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REFRIGERATION OF FRESH FRUITS - PROBLEMS IN HANDLING, STORAGE AND TRANSPORTATION WITH SPECIAL REFERENCE TO DEVELOPING COUNTRIES[1]

by

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Contents

1. BACKGROUND

The world production of fruits exceeds 150 million tons (mt.) per year. Of these about 50 mt. are grapes, 26 mt. citrus fruits, 22 mt. bananas and 19 mt. apples. Then follow stone fruits with about 11.5 mt., pears 5.8 mt., pineapples 3.4 mt. and dates 1.9 mt. The world production of tree nuts is of the order of 0.8 mt.

A large part of this production is not consumed in the fresh state but is used as raw material for processing. This is especially so with grapes. Only about 9 mt. out of the world production of 50 mt. are table grapes, the remainder being used for manufacturing wine and raisins. Also for pineapples, citrus fruits and apples much of the world crop is utilized for processing.

Only a relatively small part of the world production enters international trade as fresh fruits. Bananas and citrus fruits are at the top with about 4 mt. each, followed by apples 1.7 mt., table grapes 0.8 mt., pears 0.4 mt. and dates 0.3 mt.

A number of other fruits are produced in substantial quantities but for these no comprehensive and reliable statistical data are available, neither do they enter world trade to any appreciable extent. Among them mangoes and avocados are considered to be of special interest. The main production area for mangoes is India with an annual output of some 3.5 mt.

This paper has been written with special reference to problems in developing countries. These have been taken to include Central America, South America, Middle East, Far East (excluding Japan and China) and Africa. Production figures for the most important kinds of fruits from these areas are given in table 1.

Table 1. Production of fruits in developing countries

(Source F.A.O. Production Yearbook vol. 21, 1967. Figures in thousand tons, average for the five year period 1962 - 1966)

Fruit	Central America	South America	Middle East	Far East	Africa	Total
Apples	118	537	537	154	192	1538
Pears	32	159	163	63	91	508
Grapes (table)	80	606	2613	217	364	3880
Stone fruits	141	410	449	58	281	1339
Citrus fruits	1579	4139	1631	1832	2412	11593
Bananas	4076	9326	89	6323	1147	20961
Pineapples	393	398	-	1139	476	2406
Dates	7	-	1024	95	727	1853

As evident from the table the banana is by far the most important fruit in developing countries with an aggregate production of about 21 mt. (more than 95 % of the world production). Then follows citrus fruits with 11.6 mt. Almost 100 % of the world crop of dates, mangoes and avocados are produced in these countries and about two thirds of the pineapple world crop. More than one third of the world production of table grapes originates from developing countries, while their part in the world production of stone fruits, apples and pears is relatively small - about 12 %, 8 % and 9 % respectively.

2. BASIC FRUIT PHYSIOLOGY

2.1. Respiration

Fresh fruits are alive and they carry on within themselves processes characteristic of all living systems. While the fruits are still attached to the parent plant, reserves of food materials accumulate. After harvest there is no further access to supplies and subsequent changes are running-down processes.

The final stage of these aging, or senescent processes is that the fruit breaks down and turns brown and soft. Clearly, the more slowly senescence proceeds the longer will be the storage life. Therefore, the object of storage is to slow down the aging processes.

The most important life processes are those of respiration. During respiration fruits absorb oxygen from the atmosphere and give off carbon dioxide. Carbohydrates and organic acids are oxidized to carbon dioxide and water. Simultaneously a number of volatile organic chemicals compounds are produced, albeit in quantities which are minute compared to carbon dioxide.

Respiration is accompanied by a release of energy. The amount of heat evolved is roughly proportional to the respiration intensity measured by the amount of carbon dioxide generated.

The higher the storage temperature, the higher the rate of respiration and the greater the amount of heat generated. For every 10°C rise in temperature the respiration is roughly doubled or tripled.

Some fruits have much higher respiration rates than others at a given temperature. This means that they require considerably more refrigeration than more slowly respiring products to keep them at a specified temperature. As an example, strawberries respire approximately 5 times as fast as apples at 0°C.

