduce 'field heat' as far as possible, and consequently the demand for cold production to be met by the pre-cooling equipment, harvesting should take place early in the morning. Harvested products should be protected from the sun until they can be placed in refrigerated installations.
2. Refrigerating equipment is designed **to maintain the desired temperature** and should not be used to remove field heat from products packaged for shipping. Furthermore, **without a dehumidifier relative humidity cannot be raised or controlled by refrigerating equipment.**

Pre-cooling requires the use of a 'pre-cooling tunnel', but in the absence of such equipment, part of the cold chamber can be fitted out for this purpose.

- The pre-cooling tunnel:
  - Forced-air cooling is one of the methods used to extract field heat from freshly harvested products. It can be used with most fruit and vegetables. This method involves the use of **powerful fans** that suck up the refrigerated air and force it though the stacks of products to be cooled. Rapid and uniform convective-type cooling results from active circulation of the cooled air, at high speed around the warm fruit and vegetables. This process results in quick cooling to very low temperatures.
  - The installation must have **strong cooling power** and allow **intense ventilation**.
  - It is preferable for the air to be **sucked rather than blown through** the products because it is easier to prevent or limit 'short circuits' of the cooled air, in other words, to prevent it from flowing directly to the fan without going through the stored products. Air will not flow as uniformly if blown as it will if sucked through the products. With proper container design and orientation, products can be cooled quickly and uniformly whether they are contained in baskets, crates, bins or sacks.
  - A forced-air cooling tunnel uses cooled air much more efficiently than a cold chamber. Despite the additional cost involved, it is best to fit out a cold chamber reserved for forced-air cooling and to transport the cooled products to refrigerated premises where they can be stored over a longer period.
  - **With this method, however, it is hard to avoid a significant loss in product weight.**

Pre-cooling in a pre-cooling tunnel of oranges and clementines, packaged in crates, labelled and placed on disinfected pallets, before being moved to the cold storage room where they will remain until being shipped.

- Fitting out a section of the cold chamber:
  - A compromise is to **set up a forced-air cooling area** by partitioning a corner of the cold chamber using a **tarpaulin suspended from the ceiling**. This is an adaptation that consists of guiding the ambient air through the stacks of products by covering them with a detachable tarpaulin. This method helps to reduce temperature fluctuations but it should only be used as a stopgap measure.
  - The pallets are placed in such a way as to provide a central air recovery channel to imitate the effect of a pre-cooling tunnel.
  - This moveable system makes it possible to use cold chambers for rapid cooling.

More information can be found in an annex to this chapter on the cooling rate of produce by means of forced air and factors that influence this operation.

4.2.3. Role of packaging in the cold chain

Packaging also has an impact on product shelf life: it fills a large number of functions for fruit and vegetables, especially once they reach the consumer. In addition to protecting against shocks and ensuring market appeal, packaging is **a constraint for preservation but can also be a factor for improvement**.

Between harvest and packaging produce is generally placed in temporary containers such as crates, cardboard boxes and so on. In practice**, the size of these containers should be limited to take account of the release of respiratory heat**: a difference of at most 0.5°C between the different parts of these containers (e.g.: bottom and walls) is tolerable.

During distribution, packaging plays an **important role in the cold chain**. It acts as a division between lots and serves as a barrier to heat exchange, warming and cooling.

It is therefore important to provide the most stable temperature possible during transport. Changes of temperature can cause serious damage to products through **condensation** that occurs on cold packaging walls. If fruit and vegetables become wet, they are easily attacked at these temperatures by moulds and bacteria, especially in small packaging units, trays, plastic pouches, etc.

4.2.4. Transport

Many products are shipped in non-refrigerated containers or in pallets for air transport. This requires good coordination at the airports of departure and destination to protect the products, particularly when flights are delayed.

Airports must have temperature-controlled storage installations to ensure product quality. Refrigerator containers exist and should be used as often as possible. Tarpaulins can also be used to provide thermal insulation.

The **design of vehicles** for the transport of plant products must take account of the same constraints as those for premises. In practice, short-distance transport rarely has special means. At best, it assures a temperature close to that of loading temperature, which is usually sufficient.

