AN INTRODUCTION TO
THE CHILLING OF
FOOD PRODUCTS

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Chapter 1: Getting Started

1.1 Introduction

Welcome to “An Introduction to the Chilling of Food Products”.

Once we have looked at the learning objectives for this course, you will be introduced to the basic concepts of food chilling and see what differentiates it from freezing.

In the remainder of this brief chapter, we will examine the reasons for chilling food, ways to chill food, and finally what constitutes actual chilled storage conditions.

The following chapters will provide details about various aspects of the chilling process and the effects on food products.

1.2 Learning Objectives

After completing the “Introduction to the Chilling of Food Products”, you will:

- Be able to explain the reasons why food is chilled and how this can be accomplished.

- Be able to describe the effects of chilling on the growth rate of microorganisms which are present in food products.

- Be able to define the difference between perishable, semi-perishable, and shelf-stable foods.

- Be able to cite examples of how different food materials should be stored.

- Be able to estimate the approximate shelf-life under chilled storage conditions compared to un-chilled conditions based on a knowledge of the dependence of different mechanisms of food quality loss on temperature.

- Be able to estimate the amount of heat that must be removed from warm food products to chill them to a desired temperature.

- Be able to discuss the respiration of various food products and describe the impact of chilling on the respiration process.
• Be able to summarize the role of humidity in chilled storage as it relates to product quality.

1.3 What is “Chilling”? 

There is really no precise definition for the “chilling” of foods. Basically, we can look at it as simply reducing the temperature to any point below ambient conditions. However, there is a tendency to think of chilling as reducing the temperature of a product to 15°C, or less, while not allowing it to go below the freezing point of the product, or of pure water (i.e., 0°C).

Within this temperature range, we have what is generally considered to be what we call “refrigeration temperature” at 4°C.

Mild chilling may be done at a storage temperature below 10°C. The 15°C temperature mentioned previously is recognized by some as being mild chilling.

It should be noted that the presence of sugars and other compounds in fruits and vegetables may reduce their freezing points to slightly below that of pure water (i.e., 0°C).

In some cases, chilling may be extended below 0°C if sufficient dissolved solids are present to prevent the onset of freezing of water present in the product. These chilled temperatures may be as low as -4°C, but they are dependent on the actual food being considered.

For example purposes, we can look at the freezing point of the following foods:

- Apples: Freeze at about -1.1°C
- Green peas: Freeze at about -0.6°C
- Leafy greens: Freeze at about -0.3°C
- Most fish: Freeze at about -2.2°C.

Therefore, to simplify matters, we will look at “chilling” as the reduction of the temperature of a product to a point between the freezing point of water (i.e., 0°C) and 15°C.

1.4 How Does Chilling Differ from Freezing?

Since chilling is done at temperatures above the freezing point of water, there is no opportunity for any water present in the food to actually freeze.

This means that any water present in the food has not undergone a change in state from its liquid form to the crystalline solid form we call “ice”.

Because the water is present as a liquid in chilled foods, there is no significant difference between the food in its chilled state and the way it was prior to chilling. You may want to think about what happens when foods are dried to remove moisture which can aid in spoilage; or when food is heated and canned, which destroys microorganisms and cooks the food.

With chilling, there are no drastic changes in the food itself which may lead us to consider “chilling” as being a method of handling food as opposed to a method of processing it.
For those who are familiar with "freezing" as a method of processing and preserving food, you will be familiar with the formation of ice crystals within the product, and the effects that they can have on the overall food quality. In chilling, there are no ice crystals to rupture membranes of the cells within the food. Nor is there the problem of ice crystal growth that robs the cells of moisture causing them to shrink and create a phenomenon called "freezer burn".

1.5 Why Do We Chill Food?

The purpose of chilling various foods is to extend their usable shelf-life. "Shelf-life" is a term we use to describe how long a product will keep its level of acceptable quality and be suitable for consumption. Products with a short shelf-life will need to be consumed very soon after they are harvested, or else they will spoil and be unsuitable for eating. This would be true for leafy vegetables such as lettuce. Grains, such as wheat or rice, have a much longer shelf-life and will retain their quality long after they are harvested.

For some products, the duration of the extra shelf-life may be only a few days compared to the same product stored at room temperature. However, these few extra days can be important to food distributors who will experience less waste or will be able to expand their distribution network if refrigerated or chilled storage conditions are employed.

For other products, the storage life may be extended by a week or more. This is the case with many dairy products such as milk or cheeses, etc.

The exact time frame is dependent upon the material and the conditions within the chilled storage area. As we will see, there is more to chilling than simply lowering the temperature.

Chilling works by slowing the rate of chemical reactions which lead to deterioration of foods. It also slows the growth of microorganisms which lead to spoilage. Some fruits and vegetables contain enzymes which are biological catalysts that increase the rate of degradation at the molecular or cellular level through such things as changes in colour as seen when white cauliflower turns brown or black with time.

By slowing these degradative processes quality is maintained for longer than it normally would be if the foods were left at room temperature.

It should be mentioned that not all foods need to be refrigerated and that some should not be subjected to reduced temperatures since their quality may suffer. An example of this is bread, which we will examine later.

Perishable and semi-perishable foods are of particular interest when it comes to chilling as a means of extending shelf-life and maintaining quality.

While shelf-life extension is the main reason for chilling foods, it is not the only reason.

Chilling may be required to create special conditions to bring about desired changes in a food process. An example of this would be in the churning of butter or the making of margarine where it is necessary to produce an emulsion of water droplets in an oil.
Chilling also helps prevent the loss of flavours and aromatic compounds from foods by reducing the rate at which they evaporate and leave the food. You may have noticed if something is cold and is heated that it will give off more aroma. While this may be pleasant to the consumer, we do not want to lose these “volatile” components before the product is being used.

1.6 How Do We Chill Food?

Fruits, vegetables, meats, and other foods can be chilled by exposing them to cold air in an enclosed space. Typically, the air is cooled by passing it over refrigeration coils through which a cold liquid or gaseous refrigerant is passing.

