FOOD PRESERVATION BY REFRIGERATION

By

ALICIA O. LUSTRE, PH.D.*

Introduction

The lowering of temperature is a conventional method of preserving perishable foodstuffs. In a hot country like ours, it is indispensable for the bulk storage and marketing of foods that we traditionally consume fresh.

A better understanding among our engineers of the uses of mechanical refrigeration for preserving foods can bring about the design of better refrigerated warehouses suited to the needs and conditions of the various regions of our country. In these days of high and rising energy costs, the development of efficient refrigeration systems would be most welcome.

I come from an organization which houses Asia's largest refrigerator. FTI's central refrigerated warehouse has a floor area of 2.5 hectares, and an effective storage capacity of 55,000 cubic meters of food. My talk today will dwell both on the basic aspects of food preservation by refrigeration and on our experience in the use of central refrigeration for the large scale storage and marketing of foods.

Food Preservation

Food preservation very simply is the application of feasible methods to prevent or delay food spoilage.

There are various methods available to preserve food. Some, like the application of heat, as in the canning of foods, results in the formation of products that are almost sterile and will therefore remain stable for long periods, ranging from several months to one year. Others like salting, involves the addition of salt to improve the microbiological stability of the product, and therefore its shelf-life.

*Director, Food Research and Development Directorate, Food Terminal, Inc., Taguig, Metro Manila.

Refrigeration as a method of food preservation makes use of the removal of heat and the maintenance of continuous low temperature to extend the shelf-life of foods. Preservation is effected by the slowing down of the rates of chemical and enzymatic reactions and of microbial growth in the food system. Insect infestation is also controlled. Refrigeration does not render a food product sterile. Thus refrigerated foods are susceptible to normal spoilage as soon as desired low temperature conditions are removed.

Refrigeration as a Method of Food Preservation

A. Advantages and Disadvantages

Unlike most methods of food preservation, refrigeration is unique for the following reasons:

1. It keeps the food closest to its original form i.e. there is no extensive shrinkage as in dehydration, no strong changes in texture and flavor as in canning and no development of new flavors as in syruping or pickling.

2. It causes the least destruction of nutrients and vitamins. Because heat is not applied, vitamins particularly B and C, are well preserved, and proteins are not extensively denatured.

However, it also has its disadvantages, as follows:

1. It is costly and requires the continuous expenditure of energy to maintain the needed low temperatures.

2. It requires special equipment, and power not readily available in rural areas.

3. It requires a cold chain during the distribution process.

4. Quality of product as perceived by the consumer is very sensitive to conditions existing during transport and retail, both of which are not normally within the control of the producers.

5. For most cold stored foods, there is the problem of moisture condensation on the food surface, after withdrawal from cold storage.

B. Types

There is a delineation between two types of low temperature storage. Chilling or cold storage, involves holding food at temperatures above 0°C. Freezing and frozen storage involves bringing down food temperature below its freezing point.

The types of food generally preserved by chilled storage are vegetables, fruits, fresh meat, dairy products, cured meats, eggs. Those preserved by frozen storage are poultry beef, pork, fish and fruit purees.

C. Reasons for the Extension of Shelf-Life at Low Temperatures

Refrigeration extends the storage life of foods because of its effect on the following:

1. It retards chemical reactions responsible for losses in food quality.

2. It slows down the activity of food enzymes and therefore the rates of biochemical reactions and processes.

3. It slows down and in some cases destroys the activity of food microorganisms.

4. It does not allow the growth, activity and entry of insects and most pests.

Effects on Chemical Food Spoilage

The lowering of temperature retards the speed of chemical reactions. The Arrehenius equation for the temperature dependence of the rates of chemical reactions,

$$K = A_e{}^{-E_a/RT}$$

K = rate of reaction
A = constant
E_a = activation energy
R = gas content
T = absolute temperature

indicates that the speed of a chemical reaction is an exponential function T. The slightest change in the latter therefore can bring about enormoust changes in the speed of the reaction. It is approximated that the rate of chemical reaction is halved for energy 18°C change in temperature.

Important types of food spoilage such as those manifested as browning, rancidity and pigment losses are caused by complex chemical reactions involving food constituents and its environment. Lowering of temperature, because it reduces the speeds of these spoilage reactions retards the onset of visible deteriorative changes.

Dried fish is one example of the effect of temperature in the control of spoilage. When kept at ambient condition, dried tunsoy after 2-4 weeks readily losses its silver sheen and develops a yellow surface coloration. The yellowing of the surface which is typical of the oxidation of fats, is not evident in dried fish cold stored at −3 to −5°C, until after 7-12 months in storage.

The same retardation in the onset of visible defects due to chemical deterioration is found in many other food products that are cold stored (frozen meats, fish and poultry; chillled eggs, milk).

The higher nutritive value of refrigerated and frozen foods is due in part to the reduced rate of chemical breakdown of these vitamins, particularly vitamins B and C at low temperatures.