The storage life of different kinds of fruits generally varies inversely with the rate of respiration and evolution of heat. Thus, in apples the good keeping varieties respire more slowly than the early ones.

2.2. Climacteric and ripening

Two different patterns of respiration are found in fruits. In one case the rate of respiration after harvesting follows a straightforward, slowly declining trend. As no ripening takes place once the fruit has been removed from the mother plant, it must be picked at the optimum condition for eating. Fruit following this behaviour is referred to as non climacteric. This category includes grapes, citrus, figs and cherries.

The second group, which includes many more fruits e.g. apples, pears, bananas, mangos and avocados has a much more involved pattern of respiration. Following harvest there is a slown decline of respiration intensity until a rate is reached which is known as the preclimacteric minimum. Following this stage a very rapid increase takes place until the climacteric is reached. This is followed by a relatively rapid decline. For many fruits such as pears, the climacteric coincides with the optimum dessert stage; in others the optimum eating stage is reached one or two days after the climacteric, with bananas even later.

During the climacteric a large number of dramatic and involved biochemical changes take place. Starch is converted to sugars, pectins change from an insoluble to a soluble form resulting in softening of the fruit, tannins are hydrolyzed and thus the astringent taste of the unripe fruit disappears; pigment changes often with involved syntheses of colouring materials take place. Volatile compounds such as esters, aldehydes, alcohols and ethylene are produced in much larger quantities than in the preclimacteric stage.

Successful storage of the climacteric type of fruit implies harvesting before the climacteric rise in respiration commences. Various criteria may be used to ascertain this e.g. firmness, shape, ground colour, percentage of total soluble solids, acidity. Once the climacteric rise commences it is no longer possible to arrest the ripening process. It may be delayed but this results in ripening under adverse conditions which leads to different physiological disorders, quality disturbances etc.

2.3. The rôle of ethylene

Most varieties of fruits produce ethylene, citrus, grapes and pineapples being noteworthy exceptions. Some fruits produce very little, some relatively large amounts. Bananas at 12°C produce about 100 mg per ton per day; apples up to 60 times as much. The rate of production varies with temperature but does not necessarily follow that of carbon dioxide.

It has been an accepted canon in refrigerated storage of fruits that ethylene is dangerous and that whether it arises from the presence of ripe fruits or is artificially introduced stimulation of respiration and premature ripening are to be expected. Research in later years has led to a substantial modification of this view, unfortunately still largely unknown to practical store operators. It has been clearly established that if the temperature of storage is below 2° to 3°C, then the stimulatory effect of ethylene on ripening is negligible. Thus if such fruits as apples and pears are stored at the proper temperature ethylene does not cause any complications. On the other hand, the accumalation of ethylene can have serious consequences in the storage of tropical and subtropical fruits which often are subject to low temperature injury if kept below 10°C.

Artificial application of ethylene is used in practice to hasten and to make more regular the ripening of some fruits, e.g. bananas. With citrus ethylene is used to induce better colouring, in this case only the appearance is affected and not the ripeness, which generally holds true for non-climacteric fruits.

2.4. Transpiration

Fruits loose moisture by transpiration. This loss is readily replinished prior to harvesting. Once the fruit is removed from the parent plant this is no longer so. Water loss not only results in appreciable - and costly - weight loss but also in less attractive produce of poorer texture and lowered quality.

Water loss by the fruit for a given exposure to air is approximately proportional to the vapour pressure difference between fruit and air.

2.5. Chilling and freezing

Certain fruits are injured by low temperatures (0° to 10°C) but still above the freezing point. Such injury is referred to as chilling.

At chilling temperature fruits are unable to carry on normal metabolic processes. Often products that are chilled look sound when removed from such temperatures. However, symptoms of injury such as pitting and other skin blemishes, internal discoloration or failure to ripen soon become evident upon transfer to higher temperatures. Of great importance is that fruits may become particularly susceptible to microbial attacks upon chilling.