It is important to have as much contact as possible between the cold air and the surface of the material being chilled. A sufficient air velocity is also required to sweep away any stagnant air along the surface which can form a barrier to the effective transfer of heat from the warm food to the cold air.

We will examine the actual cooling mechanism in more detail later.

1.7 Perishability

There are three general classifications under which we can put most foods. These relate to how fast they deteriorate under various conditions of storage.

Perishable foods tend to spoil quite rapidly at room temperature and will maintain their quality for about 2 to 30 days if stored under refrigerated conditions of 0°C to 4°C. Foods included in this category are: fluid milk products, fresh meat, fish, poultry, fresh fruits and vegetables, fruit and vegetable juices, and various bakery items as well as some processed dairy products.

Semi-perishable foods do not spoil as rapidly as perishable foods, as their name implies. It is not unreasonable to expect them to have a shelf-life of 30 to 90 days when stored under proper conditions. Such conditions often involve being chilled (or refrigerated) at temperatures from 0°C to 4°C. It may also be necessary to process foods by methods such as pasteurization, pickling, or smoking to change them from being perishable to semi-perishable. The use of salt, sugar, and other food additives may inhibit the growth of microorganisms for sufficient periods of time to make them semi-perishable. Cured meats, various pickled foods, cheeses, processed salads, and a number of fruits and vegetables are examples of semi-perishable foods. Eggs are also considered as being semi-perishable.

Shelf-stable foods may last anywhere from 90 days to several years without showing signs of spoilage and quality deterioration. Even though they may seem to be non-perishable, this is definitely not the case, since all foods will deteriorate over a prolonged time period. Dried cereal grains, nuts, pasta, and other foods will have a significantly long shelf-life due to the removal of water which is necessary for microbial growth and most deteriorative reactions. Canned foods which have been thermally processed are considered as being shelf-stable since heating has reduced or eliminated the presence of spoilage microorganisms. Vacuum
packaging may accomplish the same objective.

Chilling is not really a viable way of achieving shelf-stability with most foods. In order to accomplish this, freezing to temperatures of below -18°C is generally required. Even then, there are many foods which may spoil under these conditions (e.g., baked goods, fatty meats and fish, etc.).
Chapter 2: Effects of Chilling on Microbial Growth

2.1 Introduction

Chilling is a reasonably simple and straight-forward concept to visualize. It has been applied for centuries when natural environmental conditions have made it possible.

High latitudes (i.e., north and south of the Equator towards the poles) and high elevations (e.g., mountainous regions with snowfall) are areas where it is possible to store surplus foods in low temperature surroundings for portions of the year.

Fortunately, scientific developments have made it possible to create chilled storage conditions using modern refrigeration techniques designed for various applications. Refrigeration has now brought the ability to chill foods to all areas of the world where sufficient power is available to operate these devices.

2.2 Storage Temperatures

Figure 2-1 shows a thermometer representing various temperatures and ranges typically encountered in food processing and handling plus several other important reference temperatures.

Normal human body temperatures tend to be around 37°C. This also happens to be the temperature at which many microorganisms grow best.

20°C or slightly higher is frequently considered as being "ambient" temperature or the naturally occurring temperature in the environment or in the food processing area.

The freezing point of pure water (i.e., 0°C) is also included in Figure 2-1 as both a reference temperature, and what we are regarding as the lower end of the chilled temperature range.

As seen in this figure, there is a range of chilled temperatures progressing from mild chilling (10°C down to 4°C) through the refrigeration temperature range of 4°C down to 0°C, and on through the lower chilled temperature range which goes to -4°C.

Below -4°C, we see that the product begins to freeze in a series of ranges from partial freezing (-5°C down to -8°C) to totally frozen below -10°C. When subjected to temperatures below -18°C, the material is considered to be in a deep frozen storage state.
Temperature | Comments
---|---
+37°C | Physiological (body) temperature
+20°C | Considered as ambient temperature for many environments
+10°C | Mild chilling occurs from 4°C to 10°C (some may say to 15°C)
+4°C | Refrigerated storage (between 0°C and +4°C)
0°C | Freezing point of pure water
-4°C | Lower chilled temperatures may go as low as -4°C
-5°C | Partial freezing range goes from about -5°C to -8°C
-8°C | Below -10°C food is considered totally frozen
-10°C | Below -18°C is considered as being deep frozen storage
-18°C | 

Figure 2-1: Temperature ranges encountered during food processing and handling
2.3 Temperature Limits for Growth

Now that we have examined the temperatures and ranges for chilling and freezing, let’s have a look at the temperatures which are at the lower end of the growth range for a number of food-borne microorganisms that cause spoilage and illnesses. These are shown in Figure 2-2.

Most microorganisms tend to grow well at ambient to physiological temperatures which are in the range of 20°C to 37°C. However, they can also grow above and below this range. For this reason, the temperature range from 10°C to 45°C is often referred to as the “Danger Zone”. When food products are within this temperature range they are highly susceptible to microbial growth.

![Diagram of temperature limits for microorganisms](chart.png)

Based on:
Table 1-4, page 6

Figure 2-2: Lower temperatures for the growth of various microorganisms
It is rather surprising to see that Campylobacter species do not usually grow below a temperature of about 32°C. This should not lull you into a false sense of security, however. Just because the temperature is too low to support the growth of a microorganism does not mean that it is not still present in a dormant state. Once the temperature increases to a value above its lower growth limit, the microorganism may begin to grow once again. This is what often happens in the case of chicken which has been chilled but is then improperly cooked. When the chicken is eaten, the dormant Campylobacter cells find themselves in a person’s digestive tract at 37°C where they grow and may cause a serious sickness.