Effects of Enzymatic Reactions in Foods

As we all know, enzymes are biological catalysts. They speed up rates of biological reactions because of their peculiar ability to lower the activation energy of the reaction.

Biological reactions determine the integrity of plant and animal tissues. Thus the quality of many plant and animal foods is among others, dependent on the extent to which such enzyme catalyzed reactions are controlled.

Fruits and vegetables are probably the best examples of foods whose quality is dependent on the control of a complex enzyme-catalyzed reaction known as respiration. The respiration of fruits and vegetables which continues after harvest and which increase during fruit ripening involves the breakdown of reserve carbohydrates and the release of carbon dioxide and water as follows:

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{heat}$$

Retardation of the above reaction by the use of low temperature delays ripening, senescence, visible wilting and eventual spoilage of the fruit or vegetable in storage.

There are also specific food spoilage chemical reactions that are enzyme catalyzed. In some food preservation methods, these enzymes are destroyed by heat in order to arrest the reaction. In refrigeration, the enzyme is not destroyed but enzymatic activity is retarded by the lowering of T.

The loss in sweetness of sweet corn for example due to the breakdown of sugars, an enzyme catalyzed reaction is retarded at low temperature. At 0°C, sweet corn losses only 8.1% of its total sugars, 24 hours after harvest. At 19.8°C however, it loses 25.6%. Ninety six hours after harvest losses at 0°C increase to 22%. At 19.8°C however, the losses reach as much as 62.1%.[1] 1 The enzyme catalyzed reaction which causes deterioration of the flavor of sweet corn is thus controlled at low temperature.

Effects on Microbial Growth and Activity

Any raw plant or animal food contains a variety of bacteria, yeasts and molds which under the right condition will proliferate in number, sufficient to bring about undesirable changes in food quality.

Thus, we are all too familiar with fresh fish getting slimy, fresh meat smelling putrid, onions turning wet and foul smelling, mangoes developing black patches. Most of these changes are due to the decomposition of food tissues by microorganisms.

The growth and metabollic activity of microorganisms is due to enzymes. Because the rates of enzymatic reactions are directly affected by temperature, microbial activity can be controlled by temperature. As temperature is decreased, the rate of growth of microorganisms is lowered.

Because the growth rates of bacteria is exponential in nature, small changes in temperature, cause significant change in the f'nal microbial population. Cells of *Pseudomonads fragii*, for example, a common spoilage organisms in fresh foods, divide in one hour at a T of 20°C, and in

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[1] Desrosier, Norman W. The Technology of Food Preservation AVI Publishing Co. Inc. Westpoint Connecticut. 1970 p. 68.

three hours, at a lower temperature of 7.5° C.[2] It can be calculated that, if the initial population of *P. fragii* in meat is 100 colonies, this will increase to 5960 colonies after 20 hours at 7.5°C and to 34 million colonies at 20°C. The effect of temperature lowering is thus seen to be very significant.

Types of Microorganisms Important in Low Temperature Storage

Microorganisms have an optimal, minimal and maximal temperature for growth. The lower limit for development is rigidly set at the temperature at which water freezes and the upper limit, by the thermal liability of chemical constituents important to reproduction.

At low temperatures the important spoilage microorganisms, are yeast and molds and the psychrophillic bacteria, i.e. those with an optimum temperature of growth below 20°C.

Molds and yeats do not grow well at temperatures above 35-37°C and many grow fairly well at low temperature, some even at freezing temperature. Thus we are familiar with juices, bread and eggs spoiled by molds and yeast growth, at refrigerated temperatures.

The specific type of bacteria predominating and causing spoilage, varies with temperature and with the food system. Work by Tompkin 1973[3] for example (Table 1) shows that the nature of the microbial population on chilled chicken meat at three different chilling temperature, changes.

Table 1. TYPES OF BACTERIA CAUSING SPOILAGE ON CHICKEN MEAT

Bacteria	Spoilage Flora at each T		
	1°C	10°C	15°C
Pseudomonads	90	37	15
Acinetobacter	7	26	34
Enterobacteriacese	3	15	27
Streptococcus		6	8
Aeromona		4	6
Others		12	10

[2] Frazier, W.C. and D.C. Westhoff. Food Microbiology. McGraw Hill Book Co., 1978, p. 131.

Because the bacterial population changes, the visual type of spoilage manifested will likewise change.

It is also well to differentiate between food spoilage and food poisoning microorganisms. Food spoilage microorganisms will render the food spoiled if present in sufficient number, and cause visible damage to food tissues. Food poisoning microorganisms on the other hand may not contribute to visible signs of spoilage, but produce toxins or causes infections, that pose grave risks to human health. Most of these food poisoning bacteria are capable of growth at low temperatures (Table 2). Proper care of chilled and thawed frozen food is therefore as essential as fresh foods.