The severeness of chilling injury is determined both by time and temperature. Damage may occur after a short exposure only, to temperatures considerably below the limit, while the fruit may be able to withstand a few degrees in the danger zone for a longer time. The effects of chilling are cumulative. Low temperatures in transit, or even in the field shortly before harvest, add to the total effects of chilling that might occur in storage.

The temperatures usually recommended for storing of fruits that are not susceptible to chilling are slightly above the freezing point of the fruit. If the temperature drops below this limit freezing injury occurs. The primary damage is to the cell wall membranes, destroying their and thus the tissues ability to function normally. Symptoms of freezing injury vary with kind of fruit and length and severity of exposure. Generally, tissues affected by freezing appear water-soaked.

Different fruits vary in their susceptibility to freezing injury. Most are permanently damaged even by slight freezing, while some may be partly frozen and then thawed with little or no permanent injury. Among the less susceptible fruits are apples, pears, grapes, oranges and grapefruits.

2.6. Microbial diseases

Attack of micro-organisms, especially fungi, is probably the most important cause of loss in storage of fruits (FIDLER 1966). There are at least two different patterns of attack.

The sound fruit may be infected in the field. A latent infection is produced, which develops into a rot after harvest. The spore load, the resistance of the host tissue and the conditions of storage determine the intensity of attack. Rotting usually increases as maturity progresses. Typical examples of this category of diseases are Gloeosporium on apples, mangoes and avocados and Botrytis on grapes.

Some fungi, known as wound parasites, are unable to enter sound tissue but can only infect through mechanical lesions. They can cause rotting at any stage of maturity and the rot usually spreads rapidly, often by contact to adjacent sound fruit. Penicillium sp., the green and blue molds of citrus, are an important example.

Methods to control microbial attacks include spraying in the field to reduce infection and good storage practice such as rapid cooling and correct storage conditions. In some cases application of fungicidal and/or fungistatic chemicals after harvest may be useful.

3. COLD STORAGE OF FRUITS - GENERAL PROBLEMS

3.1. Fruit quality

It is important to realize that fruits vary in their behaviour in storage more than most other types of foodstuffs. Variety, climate, soil, cultural treatment, phytopathologic conditions, time of harvest, maturity and handling practices before storage - all may have highly significant effects. Sometimes these are on the length of the storage life but frequently they necessitate different conditions of storage. Therefore, it is not possible to give a single recommendation for optimal storage requirements of a given fruit regardless of where and under which conditions it is produced.

Fresh fruit intended for storage should be as free as possible from bruises and other mechanical damages, decay and other deterioration. Not only do mechanical damages detract from the appearance of the product but they are usually the principal avenue of entrance for decay-producing organisms. In addition mechanical damage increases water loss from the fruit.

The degree of development and maturity at harvest has a critical influence on the storage properties of most fruits. Unfortunately it is not always easy to determine the optimum stage for harvesting and for some fruits it appears highly desirable to develop new and more reliable methods for such determinations. In some fruits- e.g. apples and grapes - incipient decay infection influences the economical storage life to a considerable extent. Techniques have been elaborated to forecast decay early in the storage period (HARVEY 1960, PIERSON 1958). Only lots with low disease potential should be considered for long-time storage. It appears useful to develop such methods for additional kinds of fruits.

3.2. Temperature

Refrigeration prolongs the storage life of fruits because it retards

a) respiration and other metabolic activity;

b) consequent aging due to ripening, softening and textural and colour changes;

c) moisture loss and the shrivelling that results;

d) spoilage due to invasion by bacteria and fungi.

The control of temperature is critical; deviations from the desired figure must be kept to a minimum. As an example of the effect of quite small changes in temperature on storage life, Williams pears may be kept in air for 12 weeks at -1.6°C, 10 weeks at -1.1°C, 7.5 weeks at 0°C and for only 6 weeks at +1.1°C. Thus, in this range of temperature, a difference of 2.7°C can have a twofold effect on storage life (FIDLER 1966). This is a very much greater effect than the effect of temperature on purely chemical processes, including respiration.