The problem is complex for longer transport because equipment is rarely used for just one purpose and the operating scheme must be adapted case by case depending on the requirements of the lot being transported.

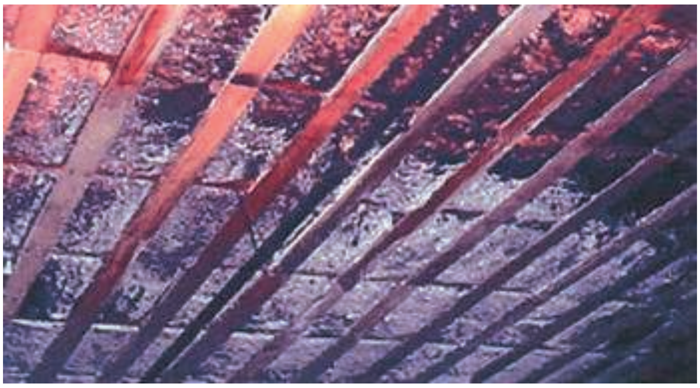
Constraints need to be analysed to ensure the best possible compromise and **surveillance is required during transport**.

4.3. Hygiene and maintenance of cold chambers

4.3.1. Cleaning and disinfecting of cold chambers

❑ **Cleaning of cold chambers**

General hygiene rules to be observed in the production chain, in fields and at the packaging station (see chapter 2) are also valid for cold chambers.



Ceiling of a refrigerator warehouse contaminated due to the accumulation of dust and condensation.

Cleaning is the first hygiene measure. It reduces the risk of development of micro-organisms that can contaminate products directly or indirectly.

Cold chambers have to be cleaned regularly (floor, gutter, walls, doors and ceiling) and be kept clean and free of all visible dirt, plant remains, filth on the floor, etc.

Waste and debris on the floor must be removed regularly during the work process. Simple **sweeping** may be enough, but vigorous scrubbing is sometimes necessary when debris attaches to the surface of walls, the floor, doors or the ceiling, or to drains and grating.

Water from condensation or from the thawing of refrigeration systems must not drip onto fruit and vegetables!

❑ **Disinfecting cold chambers**

A sanitation plan for installations is needed to **supplement daily cleaning** and to eliminate micro-organisms that can lead to rot or mould on fresh fruit and vegetables during storage or even after shipment.

Cold chambers must be disinfected **at least once a year at the start of the season**, if they are closed and the refrigeration unit has been switched off.

A **disinfectant** destroys micro-organisms present on surfaces in the cold chamber. **It is a 'biocide': it can present a risk of contamination for the food in storage. Only biocides authorised for food use are recommended.**

For effective disinfecting, **the application conditions** and **contact time necessary** must be followed. **It is important to read labels thoroughly** before using disinfectants.

Disinfection must always be performed with the area free of fresh products!

It is important to **cover electrical and metallic installations**, especially if corrosive substances are used. Special care should be taken if there is excessive contamination.

Special attention should be paid to **observing time limits** between the use of disinfectants, the ventilation of cold chambers after disinfection and the storage of new products. To ensure proper ventilation of cold chambers, doors must be opened to let outside air into the premises.

- **Rinsing**

Certain disinfectants produce smells that can give an unpleasant taste to fruit and vegetables. Furthermore, certain products can have the prolonged effect of **corroding** the materials that make up the cold chamber's structure.

To rinse, flush all surfaces treated during the disinfection abundantly with water, starting with the highest, so that residues are washed off. All standing water must be removed.

It is essential to use **potable water** to keep from recontaminating the installations.

Once the cold chambers have been cleaned, it is important to make sure that the **installations are not recontaminated** by soiled protective clothing, safety shoes, material coming directly from fields, crates, pallets, etc.

4.3.2. Maintenance and checks of cold chambers

A malfunction in the refrigeration installations can have very serious consequences on the quality of the stored products: a break in the cold chain, risk of contamination, etc.

A **maintenance and check-up programme** must be set up (see also chapter 2 on PRP programmes).

The following must be checked:

- The cleanliness of the premises and installations: walls, floor, doors, ceilings, etc.