Table 2. MINIMUM GROWTH TEMPERATURE OF FOOD POISONING BACTERIA [1]

	0°C
Staphylococcus Aureus	6.7
Salmonella	6.7
Clostridium Botulinum	
Type A	10
B	10
B (non proteolytic)	3.3
E	3
F	3.3
Clostridium Welchii	15

[1] Roberts, T.A. Microbiological Problems of Freezing, Cold Storage and Thawing of Meats. From Meat Processing, Why and How? Meat Research Institute, Longford Bristol, UK.

B. Difference in Microbial Survival at Chilling and Freezing Temperatures

Chilling temperature only arrests microbial multiplication. They do not kill microorganisms and therefore, do not render the product sterile. Thus food held in refrigerated storage will be immediately susceptible to microbial decay when transferred to ambient conditions, or if held at refrigerated temperatures for prolonged periods of time.

Freezing temperatures on the other hand, because of the formation of ice crystals, potentially damage cell structure. Damage can take the form of injury and/or complete destruction of microbial cells.

Results of microbial survival during frozen storage of shrimps, ob tained at FTI, and shown in Annex 1, shows a continously decreasing microbial population. In particular, coliforms and *E. Coli* counts are reduced to zero after one year of frozen storage at −18 to −23°C. The reduction in load is not necessarily an indication of the death of bacterial cells. It could indicate injury to cells and incapability to recover (i.e. exhibit viability) at the time of counting. Cell repair and/or recovery and therefore spoilage, can still occur on subsequent thawing and distribution of the frozen product.

Although freezing is destructive to bacterial cells, the process does not sterilize a food product nor does it make a perishable commodity, non-perishable. Thus only the best quality product must be frozen.

Low Temperature Preservation of Fruits and Vegetables

Refrigeration is the only feasible method today for prolonging the storage life of fresh fruits and vegetables.

To understand its usefulness, it is well to remember that fruits and vegetables are living tissues, i.e. they continue to respire after harvest. To be more specific, they continue to breakdown reserve carbohydrates and to release water, carbon dioxide and heat.

This is why we are all familiar with the condensation of moisture on the surface of a plastic bag of fruits and vegetables or the generation of heat in the center of the pack. A 30 kg. basket of newly harvested beans generates sufficient heat to achieve a center temperature of as high as 40°C under local conditions. A roomful of onions stored for long periods at temperature of 5 to 10°C can generate enough carbon dioxide to make the room suffocating, to a human person.

Refrigeration or low temperature extends shelf-life because it slows down the rate of respiration and in the process delays ripening of fruits and the senescence of vegetables. Other physiological processes as the sprouting of tubers, and the elongation of roots (asparagus) are also retarded. In addition the decreased loss of moisture and of heat, minimizes the progress of decay and results in an overall decrease in weight loss during storage.

Low temperature is also one of the most effective ways for delaying the development of postharvest decay of infected fruits and vegetables. It does this because low temperature per se retards the growth of pathogenic microorganisms. Secondly fruits are more susceptible to infection when ripe. Thus because low temperature retards ripening, it has the indirect effect of maintaining host resistance to parasitic infection.

Some common examples of infection in Philippine fruits and vegetables are anthracnose in mangoes, guavas and papayas, black rot in pineapple and various bacterial soft rots in onions, carrots, cabbage, celery, pepper and other vegetables.

Low temperature therefore prolongs the storage life of fruits and vegetables by slowing down respiration, ripening, moisture loss and the spread of infection. One would normally therefore hope to use a temperature as low as feasible during cold storage. There is a lower limit however to the temperature that can be used. This limit is set by the tendency of all fruits and vegetables to undergo chilling injury.

Chilling Injury

Chilling injury is an undesirable change in the physical and/or ripening quality of a fruit or vegetable during cold storage. It occurs at temperature which is low but which is much above the freezing point of tissues. Thus it is not a breakdown due to freezing.

Manifestations of chillling injury varies between fruits and vegetables. In onions, it appears as a cooked transparent watery appearance originating from the outer surface of the bulb. In bananas, there is browning of the fleshly surface, discoloration of the peel, loss of flavor, delayed ripening and hardening of the central placenta. In lanzones, it is also manifested as a browning of the skin. Tomatoes fail to develop a red color; mangoes, lack sweetness and develop brown patches on the skin.

Various theories have been proposed to explain the phenomenon. Disruption of the synchronization of the complex series of reactions involved in respiration, changes in cell membrane permeability, imbalance in the distribution of chemical compounds, impairment of enzyme activity, and accumulation of toxins at critical temperatures are some of the basic mechanisms that have been proposed.[1]

Optimum Storage Temperature and Storage Life for Fruits and Vegetables

Because of the lower limit set by chilling injury, an optimum temperature exists for the cold storage of different varieties of fruits and

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[1] Pantastico, EVB, R.A. De Fossard, and H. Safran. Chilling Injury.
From: Postharvest Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. Phoenix Press Inc. 927 Quezon Blvd. Ext., Quezon City, Philippines: (1975) p. 339.

vegetables. These temperatures and the maximum shelf-life to be expected, are shown in Tables 3 and 4.