The optimum storage temperatures for different kinds of fruits are discussed in section 5. Further details and references are found in I.I.R. (1967) and U.S. DEPT. AGRICULTURE (1968).

Maintaining uniform temperatures in all parts of a storage room is more important and even much more difficult than avoiding small fluctuations at a given point. Fruit stored in parts of the room with higher temperature ripens and deteriorates faster. This frequently results in mixing of overripe and/or decayed fruit with prime fruit on removal.

3.3. Precooling

For reasons evident from the preceding sections rapid removal of field heat soonest after harvest - precooling - generally has a substantial - and sometimes a deciding - influence on the storage life of fruits. Some recent and very interesting experimental results from South Africa (GINSBURG 1963 a & b, 1965) illustrate this point with great clearness. Thus, GINSBURG underlines that the delay between harvesting and rapid precooling should be kept at an absolute minimum for peaches - it should be a matter of hours and certainly not 24 hours. For Bon Chretien pears he concludes that they must be got into store as soon as possible after harvesting - a delay of 48 hours is permissible for early-season fruit and 24 hours or less for fruit harvested late in the season.

Apples are from the practical point of view an especially interesting commodity in this respect. To quote GINSBURG verbally on this matter: "The question is frequently posed whether rapid precooling with apples is really a very critical factor (underlined by author). If you are quality-conscious the answer is undoubtedly yes. It can be stated that apples held at about +21°C age ten times as rapidly as those held at -0.6°C. Thus, if apples after harvesting are held at an average temperature of +21°C for 4 days and then placed into cold storage a month's storage life is lost".

The rate of cooling of any commodity is primarily dependent upon four factors

a) the accesibility of the product to the refrigerating medium;

b) the difference in temperature between the product and the refrigerating medium;

c) the velocity of the refrigerating medium;

d) the kind of the refrigerating medium.

The most widely used technique for precooling is with rapidly moving air. It can be adapted to refrigerated rooms, rail cars, trucks, conveyor tunnels, or the forced air method of passing cold air through containers by pressure differential. Without comparison it is the most important method for precooling fruits.

Effective precooling may be achieved by the use of contact ice or top ice; both involve use of crushed ice either placed within containers in direct contact with produce or on top of packed containers. This method has only a few worthwhile applications for fruits.

In hydrocooling the produce is immersed in cold water. Properly used, it is one of the most rapid and efficient methods of removing field heat. Hydrocooling is specially used for peaches.

Vacuum cooling was introduced only 20 years ago. This method is extremely important for leafy vegetables but affords little interest for fruits.

3.4. Humidity

As already stated the rate of water loss from fruits is roughly proportional to the water vapour pressure deficit of the storage atmosphere. This in turn is determined by the temperature and relative humidity of the air.

At a given relative humidity the water vapour pressure deficit and consequently the rate of water loss is less at low temperature than at high temperature. This explains the beneficial influence of low storage temperature on water loss.

High relative humidity - 85 to 95 % - is generally recommended for the storage of fruits. (Nuts are an exception, cf. section 5.6.). If the relative humidity is kept lower, water losses may be expected to become high, causing shrivelling or wilting. On the other hand, if it is too high it may favour the development of decay. The control of moulds becomes particularly difficult if the relative humidity approaches 100 %, which may result in condensation of moisture. Better understanding of decay control, however, is leading to use of higher humidities. Thus, it is stated (GUILLOU el. al. 1965) that 90 % is accepted as a desirable minimum in California and 95 % is being advocated and used commercially.

Controlling humidity is a complicated technical problem. Usually it is more difficult to maintain relative humidity high enough than to keep it at a lower level. Of major importance in this connexion is to reduce the cooling load. This may be done by providing generous insulation. Still more important is to reduce the temperature difference between the cooling surface and the air. This may be accomplished in the first place by larger cooling surfaces but also by improved liquid feed, better defrosting, clean coils and larger air velocity. It should be noted though that it is costly to install cooling surfaces and their accessories to maintain 90 % relative humidity, to maintain 95 % relative humidity by cooling surface design is virtually prohibitive.