  A product lot can be contaminated by **residues of chemicals** from products used to clean and disinfect the premises, odours from products stored previously or insects nesting in the fabric of the building.

- The impermeability of installations:
  - Check that **doors are kept closed at all times** and that entering and exits are kept to a minimum and are as brief as possible.
  - Check that **doors close completely and are totally impenetrable**: damage to walls or the ceiling can allow heat, humidity, dirt and insects to enter from the outside. To check: close the doors and have a person inside the cold chamber make sure that no light enters.
  - The impermeability of pipes in which refrigerating liquids circulate must be checked regularly. **Leaks** in these pipes can contaminate the premises and the food products.

- The temperature control system:

  Temperature probes used to check the temperature in the cold chamber must be regularly **calibrated** (check of the temperature indicated by the probe using another thermometer whose accuracy has been confirmed). The probe should be adjusted or replaced as necessary.

  Reminder: mercury thermometers are prohibited!

- Air circulation:

  If air circulation is insufficient, the lot will deteriorate.

  It is essential to **leave sufficient space between the upper row of boxes and the ceiling** to allow for sufficient air circulation underneath, around and through the stack to protect the product against problems arising from:
  - **heat from product respiration**;
  - accumulation of ethylene during to product maturation.

4.4. Techniques for preparing and preserving products

4.4.1. Preparation techniques

Fruit and vegetables to be preserved must be prepared **as soon as possible after harvest**, within 4 to 48 hours at most. The longer the delay, the greater the chance that the products will deteriorate.

❒ Cleaning and washing

It is permitted[9] and even recommended to sort and clean fruit and vegetables before packing and storage in order to remove sand, attached soil and traces of dirt.

Cleaning generally consists of washing products under running water or in a basin of clean water that is changed regularly. In the absence of potable water, clean water can be used for the first washing (to remove sand/soil).

Certain types of fruit such as cherries, strawberries and mushrooms, lettuce, green beans, cucumbers and so on should never be washed because this would contribute to the spread of micro-organisms and shorten their shelf life.

For some products like head lettuce, instead of washing, the lower leaves are removed. These leaves have been in contact with the ground and are consequently the dirtiest and the most contaminated with residues (e.g.: fungicides) because they are the oldest and already formed at the time of treatments. Removing them eliminates a large part of the residues of plant protection products.

❒ Peeling and cutting operations

Many types of fruit and vegetables are peeled prior to preservation. Peeling is easy using a stainless steel knife; this detail is very important because it prevents the discoloration of the product's flesh.

It is important to cut up products because more or less equal size pieces are needed for cooking, drying and packaging. Fruit and vegetables are generally cut up into cubes, fine slices or rings, or they can be grated. **The instruments must be sharp and clean to prevent micro-organisms from coming into contact with the food**. As soon as they have been cut up, the products lose quality due to the release of enzymes and substances that are nutritious for micro-organisms.

The loss of quality also results from the fact that the product's flesh is injured by cutting. This is why the time between peeling/cutting and the preservation process should be as short as possible.

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9 Within the regulatory meaning, these operations that do not change the product's intended use do not differ from 'primary production' and do not change requirements related to the HACCP obligation, for example.

Peeling and packaging of mini-vegetables in Kenya.

Due to extensive handling of the product, great importance has to be attached to staff hygiene and clean equipment.

The health risks presented by this type of operation are not comparable with those involved in produce washing. The organisation of HACCP to identify appropriate control measures is essential.

Knives are cleaned and disinfected during the work process by soaking them in a disinfectant solution.

(Photos B. Schiffers).

❒ Blanching operations

Blanching or 'pre-cooking' is performed by immersing the fruit or vegetables in water at 90-95°C. Products can also be exposed to steam, which softens them and eliminates enzymes, but keeps vitamins intact. Leaf vegetables lose volume and **micro-organism levels are reduced**.

Vegetables are blanched before being dried to prevent changes in colour or smell and to avoid the loss of too many vitamins. In theory, it is not necessary to blanch fruit, which does not discolour. Onions and leeks do not respond well to blanching.