The tables give both optimum temperature and optimum relative humidities. The relative humidity governs the rates of moisture loss through transpiration and respiration. Very low humidities are not desired in most fruits and vegetables as this increases the loss of water from the surface and therefore shrivelling and wilting. Very high humidities on the other hand cause moisture accumulation on the surface; a situation, which facilitates decay.

For tubers, which undergo a stage of dormancy, humidities are always kept low, to prevent breakage of dormancy and the initiation of sprouting.

The heat evolved during respiration is also indicated. This heat loss is important in estimating refrigeration requirements.

The tables indicate that the optimum storage temperature vary not only for individual fruits and vegetables, but for different varieties of the same fruits and different stages of ripening for a given variety. Ripe fruits are more tolerant to low temperatures than those which are green.

The tables also show that the maximum shelf-life obtainable varies for individual commodities or that the perishability of fruits and vegetables varies among different types. In general commodities are more perishable, the higher their rates of respiration.

Vegetables with high respiration rates i.e. perishable, are the following:

- young tissues — asparagus, camote tops, kangkong, alugbate
- partly developed flowers — brocolli, cauliflower, katuray
- developing seeds — green peas, string beans, baguio beans, paayap
- immature fruits — eggplant, okra, patola, ampalaya, young

Vegetables with low respiration rates i.e. storeable are the following:

- roots — sweet potato, ubi, carrots, singkamas
- stems — Irish potato, gabi, ginger
- bulbs — onions, garlic
- mature fruits — pumpkin, squash, condol

The temperature and humidity data indicated in Tables 3 and 4 are adapted from Pantastico, et. al slightly modified to suit FTI requirements. Shelf-life estimates for vegetables are based on FTI studies.

Table 3. COLD STORAGE REQUIREMENTS OF PHILLIPPINE GROWN VEGETABLES*

Vegetables	Temp. °C	Relative Humidity (%)	Effective Storage Life (days)
Ampalaya	5 -7	88-90	5-10
Batao	1	90-95	5-10
Broccoli	0	90-95	7-14
Cabbage (Baguio) (Wet season)	1	92-95	30-60
Cabbage (dry season)	1	92-95	21-30
Cabbage (Bongabon)	1	92-95	15
Carrots, topped	2	85-90	14-21
Cauliflower	1	90-95	7-14
Celery	1	92-95	7-14
Choyote	7	80	14-30
Chinese Cabbage	0.5-2	92-90	7-14
Condol	7	85	60
Corn, green	1	90-95	10
Corn, sweet green	0.5-2	90-95	6-8
Cucumber	9 -10	85-90	21-35
Eggplant	5 -7	88-90	3-5
Garlic, dry	0 -2	70	210-270
Ginger	7	80-85	60-90
Habichuelas (snapbean)	1.5-3	90	14-21
Lettuce, leaf	0 -2	90-95	1-2
Lettuce, heading	1	90-95	1-10
Lima beans	1	90-95	14-21
Melon			
muskmelon	2	85	14-21
honeydew	7	80	60-90
watermelon	4.5	80-85	60
Mushrooms	1	85-90	7
Okra	9 -10	85-90	5
Onion, green	2 -3	85-90	7-14
Onion, bulb red	1 -3°C	65-70	150-210
Onion, bulb white	2 -5	65-70	90-120
Patola	5 -7	85-90	14
Pechay	3 -4	85-90	7
Pepper, native	1	65-70	30
Pepper, sweet green	7 -10	85-90	14-21
Pepper, sweet ripe	5 -7	85-90	5-7
Potato, Irish	4	80-85	60-90
Potato, sweet	3	80-85	14-30
Raddish	2 -4	88-92	7-14
Sitao	5 -7	88-92	3-7
Squash	7 -10	85-90	30-45
Sweet peas	4 -7	88-92	7-10
Tomato, mature green	7 -10	85-90	14-21
Tomato ripe	7	85-90	7
Upo	7	85-90	21-30

*Temperature and Relative Humidity Requirements adapted from: Pantastico, E. R. Postharvest Physiology. AVI Publishing Company. But modified to suit FTI requirements. Storage life estimates is based on FTI studies.

**Table taken from: Guidelines for the Acceptance and Handling and Storage of Vegetables. Food Research Department, Food Terminal, Inc. (1980).