*Clostridium botulinum* is the microorganism of interest when dealing with vegetables for canning etc. Proteolytic strains of *C. botulinum* and *Clostridium perfringens* tend not to grow below a temperature of about 12°C. In contrast, non-proteolytic strains of *C. botulinum* can grow to temperatures as low as 3°C which is well within the range of chilled temperatures and slightly below the commonly used refrigeration temperature of 4°C. There are other microorganisms which may also grow under chilled conditions, as shown in Figure 2-2. These include *Staphylococcus aureus*, *Escherichia coli*, various Salmonella species, *Bacillus cereus*, and lactic acid bacteria. While lactic acid bacteria may be beneficial in the fermentation of milk-based products, many of the others in this list are pathogenic (i.e., capable of causing illnesses, or even death).

Continuing to look at Figure 2.2, we can see that there are even microorganisms which are capable of growth at or below the freezing point of water. Not only does this show us the adaptability of microorganisms in being able to grow under difficult conditions, but it tells us that chilling alone is not sufficient to protect us from microbial growth in food products. We absolutely must use chilling in conjunction with other approaches to maintain safety and quality in the foods we eat. Most important among these is ensuring cleanliness at all steps of the food chain.

### 2.4 Effects of Temperature on Microbial Growth

#### 2.4.1 Phases of Growth

We have already stated that lower temperatures slow the growth rate of microorganisms. Now, we will take a look at this in somewhat more detail.

Those who have taken a course in microbiology may be familiar with the typical patterns exhibited by yeasts and bacteria etc. as they grow under ideal conditions in a fermentation process.

Figure 2-3 shows the growth behaviour of microorganisms when they are at suitable temperature with an adequate supply of nutrients. This is the red (upper) curve in Figure 2-3.

When microorganisms are first introduced into their new environment (at time t₀), it takes them a period of time to adjust to their new surroundings. This is when they begin to produce enzymes to break down starches if they find themselves faced with starch as a food supply. As a result, there is only a slight change in the actual number of microorganisms present since there is little or no growth during this “lag stage”.

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Once the microorganisms have adjusted to their new environment, they begin to increase in number by utilizing the available nutrients. Notice how the microbial population is growing logarithmically during this period of time which is referred to as the "log phase".

Eventually, the microbial population will reach a point where it has consumed most of the available nutrients that are present. Growth will begin to slow and the cell population will level off as we reach the "stationary phase" of the growth pattern. In some cases, the stationary growth phase may begin due to the production of by-products formed by the microbial cells as they grow. These by-products, such as alcohol, may inhibit further growth once they reach a threshold concentration.

If everything in the fermentation process described by the red/upper curve in Figure 2-3 is kept constant, except for the temperature which is being lowered to below 10°C, we will see a pronounced change in the growth pattern of the microorganism. This is shown by the blue/lower curve in Figure 2-3.

The initial population of cells will start out as being identical to the more "ideal" fermentation at the higher temperature. As the "lag phase" begins, the cells are slower to adjust to their new environment due to the reduced temperature. As a result, the lag phase lasts significantly longer under chilled conditions than it did when the system was warmer.
Once the microorganisms begin to pull out of the lag phase and enter into the logarithmic or "log" phase, their overall rate of growth is still much slower than it was at higher temperatures.

One of the objectives of chilling, or refrigeration, is to maintain storage conditions with a temperature low enough to keep any microorganisms present in a food product in their "lag phase" and prevent them from entering their "log phase" of growth. While this may not always be possible, lowering the temperature will reduce the rate of growth in the event that the microbial cells do adjust to their new surroundings and begin their log phase of growth.

2.4.2 Q_{10} Values in Microbial Growth

In the late 1800's, a famous physical chemist named van’t Hoff studied the relationships between the rates at which chemical reactions proceeded at the temperatures at which they were taking place. He developed the "van’t Hoff Equation" which was published in 1884. In 1889, another physical chemist, Arrhenius expanded on this work and put forth the "Arrhenius Equation". We will not go into any great detail about this here.

A major outcome of the work of van’t Hoff and Arrhenius was that the rates of many chemical reactions doubled when the temperature was increased by ten degrees on the Celsius scale. For example, if the rate at which a reaction takes place between two chemicals at 10°C is measured and compared to the rate for the same chemical reaction at 20°C, it will be found that the rate at the higher temperature is approximately double that at the lower temperature.

A similar trend has been observed in the growth of microorganisms, which is really just a series of chemical reactions within living cells.

The ratio of the growth rate of microorganisms at one temperature to the growth of the same microorganism at a temperature ten Celsius degrees (i.e., 10 C°) lower is defined as being its Q_{10} value.

Putting this into an equation format:

\[
Q_{10} = \frac{\text{rate of growth at } T + 10 \text{ C}°}{\text{rate of growth at temperature } T}
\]

For example purposes, let's consider a microorganism with a Q_{10} value of 2.0. This means that if the temperature rises by ten Celsius degrees within the acceptable growth limits of the microorganism, its rate of growth will double. Conversely, if the temperature is lowered by ten Celsius degrees, the rate of growth will be reduced by half.

To continue with our example, let's also say that the microorganism grows at a rate of 1000 cells per hour in a certain small volume of product at 37°C.

If we lower the temperature by 10 C° to 27°C, the rate of growth will decrease by a factor of 2.0. Therefore, the population of the microorganism will grow at a rate of 500 cells per hour which is half the initial rate. If the temperature is lowered to 17°C, the growth rate will be further reduced by a factor of two so that it will be 250 cells per hour. A further reduction of 10 C° will bring the temperature down to 7°C which is below the lower temperature limit for growth of many microorganisms. If growth was not totally halted and followed the Q_{10} trend, the rate of
growth would be about 125 cells per hour.

Although this is not a strict rule, it is a good approximation upon which to base our views of microbial growth in food systems.

We will take a closer look at the $Q_{10}$ values for foods when we examine respiration in a subsequent chapter.

### 2.5 Enzyme Activity in Stored Foods

Enzymes are biologically active protein molecules produced by the cells of plants and animals to carry out some very specialized functions. These functions generally relate to promoting or "catalyzing" various biological reactions.

In the brewing process, yeast cells produce enzymes capable of breaking down starches into smaller components (i.e., sugars) so that they can be used as nutrients. Without these amylase enzymes, the large starch molecules would be unusable by the yeast cells.