4.4.2. Preservation techniques

To preserve foods, sometimes it is necessary to drastically change the environment of micro-organisms. This can involve **removing water** (drying), **increasing acidity** or **heating the products** (to kill bacteria) before storing them in airtight containers to keep oxygen from entering (preserved/tinned foods).

❒ Drying

Drying is one of the oldest preservation methods. The moisture content of agricultural products decreases to **10 to 15 %**, which **prevents micro-organisms from multiplying and neutralises enzymes**. Dehydration is generally not taken further because it would make the products crumbly. To prevent damage to dried foods, they should be stored in a dry place.

Drying is theoretically very simple. With the loss of water, products become lighter, which makes transport easier. There are two disadvantages, however: foods lose vitamins and their appearance changes.

The drying method used most widely consists of **exposing products to the air**. The air absorbs the water, and the warmer the air the more water is absorbed. For the best results, the air should be warm, dry and in movement. In a closed environment, the air must be changed regularly to keep it from becoming saturated with the moisture absorbed from the products. So it is very important to ventilate the premises well.

Relative humidity (RH) must be less than 65 %. If this is not the case, the fruit and vegetables will end up drying, but not completely. When the sun is shining, RH is generally less than 65 %, but when it is cloudy and especially when it rains, the RH is usually higher. The presence of sunshine is therefore very important! This is why products cannot be dried in this way in all seasons.

Before processing the fruit and vegetables, they are washed and possibly cut up into pieces. Sometimes they have to be prepared to protect their colour and to keep the loss of nutritive substances to a minimum. Fruit and vegetables that are to be dried must be of good quality. Rotting or damaged fruit must not be mixed in with healthy fruit. Products have to be dried as quickly as possible after harvest to keep them from losing quality.

❒ Sulphuring

Fruit is sometimes treated by **burning sulphur** and exposing it to the 'smoke' (sulphur dioxide gas) or dipping it in a sodium sulphite or bisulphite solution to prevent browning. This process is used for lychees.

These treatments protect colour, taste and vitamin C, but the sulphite residues in the product can be dangerous (at high concentrations sulphites are allergens) and can alter the product's taste.

❒ Preservation of vegetables in salt and/or vinegar

Salting is one of the oldest methods of food preservation, especially in areas where inexpensive salt is available. However, it is not used for fruit.

Salt **absorbs a large quantity of water** from food, making it hard for micro-organisms to survive. Use of a large quantity of salt is detrimental to the flavour of foods. To avoid this problem, the foods can be rinsed or soaked in water before being eaten. This reduces their nutritional value, however, which is why this technique should be reserved for cases where there is a surplus of fresh vegetables and no other method is possible.

The use of salt in small quantities is not sufficient in itself to prevent bacterial growth, but it encourages the development of certain bacteria that produce acid and limit the growth of other bacteria. Sauerkraut, for example, is made in this way. It has high nutritive value.

Another method for preserving vegetables is to add vinegar or acetic acid. This method is used for vegetables like cabbage, beets, onions and cucumbers and for fruit, including lemons and olives. The product must be salted and heated before being immersed in vinegar for storage. The vinegar must have a minimum concentration of 4 % (its pH must be less than 3.5 and should be checked with litmus paper).

Appendices

A.1. Recommended temperature and relative humidity for certain fruit and vegetables

Sources: Cited on the FAO site.

- *McGregor, B. M. (1989). Tropical Products Transport Handbook. USDA Office of Transportation. Agricultural Handbook 668.*
- *Kader, A.A. (1993). Postharvest Handling. In: Preece, J.E. and Rend, P.E., The Biology of Horticulture - An Introductory Textbook. New York: John Wiley & Sons. pp. 353-377*