Table 4. RECOMMENDED COLD STORAGE CONDITIONS, HEAT OF RESPIRATION AND LOSS IN WEIGHT OF FRUITS GROWN IN THE PHILIPPINES

Fruits	Temp °F	Relative Humidity	Storage Life	Heat Evolution ETU/ton-day
Avocado, West Indian	55	85-90	2	10,400
Avocado, Guatemalan	42-55	85.90	4	4,400-7,700
Banana				
Lakatan green	55-60	85-90	4	5,280-6,600
Lakatan, ripe	55	85-90	1.5	9,282
Latundan, green	58-60	85-90	3.4	5,500-6,600
Latundan, ripe	55-58	85-90	1	
Cavendish, green	55-58	85-90	3-4	6,600
Cavendish, ripe	55	85-90	1.5	11,200
Plantain, green	50	85-90	5	3,960
Plantain, ripe	45-50	85-90	1.5	
Caimito, ripe	37-42	90	3	1,600-1,400
Cashew	32-35	85-90	5	6,600-7,600
Citrus				
Calamondin	48-50	90	2	5,500
Valencia Orange	40-43	88-92	5.6	2,545
Swinkom orange	48-50	85-90	4-5	3,300
Ponkan orange	40	85-90	3-4	2,200
Lime, yellow	52-55	85-90	8	1,760-2,640
Lime, green	52-55	85-90	7	880-1,760
Pomelo	45-48	85-90	12	1,800
Custard apple	41	85-90		
Durian	39-42	85-90	6-8	
Guava	47-50	85-90	2-5	7,040-7,700
Jackfruit	52-55	85-90	6	
Lanzones	52-55	85-90	2	15,400-16,000
Mango				
Carabao	45-50	85-90	2.5-3.5	6,700
Pico	45-50	85-90	2.5	6,700
Mangosteen	39-42	85-90	7	
Papaya, green	50	85-90	3-4	2,500
Papaya, turning	47	85-90	2-3	
Pineapple, all green	47-50	85-90	4-6	1,700
Pineapple, 25% yellow	40-44	85-90	1-2	
Pomegranate, 'Khandan'	32-35	85-90	11	
Rambutan	50	90-95	1-2.5	13,200
Santol, 'Bangkok'	45-48	85-90	3	
Sapota, turning	67-70	85-90	2.5	3,300-5,500
Sapota, ripe	32-36	85-90	2	
Sugar apple, turning	45	85-90	4	
Sugar apple, ripe	34-37			

[a]Represents steady heat production during storage at indicated temperatures.

Taken from: Pantastico ErB, T.K. Chattopadhyay, H. Subramanyam. Storage and Commercial Storage Operations. Post harvest and Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables. Phoenix Press Phil. (1975) p. 314.

As can be seen from the table, most fruits and vegetables have very short storage lives. For many of these commodities except onions, potatoes, garlic and cabbage, there is really no storage life to speak of, and low temperature or refrigeration, serves as a means to keep the commodity as fresh as possible during marketing.

Low Temperature Preservation of Meat

Meats are preserved at both chilling and freezing temperatures.

Meat Chilling

Meat chilling refers to the hanging of freshly slaughtered carcasses in a room held at 0-2°C to bring down its internal temperature just above its freezing point, within 24 hours. Unless chilled, the natural microbial population of the carcass will increase rapidly causing slime and spoilage within 5-10 hours, depending on conditions. The rapid rise in microbial count is due to the fact that freshly slaughtered carcass has a temperature of 38°C which is within the optimum growth range for most bacteria.

In addition to retarding microbial growth, chill hanging also has a softening effect on beef muscles and thus improves its eating quality. Chilled carcasses are also more rigid than freshly slaughtered carcass and this facilitates fabrication into retail cuts without excessive trimming.

Unfortunately in our country, chilling is not an accepted integral procedure of meat marketing. Both pork and beef carcasses go to public markets directly from slaughterhouses. Chill hanging is not practiced because it is expensive and it results in 2% loss in carcass weight. The effect of non-chilling on market losses and spoilage is not documented. Probably market vendors are able to dispose all carcasses before spoilage can set in.

Chilled meats can also take the form of retail cuts sold in supermarkets. This particular product form, caters to clients who want their meats pre-cut but not frozen. The recommended storage life of chilled meat held under these conditions is as follows:

Recommended Storage Life for Chilled Meats[1]