Enzymes that are present in the cells of fruits and vegetables can speed the spoilage process. A good example of this is the enzyme polyphenol oxidase which is present in such plants as cauliflower. When selecting cauliflower for eating, we try to choose ones with white florets, since they are fresh and of high quality. If the cauliflower is allowed to stand at room temperature for an extended period of time, the florets will begin to turn from white to light brown and then darken as time goes on. Ultimately, the florets will become dark brown, purple, or black in colour. The reason for this is the reaction between the polyphenol oxidase and various phenolic compounds in the plant cells which change colour when they are reacted with oxygen.

In Figure 2-4, we see a fresh cauliflower having creamy white florets.

![Figure 2-4: Fresh cauliflower](image1)

After remaining at room temperature for a number of days, we can see the change in colour as shown in Figure 2-5.

![Figure 2-5: Cauliflower after sitting at room temperature for several days](image2)
When fruits and vegetables are going to be frozen, they are usually “blanched” by soaking them in boiling hot water for approximately two minutes. This severe temperature treatment deactivates the enzymes and essentially eliminates the problems of “enzymatic browning”, as it is called.

While blanching is possible when foods are being processed for longer term storage, we do not want to do anything of this nature to foods which are intended to be consumed in their fresh state. Since enzymatic reactions are actually chemical reactions involving biological catalysts, we can slow their rates by chilling. Using the approach that reducing the storage temperature by 10 C° will reduce the deterioration rate by one-half, we can see the obvious advantages to chilling many fruits and vegetables.
Chapter 3: Effects of Chilling on the Respiration of Foods

3.1 Introduction

Just as we must breathe to sustain our lives, so too must the cells of fruits and vegetables and other food materials of biological origin.

In this chapter, we will examine the respiration process in foods and show how chilling can be used to slow the respiration process and extend the storage life of these products. We will look at fruits and vegetables separately from meat products.

3.2 Respiration in Fruits and Vegetables

In the respiration process for fruits and vegetables, glucose reacts with oxygen to give carbon dioxide, water and heat.

Equations 3-1 and 3-2 show the respiration process in both word form and as a chemical reaction.

As can be seen from Equation 3-2, one mole of glucose reacts with six moles of oxygen gas to give six moles of carbon dioxide, plus six moles of water and 2,872 kiloJoules of heat. If you are not familiar with chemical reactions, please just refer to Equation 3-1 and do not worry about what is happening in Equation 3-2.

Figure 3-1 shows a diagrammatic representation of the respiration process using an apple as the example.

\[
\text{Glucose + Oxygen} \rightarrow \text{Carbon Dioxide + Water + Heat} \quad \text{(Eq'n 3-1)}
\]

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2,872 \text{ kJ} \quad \text{(Eq'n 3-2)}
\]

Figure 3-1: Respiration process for an apple
The glucose for the respiration process is provided internally within the tissue of the apple itself.

A closer examination of the reactions shown in Equations 3-1 and 3-2 will enable us to understand how to control the respiration process.

First and foremost, it is important to understand that respiration in fruits and vegetables generally leads to a loss in quality and ultimately makes them unsuitable for consumption. Therefore, we need to do whatever we can to slow the rate of respiration as much as possible, without freezing the product.

Using chemical principles, it is possible to alter the rate of a chemical reaction by changing the concentration of the reactants or the products. If we want to speed up a chemical reaction, we can increase the concentration of the reactants, which are on the left-hand side of the equation; or we can reduce the concentration of the products which are on the right-hand side of the equation.

We cannot change the concentration of the glucose present in the starting material since this is established by the sweetness of the material, such as the apple. However, we can limit the concentration of oxygen present. With less oxygen, the respiration will slow down somewhat.

Looking at the reaction products in Equations 3-1 and 3-2, we can manipulate the concentration of carbon dioxide and water vapour in the enclosed storage space as well as the temperature of the storage environment.

Technically speaking, if the temperature is allowed to increase, it should lower the rate of respiration based on these equations. However, we know that increasing the temperature will increase the rate of other reactions which are occurring, so overall, it is better to cool the storage area rather than have it warm up.

It should also be possible to allow the moisture content of the storage area to increase. This increase in the reaction products should also tend to slow the respiration process. Unfortunately, if the moisture content of the air rises to an excessive level, conditions will become favourable for the growth of molds and other undesirable microorganisms.

This leaves increasing the concentration of carbon dioxide as a potential way of lowering the rate of respiration. In practice, this is actually one of the things that is commonly done in the storage of such things as apples. By increasing the concentration of carbon dioxide to about 3.5% in the storage areas and reducing the temperature to the lower end of the chilled temperature range, apples may be successfully stored for several months while still retaining a relatively high quality. The first indications that quality is beginning to deteriorate is the development of small brown marks in the fleshy portion of the apple, followed by a softening of its texture.
3.3 Modified Atmosphere Packaging

As discussed above, the combination of chilling plus altering the atmosphere in which the material is being held can enhance its storage life appreciably.

This modified atmosphere packaging (MAP) approach is used for a variety of products, especially leafy vegetables like lettuce and spinach etc. which are used for salads (see Figure 3-2).

Often, the leaves are rinsed in a chlorine solution to reduce their microbial load and then washed thoroughly to remove any residual chlorine before packaging. The leaves are placed in specially designed "plastic" bags which allow the transfer of gases between the contents of the bags and the outside air. By having pores or openings in the plastic which control the exchange of gases within certain limits, it is possible to have the desired balance of carbon dioxide and oxygen to maintain a low respiration rate while the bags are held under chilled storage conditions in the supermarket.

Additional details on modified atmosphere packaging are available in the course on Shelf-Life Enhancement.

3.4 Respiration Rates of Various Fruits and Vegetables

Respiration rates vary with the particular fruit or vegetable and may be classed as ranging from very low to very high. Even after harvesting, produce continues to respire. Respiration will have an impact on the quality and chemical composition of the produce due to the consumption of carbohydrates (i.e., sugars) as a source of energy that is released in the respiration process.