Product	Temperature (°C)	RH (%)	Approximate storage life
apricots	0	90-95	1-3 weeks
garlic	0	65-70	6-7 months
pineapples	7-13	85-90	2-4 weeks
artichokes, globe	0	95-100	2-3 weeks
asparagus	0-2	95-100	2-3 weeks
aubergines	12	90-95	1 week
avocados	4.5-13	85-90	2-8 weeks
bananas (green)	13-14	90-95	1-4 weeks
chard	0	95-100	10-14 days
boniato (sweet potato)	13-14	85-90	4-5 months
broccoli	0	95-100	10-14 days
cantaloupes (¾-slip)	2-5	95	15 days
cantaloupes (full-slip)	0-2	95	5-14 days
carambola	9-10	85-90	3-4 weeks
carrots, bunched	0	95-100	2 weeks
carrots, mature	0	98-100	7-9 months
carrots, immature	0	98-100	4-6 weeks
celery	0	98-100	2-3 months
celeriac	0	97-99	6-8 months
cherries, sour	0	90-95	3-7 days
cherries, sweet	-1	90-95	2-3 weeks
mushrooms	0	95	3-4 days
cabbage (early maturing)	0	98-100	3-6 weeks
cabbage (late)	0	98-100	5-6 weeks
cauliflower	0	95-98	3-4 weeks
lemons	10-13	85-90	1-6 months
pumpkins (winter squash)	10-13	50-70	2-3 months
clementines	4	90-95	2-4 weeks

cucumbers	10-13	95	10-14 days
taro root/dasheen	7-10	85-90	4-5 months
dates	0	75	6-12 months
endive	2-3	95-98	2-4 weeks
spinach	0	95-100	10-14 days
figs, fresh	0	85-90	7-10 days
strawberries	0	90-95	5-7 days
winged bean	10	90	4 weeks
ginger	13	65	6 months
pomegranates	5	90-95	2-3 months
green beans	4-7	95	7-10 days
yams	16	70-80	6-7 months
jicama	13-16	65-70	1-2 months
lettuce	0	95-100	2-3 weeks
greens, leafy	0	95-100	10-14 days
limes	9-10	85-90	6-8 weeks
lychees	1.5	90-95	3-5 weeks
corn, sweet	0	95-98	5-8 days
mandarins	4	90-95	2-4 weeks
mangoes	13	85-90	2-3 weeks
Yucca root	0-5	85-90	1-2 months
melons (Casaba, Crenshaw, Honeydew, Persian)	7	90-95	2-3 weeks
turnips	0	95	4-5 months
nectarines	0	90-95	2-4 weeks
coconut	0-1.5	80-85	1-2 months
olives, fresh	5-10	85-90	4-6 weeks
onions, dry	0	65-70	1-8 months
onions, green	0	95-100	3-4 weeks
blood oranges	4-7	90-95	3-8 weeks
oranges (CA, AZ)	3-9	85-90	3-8 weeks
oranges (TX, FL)	0	85-90	8-12 weeks
oranges Jaffa	8-10	85-90	8-12 weeks
grapefruit	15	85-90	6-8 weeks
papayas	7	85-90	1-3 weeks
watermelons	10-15	90	2-3 weeks
squash, summer	5-10	95	1-2 weeks
sweet potatoes	13-15	85-90	4-7 months
parsley	0	95-100	2 months
peaches	0	90-95	2-4 weeks
pepinos (cucumbers)	4	85-90	1 months
peppers, dry	10	60-70	6 months
leeks	0	95-100	2-3 months
pears	-1.5-0.5	90-95	2-7 months
peppers, sweet	7-13	90-95	2-3 weeks
apples	-1-4	90-95	1-12 months
potatoes, early crop	15	90-95	10-14 days

potatoes, late crop	13	90-95	5-10 months
pumpkins	10	50-70	2-3 months
plums and prunes	0	90-95	2-5 weeks
radishes/daikon	0	95-100	1-4 months
horseradish	- 1-0	98-100	10-12 months
grapes, vinifera	- 1	90-95	1-6 months
rhubarb	0	95-100	2-4 weeks
tomatoes, mature-green	8-22	90-95	1-3 weeks
tomatoes, firm-ripe	3-15	90-95	4-7 days

A.2. Compatibility groups for storage of fruit and vegetables

Source: McGregor, B.M. 1989. Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668. Cited on the FAO site.