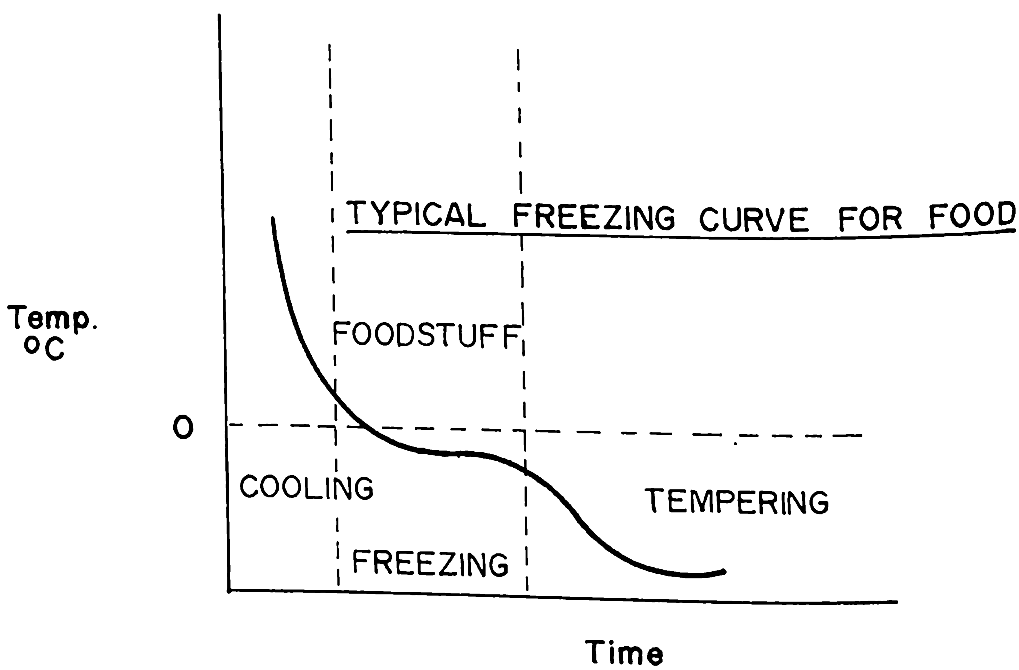
[1] Proceedings of the Meat Institute Symposium Meat Research Institute, Bristol, UK (1974).

	T	RH (%)	Storage Life
Beef	0°C	85	10-15 days
Pork	−1 to 0°C	85-90	7-14 days
Lamb	−1 to 0°C	85-90	7-14 days
Poultry	0 to 1°C	85-90	7 days
Rabbits	−1 to 0°C	90-95	5 days

One can see from the data that properly chilled meats can last from 1 to 2 weeks. In practice however we may achieve only half of those values as slaughtering practices and temperature and stacking condition in the retail shelf or holding rooms, are seldom ideal.

Meat Processing

In order to hold meats for periods longer than 1 week freezing is essential. Meat freezes at a temperature of −2.2°C. The freezing of meat like that for most food products follows the following pattern.



Although water freezes at 0°C, a block of beef will not begin to freeze until its temperature reaches about −2.2°C. This is due to salts and other chemicals present in the cells which effectively lower the freezing point.

As the temperature falls below −2.2°C and −5°C is a critical range. Because of the exposure of muscles to high concentrations of solute at this time, it must be passed in the shortest possible time. Quick freezing also causes the formation of smaller ice crystals and therefore less cellular damage.

The time necessary to freeze meat varies widely with initial temperature, size of the black, velocity of air, temperature of air and stacking inside the freezer. Pork carcases can freeze in 8-10 hours, cartoned meat in 20 hours at an air temperature of −40°C, a velocity of 6.2 meters per second and a final product temperature of −18°C.[1]

Freezing retards microbial growth and in many cases is damaging to vegetative cells of microorganisms. It retards enzymatic activity and the rates of chemical reactions causing flavor and color changes in the meat. Destruction of the B vitamins as a result of freezing and thawing is considered minimal.

Storage Life of Frozen Meat

The storage life of frozen meat depends on several factors, as follows:

1. The slaughter factors such as breed and feed oι animal, fatigue, pre-slaughter care.

2. Slaughtering techniques, particularly standards of hygiene in the slaughterhouse.

3. Maintenance of non-fluctuating storage temperature. Fluctuating storage temperature causes desiccation of the meat surface and therefore shortens storage life.

4. Proper packaging in storage. The frozen meat must be properly wrapped in plastic bags and cartons.

Under good conditions of slaughter and pre-slaughter care, the recommended storage life for various frozen meats is as follows:

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[1] Fleming, A.K. The New Zealand Approach to Meat Freezing, Why and How? Meat Research Inst. Bristol UK p. 24 (1974).

Meat	Storage T (°C)	RH	Recommended Maximum[1] Period of Storage
Beef	−18°C	95%	8-12 months
Pork	−18°C	95%	4-6 months
Lamb	−18°C	95%	6-10 months
Poultry	−18°C	95%	8-8 months (in moisture proof packs)
Rabbit –	−23 to −18°C	95%	6 months

The above storage recommendations should be used only as a guide because the storage lives indicated are difficult to achieve if slaughtering and handling conditions are not as required.

Fat Rancidity in Stored Frozen Meats

The most important factor that limits the storage life of frozen meats especially from the point of view of palatability, is the oxidation of the fat.

The type of fatty acid present in the meat which is an important factor in fat oxidation determine storage stability. Beef and mutton are both very hard fats, which contain few unsaturated fatty acids, whereas pork fat or lard is a softer fat, thus, storage life of pork is considerably shorter than beef.