The respiration rates of the same fruits or vegetables will also vary depending on the form in which it is present. For example, dried apple slices will not have the same respiration rate as those from a fresh apple (Figure 3-3). As one would expect, the respiration rate of the apple cells with almost all of their moisture removed should be extremely low, to the point where the rate is approaching zero.

![Dried apple slices and a fresh apple](image)

Figure 3-3: Dried apple slices and a fresh apple

Table 3-1 summarizes the respiration rates of various fruits and vegetables.
<table>
<thead>
<tr>
<th>Level of Respiration Rate</th>
<th>Examples of Produce</th>
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<tbody>
<tr>
<td>Very Low Respiration Rates</td>
<td>• Dried fruits</td>
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<td>• Dried nuts</td>
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<td>Low Respiration Rates</td>
<td>• Apples</td>
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<td>• Garlic</td>
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<td>• Grapes</td>
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<td>• Onions</td>
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<td>• Potatoes (mature)</td>
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<td>• Sweet potatoes</td>
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<td>Moderate Respiration Rates</td>
<td>• Apricots</td>
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<td>• Cabbages</td>
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<td>• Carrots</td>
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<td>• Figs (fresh)</td>
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<td>• Tomatoes</td>
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<td>High Respiration Rates</td>
<td>• Artichokes</td>
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<td>• Brussels sprouts</td>
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<td>• Cut flowers</td>
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<td>• Green onions</td>
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<td>Very High Respiration Rates</td>
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<td></td>
<td>• Sweet corn</td>
</tr>
</tbody>
</table>
Even when stored at refrigerated temperatures of 2°C, the rate of respiration has a major impact on how long these items will retain their freshness and quality. Table 3-2 shows the storage life of several fruits and vegetables under these conditions.

**Table 3-2: Storage Life at 2°C**

<table>
<thead>
<tr>
<th>Products</th>
<th>Storage Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus, mushrooms etc. (Very High Rates)</td>
<td>2 or 3 days</td>
</tr>
<tr>
<td>Lettuce, Cabbage, etc. (Moderate Rates)</td>
<td>1 to 2 weeks</td>
</tr>
<tr>
<td>Carrots, turnips, etc. (Moderate Rates)</td>
<td>5 to 20 weeks</td>
</tr>
<tr>
<td>Potatoes, onions, garlic, etc. (Low Rates)</td>
<td>25 to 50 weeks</td>
</tr>
</tbody>
</table>

In this article, Dr. Saltveit explains how the $Q_{10}$ values for foods vary somewhat over different ten degree temperature increments.

Table 3-3 reproduces information which Dr. Saltveit presents describing the range of $Q_{10}$ values for ten degree temperature increments beginning at 0°C and going up to 40°C.

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>$Q_{10}$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C to 10°C</td>
<td>2.5 to 4.0</td>
</tr>
<tr>
<td>10°C to 20°C</td>
<td>2.0 to 2.5</td>
</tr>
<tr>
<td>20°C to 30°C</td>
<td>1.5 to 2.0</td>
</tr>
<tr>
<td>30°C to 40°C</td>
<td>1.0 to 1.5</td>
</tr>
</tbody>
</table>

What is most useful and interesting from Dr. Saltveit's studies is the application of the information in Table 3-3 to the prediction of storage life. In his article, a storage life of 13 days is assumed for a perishable commodity at 20°C. Based on this starting point and assuming a $Q_{10}$ value within the ranges specified in Table 3-3, it is possible to predict the relative shelf-life at other temperatures. This information is reproduced below, in Table 3-4.

3.5 $Q_{10}$ Values for Respiration

In Chapter 2, we examined microbial growth in food products and saw that the rate at which microorganisms grow is influenced significantly by the storage temperature. The $Q_{10}$ concept as it applies to microbial growth can be used as a general guideline with the rate of growth doubling for a ten Celsius degree increase within the temperature limits.

We can also look at $Q_{10}$ values applied to respiration (or metabolism, if you prefer). An article describing the "Respiratory Metabolism" in foods by Mikal Saltveit is available on the Internet at the following URL address:

www.ba.ars.usda.gov/hb66/respiratoryMetabolism.pdf
Table 3-4: Effect of Temperature on the Rate of Deterioration  
(based on M. Saltveit)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Assumed Q₁₀ Value</th>
<th>Relative Shelf-Life</th>
<th>Relative Deterioration Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>---</td>
<td>100 days</td>
<td>1.0</td>
</tr>
<tr>
<td>10°C</td>
<td>3.0</td>
<td>33 days</td>
<td>3.0</td>
</tr>
<tr>
<td>20°C</td>
<td>2.5</td>
<td>13 days</td>
<td>7.5</td>
</tr>
<tr>
<td>30°C</td>
<td>2.0</td>
<td>7 days</td>
<td>15.0</td>
</tr>
<tr>
<td>40°C</td>
<td>1.5</td>
<td>4 days</td>
<td>22.5</td>
</tr>
</tbody>
</table>

To develop a treatment as shown in Table 3-4, it is necessary to begin by assuming representative Q₁₀ values from Table 3-3 and insert them into the proper locations in Table 3-4. At 10°C, the respiration rate is three times what it was at 0°C. At 20°C, the respiration rate is 2.5 times what it was at 10°C, and so on, up to 40°C.

In going from 20°C with a shelf-life of 13 days to 30°C, the Q₁₀ value indicates that the reaction rate doubles (i.e., Q₁₀ = 2.0). This indicates that the product storage life will be halved by such a temperature change, so the expected shelf life would be reduced to approximately 7 days. Going from 30°C to 40°C, the deterioration reaction rate increases by a factor of 1.5, based on the Q₁₀ value in Table 3-4. Dividing the 7 day shelf-life at 30°C by 1.5 gives us a four-day shelf-life at 40°C (allowing for round-off in our calculations).