Group 1: Low temperature (0 to 2°C), high RH (90-95 %), can produce ethylene

apricots cherries mushrooms figs (not with apples) strawberries raspberries pomegranates persimmons lychees turnips nectarines	coconuts oranges (Florida, Texas) peaches apples leeks pears plums radishes horseradish grapes (without sulphur dioxide)

Group 2: low temperature (0 à 2°C), high RH (90-95 %), can be sensitive to ethylene

artichokes asparagus bok choy broccoli carrots mushrooms celery cauliflower endive/escarole spinach kiwifruit	lettuce leafy greens sweet corn turnips (without leaves) parsley peas leeks (not with figs or grapes) onions, green (not with figs, grapes, rhubarb or corn) radishes rhubarb

Group 3: Low temperature (0 to 2°C), lower RH (65-70 %), humidity damages these products

garlic
onions, dry

Group 4: 5°C, 90-95 % RH

cantaloupes lemons clementines lychees mandarin	yucca root oranges (California, Arizona) pepino tangelos

Group 5: 10°C, 85-90 %, sensitive to chilling injury, can be sensitive to ethylene

aubergine cucumber squash, summer okra beans green beans kiwano malanga	olives paprika peppers, hot peppers, sweet potatoes, storage taro root/dasheen

Group 6: 13-15°C, 85-90 % RH, sensitive to chilling injury, can produce ethylene

pineapples avocadoes bananas boniato carambola squash, winter feijoa ginger limes	mangosteen mangoes melons grapefruit papayas plantain potatoes, new tomatoes, ripe

Group 7: 18-21°C, 85-90 % RR, sensitive to chilling injury, produce ethylene

tomatoes, mature green
pears (for ripening)

Group 8: 18-21°C, 85-90 % RH, sensitive to chilling injury, sensitive to ethylene

yams
jicama
watermelon
sweet potatoes

A.3. Product 'cooling times'

Source: Hugh W. Fraser (1998). Tunnel Forced-Air Coolers for Fresh Fruits & Vegetables. Factsheet. Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada (http://www.omafra.gov.on.ca/english/engineer/facts/98-031.htm).

All fruit and vegetables cool quickly at first, then more slowly. The rate of cooling by means of forced air depends on several factors:

- density of produce in the container (the less dense the produce pile, the faster the cooling);
- container type, orientation and venting characteristics (if air passes uniformly and evenly around the produce, cooling is faster);
- volume to surface area of produce; the lower the ratio, the faster the cooling (cherries cool more quickly than melons);
- travel distance of the cooling air (the shorter the distance, the faster the cooling of the overall pile);
- airflow capacity (the higher the airflow, the faster the cooling).

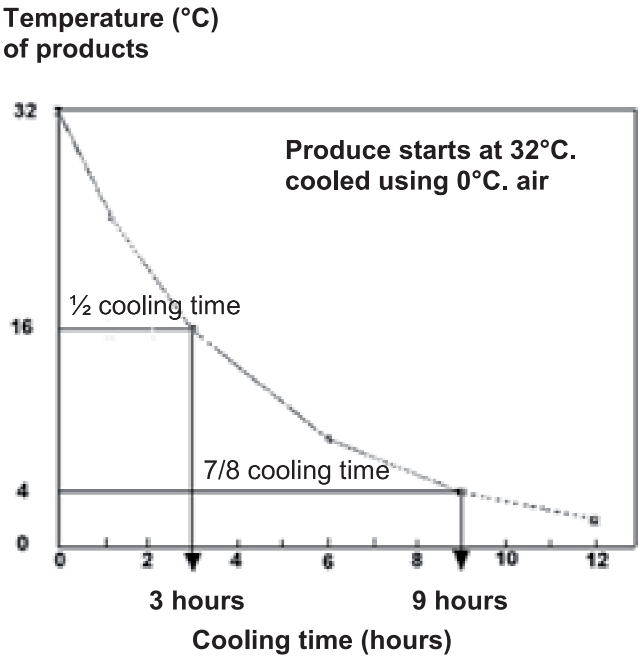
The relative humidity of the cooling air has little impact on moisture loss if it is above 85 % and if the cooling period is less than one to two hours.