Factors that can minimize fat rancidity during frozen storage are:

1. Packaging in oxygen impermeable films

2. Low temperature. The storage life of pork can be increased from 4-6 months to 8-10 months if storage T is reduced from −18 to −23°C.

3. Freezing as whole carcasses than as cuts. Minced meat has a much shorter shelf-life than whole meat. The release of myglobin as a result of mincing promotes rancidity.

4. Light removal — Light is an important preoxidant. Reportedly flourescent light can halve the storage life of vacuum pack beef steaks held at −20°C.

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[1] Proceedings of the Meat Research Institute Symposium Bristol, UK (1974)

Marketing Problems

Although frozen meat may be of good quality even on prolonged storage, there is very strong consumer resistance against the purchase of frozen meat. In retail marketing, one of the major problems is appearance. The poor color of the frozen products and the associated drip or loss of fluid on thawing can make good frozen meat unappealing to the consumer. Further, many consumers feel that they have no basis to judge whether a piece of frozen meat is of good quality or not, unlike if they were purchasing the product, fresh.

Thus, although freezing continues to be a major form in which meats are kept during periods of glut, its acceptance in the retail market, except for poultry is still minimal. At the present time, most meats are still frozen for manufacturing purposes rather than for retail sale.

Low Temperature Preservation of Fish

Unlike meat, fish is not chilled by mechanical refrigeration, but by ice. Mechanical chilling of fish is not normally practiced because icing is more practical and preserves product quality well.

Fish Freezing

Low temperature preservation of fish is done mainly by freezing.

Fish contains from 60 to 80% water depending on the species. Freezing of this water will enable storage of the commodity for several months. If properly done and when storage conditions are adequate, thawed frozen fish can be very similar to the fresh products.

In order to obtain a good frozen fish product, the following are essential:

a. The zone of maximum ice formation must be passed as quickly as possible i.e. quick freezing is essential. When fish is quick frozen, ice crystals formed are small and the fish proteins are not exposed to high concentration of salt and enzymes from the partially frozen liquid, for prolonged periods of time. There is thus less damage to the cells.

Quick freezing of fish is defined by the British Ministry of Food as a freezing rate which enables the fish to go down in temperature from 0 to −5°C, in two hours. This range represents the temperature range of maximum ice formation.

b. The original fish must be fresh. The defects of initially poor quality fish are not removed by freezing and in cases, may even be magnified on storage.

c. Fish must be stored at the right temperature.

d. Fish must be properly packaged in storage.

Storage Life of Frozen Fish

As in meats, the storage life of frozen fish depends on species and on the storage temperature. While much work has been done for fish abroad, relatively less has been established for local fishes.

Our work at the Food Terminal indicates that properly frozen good quality milkfish stored in polyethylene bags and master cartons is highly acceptable up to 6-7 months of cold storage at −18 to −23°C. Packed in plastic sacks, it will last for only 3 months.

The major factors that limits storage life is protein denaturation which is manifested as a dry tough texture of the flesh. The fish losses its elasticity and becomes very bland in flavor. One to two months beyond its normal storage life, it shows evidence of rancidity of the fat.

The storability of other species of local fishes remains to be investigated.

Just like meats, public acceptance of frozen fish and of other marine products is poor.

Low Temperature Preservation of Eggs

Table egg is another commodity stored in bulk at low temperature. Bulk storage is essential because the supply is high in the hot summer months and low during the cooler months of October to February.

A freshly laid egg has a pH of about 7.6, a thick white and a firm yolk, rigidly held in place by the vitelline membrane. As eggs are stored, carbon dioxide diffuses from the shell. The pH rises, the white thins out and the yolk flattens.

At our local ambient conditions, fresh eggs will remain good for only 4 weeks. When stored at −20°C however and a relative humidity of. 82% they will last for 2-3 months. The eggs don't change in physical quality but develop an undesirable stored flavor. Changes in white and yolk are manifested after 5-6 months. Low temperature minimizes the rate of diffusion of carbon dioxide and moisture from the shell and therefore, the rate of chemical change in the white and yolk.

Constraints in the Low Temperature Storage of Eggs

Eggs should normally be quite resistant to microbial spoilage because the surface is filled with organic material which hinders microbial invasion. The egg membrane is in itself an effective barrier and the egg white contains constituents which increase egg resistance to microbial attack.

Long storage of egg (beyond 2-3 months), however is difficult to achieve unless humidities are properly controlled at high enough levels to prevent excessive loss in moisture without encouraging the growth of molds.

Eggs are also extremely sensitive to stored odors. Thus, they cannot be kept with odorous commodities as onions or apples and must be held in clean non-odorous containers.

Post storage distribution of cold stored eggs is difficult as moisture readily condenses on the surface at room temperature after withdrawal from cold storage. This is immediately followed by mold growth in 24 hours and spoilage soon after. Conditioning the eggs to slowly rising temperatures is the recommended method for the prevention of post storage moisture condensation in stored eggs, but we have not found this to be practical. Blowing the commodity with dry air has been a feasible temporary solution.