If we start at 20°C and lower the storage temperature to 10°C, we can expect to prolong the shelf-life by a factor of 2.5, since the Q₁₀ value is 2.5 when the temperature is increased from 10°C to 20°C. It must be remembered that the shelf-life will increase as the temperature is decreased. As a result, a 33 day shelf-life can be expected at 10°C (i.e., 2.5 x 13 days). Finally, if the temperature is lowered to 0°C, the deterioration rate will be reduced by a factor of 3.0, so the shelf-life will increase to about 100 days (i.e., 33 days x 3.0), with allowances for round-off and acknowledging the approximation of these values.

By multiplying the Q₁₀ values involved in going from one temperature to the next, we can obtain a deterioration velocity relative to the initial temperature. When going from 20°C to 40°C, the Q₁₀ values used are 2.0 and 1.5. Multiplying these two values gives us a factor of 3.0 which tells us that the deterioration rate will increase by a factor of 3.0 over this temperature range and that the shelf-life will go from 13 days down to about 4 days, which is approximately one-third of 13 days.

If the temperature is lowered from 20°C to 0°C, the deterioration velocity will be reduced by a factor of 7.5 (i.e., 2.5 x 3.0). As a result, the shelf-life will be increased by a factor of 7.5 and be increased to approximately 100 days (i.e., 13 days x 7.5). Once again, it must be remembered that these are only approximations and actual shelf-life times will vary.
Taking a final look at Table 3-4, it is striking to see how the shelf-life of the example product increases from only four days to approximately 100 days by simply chilling it. Here, the relative deterioration velocity changes by a factor of 22.5.

3.6 Climacteric Ripening

3.6.1 What is Climacteric Ripening?

While on the subject of ripening, we should discuss an additional aspect of this topic.

Respiration rates are not always constant during storage. This is especially true for some fruits. There can be significant increases, or “spikes”, in the respiration rates as the fruits near their optimal ripeness. This is called “climacteric ripening”.

Climacteric ripening is characterized by the production of ethylene which is a ripening hormone that accompanies the process. A knowledge of this behaviour can be used to control the ripening of climacteric fruits.

Climacteric fruits include: apples, avocados, bananas, mangoes, peaches, pears, plums, and tomatoes.

Figure 3-4 shows an image of the ripening of a climacteric fruit. The vertical axis shows the rate of respiration and ethylene generation on a qualitative basis for a generic case, without specifying actual values. The horizontal axis is really based on time, but it emphasizes the sequential stages of development of the fruit.

Climacteric fruits are usually picked when they reach their full size but are still green, or not ripe. We can see this at the left side of the horizontal axis in Figure 3-4. With time, the fruit begins to ripen which is indicated by an increase in its respiration rate and the production of ethylene. The climacteric rise continues until the fruit reaches its fully ripened state. Following the climacteric peak, the rates of respiration and ethylene production begin to decrease as the fruit enters a period of senescence where the quality is diminishing and the fruit eventually rots.

Ethylene production in some fruits is autocatalytic which means that production of a small amount of ethylene triggers the production of increasing amounts of ethylene to hasten ripening.

![Figure 3-4: Climacteric ripening of fruits](Internet Image)
3.6.2 Applications of Climacteric Ripening

As stated above, a fundamental knowledge of climacteric ripening can be beneficial in helping to control the ripening of various fruits. By introducing ethylene into ripening chambers, the process can be accelerated as required. It should be noted, however, that exposure times to ethylene must be limited to avoid complications.

Bananas are an excellent example of a climacteric fruit. Bananas are picked when they are considered to be "commercially mature" and are shipped to their destinations where they are ripened by means of exposure to ethylene in ripening chambers.

"Commercially mature" fruits like bananas, mangoes, and tomatoes are usually green and quite firm in order to resist damage during shipment and to prevent over-ripening before they reach the consumer.

Fruits that are vine-ripened or tree-ripened have a much shorter shelf-life ahead of them and are usually sold at local markets where they will be purchased for more immediate use.

Getting back to our example of bananas, the bananas will be harvested green and firm. Following shipment by air or ship to their port of destination, they will be placed in a controlled-environment ripening chamber. Ethylene gas is generated from ethanol and is introduced into the chamber at prescribed computer-controlled rates to maintain the desired concentration for the ripening of the bananas. It is important to maintain the proper ethylene concentrations because improperly ripened bananas will lose their desired taste and texture. The bananas are not fully ripened in these chambers since they must still be distributed to supermarkets for sale to the consumer. At this stage, they may still be somewhat green, but will ripen in a short period of time in the consumer's home.

Figure 3-5 shows a pictorial representation of climacteric ripening where green bananas are exposed to ethylene gas (i.e., $\text{H}_2\text{C}=\text{CH}_2$).

![Image of bananas ripening](image_url)

Figure 3-5: Ripening of green bananas using ethylene gas
In the home, an understanding of climacteric ripening can be used to assist in the ripening of green bananas by placing them in a confined space with a high ethylene-producing fruit. Placing slices of apple (i.e., the ethylene gas source) in a paper bag with unripe bananas is one way to accomplish this. Figure 3-6 gives a pictorial representation of the reaction sequence.

Figure 3-6: Using apples as an ethylene source to ripen green bananas.

As a matter of record, we should also take a look at how respiration rates of non-climacteric fruits compare to those of climacteric fruits. As can be seen in Figure 3-7, there is a continuous but gradual decrease in the respiration rate of non-climacteric fruits that tends to follow a linear pattern over time.

Figure 3-7: Comparison of respiration rates for climacteric and non-climacteric ripening.
Chapter 4: Other Factors in the Chilling of Fruits and Vegetables

4.1 Introduction

So far, we have looked at the effects of chilling on the growth of microorganisms and the rate of respiration in fruits and vegetables. The overall results of chilling have been positive based on what we have seen so far.

In spite of the advantages that chilling offers over storage at ambient temperatures or freezing, there are some potential problems which need to be discussed, as well as some other positive factors which have not been covered previously.