Regardless of the temperature of the cooling air or the starting temperature of the produce, the shape of the cooling curve remains the same, provided that all the other factors listed above are kept constant. Only the rate of cooling changes.

The expression '7/8 cooling time' is a standard industry term that describes the time needed to remove seven-eighths (87.5 %) of the temperature difference between the starting produce temperature and the temperature of the cooling medium (refrigerated air, in the case of forced-air cooling).

This is a convenient method for indicating when produce has come as close as possible in practical terms to the temperature of the cooling medium.

The 7/8 cooling time is measured from the time the produce is first placed in the cooling tunnel. For example, with the air at 0°C, if it takes nine hours to lower the temperature of a peach from 32°C on its arrival to 4°C, 7/8 cooling time is nine hours. In other words, the temperature difference between the produce and the cooling air, which was 32°C, has been reduced by 28°C. The 7/8 cooling time is theoretically three times as long as the 1/2 cooling time. As a result, the same peach that took nine hours to cool to 4°C would take only three hours to cool to 16°C, the temperature at 1/2 cooling time, all other things remaining equal. In practice, 7/8 cooling time does not often correspond to three time the 1/2 cooling time because conditions rarely remain exactly the same over the forced-air cooling period.



Sometimes the time a product will take to reach 7/8 cooling can be estimated if other cooling times are known. The table below lists cooling time relationships.

Factors used to calculate 7/8 cooling time	
If you know ...	**... multiply by the following to estimate 7/8 cooling time**
1/4 cooling time	7.5
3/8 cooling time	4.5
1/2 cooling time	3.0
3/4 cooling time	1.5

For some crops, it might not be necessary to operate the forced-air cooler at temperatures as low as the optimum holding temperature for the products. For example, some produce can be cooled with forced air to 5° C, then slowly room-cooled in an adjacent cold chamber. This compromise could eliminate the need for a refrigeration defrosting system in the forced-air cooling room.

Most fruit and vegetables can be forced-air cooled but the 7/8 cooling time should be shorter for some products with the following characteristics :

- have high respiration rates at harvest;
- lose moisture easily (berries, leaf vegetables);
- are quite ripe, such as tree-ripened peaches;
- are to be shipped to distant markets.

A.4. Drying methods source

Drying in the open air is called natural drying. We speak of artificial drying when the air is first heated to decrease the relative humidity to a desired level. Both methods are described below.

❒ Natural drying

Drying in the open air is a simple and inexpensive process. It does not require any costly energy, just sunlight and wind. The product to be dried is placed in thin layers on trays (see Figure 6) or black plastic and exposed to direct sunlight. The trays are usually made of wood, and lined with plastic or galvanized nets. The trays should be placed one metre above the ground on stands set on a flat surface. This way no dirt can come in contact with the food from below and the food can receive maximum sun exposure. If necessary, the trays can be covered to protect the food from rain, dust, birds, insects and other pests. Mosquito netting probably offers the best protection from pests. To ensure that the fruits or vegetables dry uniformly, it is best to turn them regularly or at least to shake the trays. This does not apply to tomatoes, peaches or apricots, which are cut in half and arranged in a single layer on the trays.

Fruit dries very well in the sun, but some products are damaged by exposure to direct sunlight and are therefore dried preferably in a shady spot. Beans and (red) peppers, for example, are bunched and hung up under some type of shelter. Of course, drying these products takes more time.

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In areas with a high chance of rain, it is advisable to have an artificial dryer that can be used when it is raining or when the RH is too high. This will prevent interruption in the drying process and thus also a loss of food quality. In the event of rain, the (moveable) trays should be covered with plastic or placed under a shelter. Afterwards, they should be returned as soon as possible to the drying spot. It takes about two to four days to dry tropical vegetables.

❒ Artificial drying

The temperature of outside air often needs to be increased by just a few degrees to make drying possible. The product releases water faster at higher temperatures.

The air can be heated with solar energy or by burning natural or fossil fuels.
The **maximum drying temperature** is important because above this temperature the quality of the dried product decreases quickly. Another reason for not drying at very high temperatures is that the product then dries quickly on the outside, but remains moist on the inside.

Personal notes