Requirements for Good Quality Chilled and Frozen Foods

I have, in this talk, chosen four important commodities where refrigeration plays an important role in storage and marketing; namely fruit and vegetables, meat, fish and eggs. They are also commodities preserved at different temperature levels; (fruits and vegetables between 2 to 15°C; eggs, 2°C and meat and fish at freezing temperature of −18 to −23°C), and therefore provide good examples of the requirements for proper preservation and the factors limiting storage life.

Food covers a very wide scope however and as in other methods of preservation every type and variety has its own requirements for proper refrigeration, freezing and storage.

1. Original quality of product to be chilled or frozen must be good. Defects in the raw material are not corrected by the Low-Temperature treatment.

— Defects such as vegetable rots, can spread during chilled storage. Ripening fruits because they release ethylene gas, can accelerate ripening of other nearby fruit batches.

— Defects can be magnified by the low temperature treatment. For example, partly rancid pork when frozen, becomes more rancid after storage and thawing, because exposure of the fat to high concentrations of solutes during the freeze-thaw cycle, accelerate the oxidation process.

— Immature onion bulbs, will be very sensitive to sprouting during low temperature storage.

2. Commodities for chilling and/or frozen storage must be properly packaged and bulk packed.

Proper packaging is necessary to facilitate handling, to allow proper circulation of cold air, to permit maximum utilization of storage space, and to prevent quality changes as dehydration, oxidation and the absorption of stored odors.

Proper packaging is one of the most difficult requirements to meet under local conditions. Fruits and vegetables and other foods come in variety of containers as sacks and baskets, of different forms and sizes. In these containers, they are readily bruised, cracked and compressed; conditions that not only destroy consumer appeal but which initiate and facilitate decay in the cold store. Crated onions for example, will last 1 to 2 months longer in cold storage compared to onions in sacks.

Frozen commodities if intended for long storage must be protected from dehydration and the absorption of stored odors. This means plastic packaging and holding in cartons or plastic boxes is necessary.

The problem of proper packaging is related to the lack of hard-estimates of the cost/benefit picture of correct packaging.

3. The required temperature and humidities for storage must be exceptionally well maintained.

Fluctuating temperatures promote chilling injury in fruits and vegetables, dehydration and large losses on thawing in stored meats.

High temperatures per se shortens storage life by accelerating the progress of deteriorative reactions which low-T is supposed to control. Decay does not only become more extensive, but also more intensive; fat oxidation is accelerated; microbial growth may produce significant changes in flavor.

The maintenance of proper temperatures and humidities are engineering and storehouse management problem. The refrigeration zone and equipment must be adequately designed, built and maintained and its use as methods of room stacking and the opening and closing of doors, have to be managed.

4. Commodities for frozen storage must be properly frozen.

Freezing must be as short as possible and product temperature must at least be −18°C prior to storage.

5. Cold stored commodities must be properly mixed in storage zones.

In combining commodities in a given room, T and RH requirements must be adequately matched and the possibility of mixing stored odors must be avoided. Eggs and onions for example although requiring similar temperatures cannot be mixed.

6. Cold stored commodities must be properly handled after removal from the cold store.

Commodities that are to go into ambient marketing must be re-dried to remove surface moisture that immediately condense on the surface of the goods after withdrawal from the cold store. Otherwise commodities as onions will be susceptible to sprouting and eggs, to mold growth.

Frozen commodities must be kept properly frozen until they reach the consumer. The international standards for the temperature in transit of frozen foods is −10°C.

Frozen commodities if to be used must be thawed as fast as possible.

Chilling and freezing are very effective ways for preserving the quality of foods, in their fresh form over specified periods. Although an expensive method of preservation, its use is almost indispensable in holding large volumes of perishable goods, until they can be properly marketed. It is hoped that the food technologist, the engineer and the economist can work hand in hand in improving the present state of technology and quality of locally chilled and frozen foods.

Annex 1. Microbial Load of Prawns at Different Length of Storage

Storage — Time	Total Aerobic Plate Count (No. of colonies/gram)		Coliform Count (MPN/gram)		E. Coli Count (No. of colonies/cm)		Test for Salmonella	
	Head	Body	Head	Body	Head	Body	Head	Body
0 — Time	1,055,000	215,000	39,500	6,150	26,500	0	Negative	Negative
One week	—	58,000	—	75	—	75	—	Negative
One month	79,500	48,500	65	105	50	105	Negative	Negative
Three months	12,550	16,250	25	15	0	0	Negative	Negative
Six months	74,500	2,720	70	5	0	0	Negative	Negative
One year	2,050	170	20	0	0	0	Negative	Negative

From: Dolendo et. al. Standardization of Handling, Transport and Freezing of Sugpo *(Penaeus monodon)*