4.2 Reduction of Moisture and Volatile Losses

Most of us are familiar with the evaporation of water and its dependence on temperature. For example, we use warm air to dry food products rather than cool air. If we set a wet object out in the hot sun, it will dry faster than it would on a cloudy, cooler day. This moisture removal is related to the increase in vapour pressure caused by heating the material and the air around it.

You may have also noticed that when spices are at lower temperatures, their aromas are not nearly as strong as they are when the spices are heated. Once again, this is related to the vapour pressure of the compounds present in the spices.

A high vapour pressure is indicated by a strong presence of the compound in the air. The more water vapour that is present in the air, the higher we can say its vapour pressure is. We will not go into the actual physical chemistry involved here.

Figure 4-1 shows the vapour pressure of water in air over a range of temperatures.

![Figure 4-1: Vapour pressure of water as a function of temperature.](image)

If we look at the vapour pressure of the water vapour at 20°C (see Figure 4-2), we can see that it is approximately 17 to 18 mm of mercury (i.e., about 17 to 18 torr). Chilling the air to 10°C lowers the vapour pressure to approximately 10 torr, as shown in Figure 4-2.
Figure 4-2: A comparison of the vapour pressure of water in air at 10°C and 20°C.

“Volatile” are compounds present in foods and beverages that evaporate easily. They are often quite aromatic and are responsible for the characteristic smells which we associate with various foods. These compounds can be lost quite easily at elevated temperatures, but are retained in the products at lower, or chilled temperatures.

In spite of lowered temperatures, we can still have a loss of moisture from fruits and vegetables which give up moisture by a process known as “transpiration”. This is similar to the loss of moisture from plants through their leaves.

Moisture loss from products can cause a number of problems. First, just the simple loss in weight of the product can reduce the weight of product that is ultimately available for sale. A weight loss of one or two percent will translate into a loss of one or two percent revenue when it comes time to sell the product.

Retention of moisture within the cells and tissue of a product helps keep it plump and firm. A loss of moisture can cause the product to shrivel or wrinkle. Products like celery or carrots will lose their firmness (i.e., turgor) and become limp or flaccid. This is shown in Figures 4-3a and 4-3b.

Figure 4-3a: Firm crisp carrots

Figure 4-3b: A carrot which has lost its crispness due to moisture loss.

Another problem encountered in refrigerated or chilled storage also involves the loss of moisture from products. As moisture enters the air from the product, the relative humidity of the air increases to the point where it becomes saturated with moisture (i.e., the relative humidity reaches 100%). At
this point, the air is holding the maximum amount of water that it is capable of holding. With all the moisture in the air, condensation begins to take place on cool surfaces such as the walls and ceiling of the storage area. Droplets of condensed moisture can then fall onto the surface of the food being stored and create an idea situation for mold growth to occur. Mold growth may also occur on the walls and ceiling of the storage chamber.

In order to prevent condensation from taking place, it is necessary to maintain a suitable level of air circulation and prevent the air from reaching 100% relative humidity. However, if the relative humidity of the air is too low, this will encourage evaporation of moisture from the stored product, which we have already discussed as being a bad thing. Relative humidities of approximately 90% are recommended at these low temperatures to maintain a balance between the loss of moisture and the occurrence of condensation. Warm temperatures and low relative humidities should be avoided (Figure 4-4).

4.3 Avoiding Moisture Loss

In addition to controlling the relative humidity within the chilled storage chamber, there are additional steps which can be taken to reduce the loss of moisture from certain fruits and vegetables.

Applying a thin coating of wax to the outer surface of the produce provides a barrier through which moisture cannot diffuse. Cucumbers and turnips, as well as peppers and tomatoes are routinely wax-coated to retain their crispness and prevent them from shrivelling due to moisture loss. An additional advantage of waxing is that it creates a smooth shiny surface, which is appreciated by consumers. Figure 4-5 shows a waxed sweet green pepper.

![Figure 4-5: Waxed sweet green pepper](image)

Some produce, such as carrots, may be given a thin coating of a starch-based material to prevent the loss of moisture.
4.4 Chilling Injury

Most produce tends to have a longer shelf life when it is stored at refrigerated conditions between 0°C and 4°C. However, this is not always the case.

There are certain fruits and vegetables which will undergo undesirable changes if they are subjected to the reduced temperatures commonly found in refrigerated storage.

Bananas are particularly susceptible to chilling injury. In the mid-1940's, the Chiquita Banana Company created an advertisement with a very popular "jingle" to educate the American public in how to store bananas. The final line of the song (see below) indicated that bananas should never be placed in a refrigerator.

"I'm Chiquita banana and I've come to say - Bananas have to ripen in a certain way - When they are fleck'd with brown and have a golden hue - Bananas taste the best and are best for you - You can put them in a salad - You can put them in a pie-aye - Any way you want to eat them - It's impossible to beat them - But, bananas like the climate of the very, very tropical equator - So you should never put bananas in the refrigerator."

"Chiquita Banana" (words and music by Garth Montgomery, Leonard Mackenzie, William Wirges) under license to Chiquita Brands L.L.C. © 1945 Shawnee Press Inc.

When bananas are stored at about 10°C, they may show signs of colour change to both the interior and on their skin. It is also possible that they may not ripen and the banana itself may go mushy as it starts to break down. The lower the temperature, and the more time the bananas spend at that temperature, the worse the damage will be.

A very comprehensive article "Refrigeration and Freezing of Food" appears on the Internet. It can be accessed by entering the following into your search engine:

highered.mheducation.com/sites/dl/free/0073398128/.../Chapter17.pdf.

This article provides information based on data from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' ASHRAE Handbook--Refrigeration.

According to the ASHRAE Handbook-Refrigeration, cucumbers must not be stored at temperatures below 10°C. Eggplant (Figure 4-6), okra, and sweet peppers should be stored above 7°C. Sweet potatoes should not be stored below 13°C and ripe tomatoes should only be subjected to mild refrigeration conditions from 7°C to 10°C.

Figure 4-6: Eggplant should not be stored below 7°C
4.5 Storing Potatoes

Potatoes (Figure 4-7) and other starchy materials offer an additional challenge when it comes to storage. The ASHRAE Handbook on Refrigeration recommends storing main crop potatoes at temperatures between 3°C and 10°C. However, there is a chance that within this temperature range, the starches present can be converted in their constituent sugars. Though a sequence referred to as the “Maillard Reaction”, a brown colouring could be produced by the reaction between these reducing sugars and other compounds found within the flesh of the potatoes (i.e., amino acids).

This process is referred to as “cold sweetening” due to the increase in sugars.

For applications such as frying the potatoes in oil to make potato chips or French fries, the sugars must be present in just the right balance or there will be excessive browning and the development of off-flavours.

Figure 4-7: Potatoes may suffer from cold-sweetening if stored improperly

4.6 Storing Bread Products

Care must be taken considering the storage of bread and bread products. They should not be stored in a refrigerators, since this actually speeds up the process of staling by accelerating the process of “retrogradation”. Let’s take a look at what happens when bread is baked and why refrigeration is not recommended for bread.

Wheat flour which is the basis for the bread is composed primarily of starch. As such, it has a crystalline structure composed of amyllose and amylopectin molecules that are aligned in an organized fashion.

When bread is made, the wheat flour is mixed with water and other ingredients and baked in an oven. As the temperature rises, the starches in the flour swell due to the uptake of water and they form a rather unstructured or formless network of starch molecules that could be considered to be a type of “gel”. The starch is now gelatinized.

Once the baked bread is cooled, the gelatinized starches begin to re-align themselves in to a structure similar to the one that existed before the dough was baked into bread. This process of re-organization or recrystallization of the starch molecules is referred to as “retrogradation”.

At room temperature, retrogradation takes place rather slowly. However, if heat is removed from the bread and it is cooled to refrigerated temperatures, the crystalline structure of the starches becomes favoured over the non-crystalline alignments and staling is accelerated.
Chapter 5: Chilling of Meats

5.1 Introduction

The chilling of meats presents challenges which are not typically found in the chilling of fruits and vegetables. It is really a subject in its own right and cannot be adequately covered in a course such as this.

We will look at a few of the more important aspects of meat chilling.

5.2 Respiration in Meat

While living, tissue cells within the bodies of animals receive oxygen by means of the blood. The blood becomes oxygenated in the animal’s lungs and circulates to all parts of the body. Oxygen is then released from the blood haemoglobin and diffuses across the cell membranes into the cells. By-products of the cellular respiration (i.e., carbon dioxide) travel from inside the cells across the cell membrane and become attached to the blood haemoglobin. The blood then travels back to the lungs where the carbon dioxide is exchanged for oxygen. The re-oxygenated blood once again circulates to the cells and the process continuously repeats itself.

As you can see, respiration relies on the presence of oxygen in the blood. After the animal is slaughtered, blood circulation ceases and the aerobic respiration at the cellular level declines due to a lack of oxygen.

With the decline in the rate of aerobic respiration (i.e., based on oxygen), there is an increase in the rate of anaerobic respiration (i.e., without oxygen) within the cells.

During anaerobic respiration, glycogen in the cells is converted to lactic acid. Glycogen consists of up to 30,000 glucose molecules joined together to form a large energy storage structure within the cells. When lactic acid is formed, the acidity within the cells increases and the pH falls. The change in pH triggers changes in the animal tissue and we see the onset of “rigor” or “rigor mortis” when the muscle tissues begin to stiffen.

Cooling is required once rigor has set in to obtain the appropriate colour and texture of the meat. If the meat is cooled before rigor mortis has set in, then “cold shortening” can occur which results in dark, tough meat.

5.3 Storage of Chilled Meat Products

Regulations for the temperatures to which meat products should be chilled and the times for which they can be held at those temperatures will vary from one country or jurisdiction to another. However, as a general rule, most jurisdictions require meat to be chilled to 4°C (or lower) within a few hours of slaughter. For chilled products, the temperature should not fall below its freezing point.
Table 6.1 is based on information published by the Food Safety and Inspection Service of the United States Department of Agriculture, in Washington, D.C. In the on-line article titled "Safe Storage of Meat and Poultry: The Science Behind It", the need for maintaining chilled conditions throughout the entire handling and distribution system is continuously stressed.

It is mentioned that all fresh chilled meat products should be used prior to its "Use-By Date". If no date is available, then the dates in Table 6.1 may be used, assuming that the meat is fresh when purchased.

<table>
<thead>
<tr>
<th>Type of Product</th>
<th>Recommended Storage Time After Purchase (at 4°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Beef and Veal</td>
<td>3 to 5 days</td>
</tr>
<tr>
<td>Fresh Pork</td>
<td>3 to 5 days</td>
</tr>
<tr>
<td>Fresh Lamb</td>
<td>3 to 5 days</td>
</tr>
<tr>
<td>Uncooked Sausage (beef, pork, or turkey)</td>
<td>1 to 2 days</td>
</tr>
<tr>
<td>Fresh Poultry</td>
<td>1 to 2 days</td>
</tr>
<tr>
<td>Fresh Variety Meats (liver, tongue, kidneys, heart, etc.)</td>
<td>1 to 2 days</td>
</tr>
<tr>
<td>Cured Ham (cook before eating)</td>
<td>5 to 7 days</td>
</tr>
<tr>
<td>Ground Meats (including poultry)</td>
<td>1 to 2 days</td>
</tr>
<tr>
<td>Seafood (i.e., fish)</td>
<td>1 to 2 days</td>
</tr>
</tbody>
</table>

Storage times for processed meats such as bacon will be longer. The USDA article states that bacon may be kept for up to two weeks if the package is unopened. However, once opened, the product should be used within a short period of time.

Similar recommendations are made for hotdogs and luncheon meats, as well as other cooked meats.

If meat products need to be kept for any appreciable period of time, they should be frozen at a temperature of approximately -18°C (or lower).