As an alternative, systems have been developed to add pressure - atomized water or water vapour to the storage atmosphere (cf. GUILLOU et. al. 1965). Still another solution is afforded by the jacket system. In this the room is cooled by air circulating through a jacket, or envelope, surrounding the room. Advantages and disadvantages of the jacket system are discussed by LENTZ (1960, 1965) and LENTZ & ANQUEZ (1965).

Loss of moisture may be further decreased by the application of protective packaging. Plastic materials of different kinds can be used for consumer size packaging or for box liners, pallet covers or tarpaulins to protect stored fruits. Such moisture proof materials retard the loss of water from commodities to the atmosphere. It is necessary, though, to keep in mind that certain films, when sealed or otherwise tightly closed, may restrict the exchange of oxygen and carbon dioxide as well as that of water vapour. This may lead to the development of too high concentrations of carbon dioxide and possibly also of too low concentrations of oxygen.

3.5. Air distribution

As already stressed it is of paramount importance to maintain uniform temperatures in all parts of a storage room. To achieve this, air must be circulated through the store. Different types of arrangements for air circulation are in use, including fans to provide forced air circulation and more or less complicated duct arrangements.

For precooled produce a high air velocity is unnecessary and usually undesirable. Only enough air movement should be provided to remove respiratory heat, eventual fan heat and heat entering the store from the outside. It is very important, however, that the circulating air is uniformly distributed through all parts of the room. Experience shows improper adjustment of air distribution systems to be a major cause of non-uniform storage temperature. SAINSBURY (1961) indicates that for maintenance of uniform temperatures, the quantity of air circulated should be sufficient to provide an air turnover rate of at least 7.5 times per hour in an empty storage.

The effect of the rate of air circulation on water loss is closely related to its effect on relative humidity of the air surrounding the product. Provided humidity is high rapid circulation does not appreciably increase water loss. However, if the humidity is low, commodities in rooms with no circulation show less shrivelling. The reason for this is that transpiration from the commodity in such rooms causes the humidity of the air adjacent to the product to increase.

Cooling and temperature distribution are significantly influenced by the nature of the packing material used and the stacking of the packages in the store. If poor stacking prevents airflow even the most elaborate system for air distribution is useless. Air always follows the path of least resistance. Thus, wide aisles in the direction of the airflow may result in much of the air bypassing the stacked commodities. Similarly, if spacing is not reasonably regular, wider spaces get a greater volume of air than the narrower ones. If spaces are partially blocked, areas occur with no or very little air circulation with resultant higher temperatures.

The increasing use of cardboard boxes and of palletizing arrangements has made the problems of cooling in relation to stacking more complicated. This matter is further discussed in section 6.3.

3.6. Ventilation

With very few exceptions it is indispensable to provide storage spaces for fruits with a supply of fresh air (ventilation). This is to prevent the build-up of dangerous concentrations of volatile products of respiration in the storage atmosphere. Prominent among these is ethylene, which even in very low concentrations may induce premature ripening (cf. section 2.3.). While this risk is negligible at storage temperatures below 3°C it may become very real at higher temperatures, suitable for storage of such fruits as bananas, avocados and mangoes.

Volatiles of greater molecular weight than ethylene, including alcohols, aldehyds, ketones, esters, terpenes etc., are produced by fruits; the total production is usually less than that of ethylene. It has been argued that these heavier volatiles may stimulate respiration and induce certain physiological disorders. However, according to FIDLER (1961), there does not exist any unambiguous evidence that elimination of heavy volatiles from a properly designed and operated refrigerated store has any practical value.

Carbon dioxide may cause injury in many kinds of fruits. However, it is generally dangerous only in fairly high concentration.

Because of economical considerations ventilation should be kept at a necessary minimum. Often enough fresh air is supplied by leakage, opening of doors etc. Modern constructions, however, are often more gas-tight than older ones and it may be desirable to provide for facilities to regulate and check the supply of fresh air.

Air purification has been advocated as a supplement or alternative to ventilation. The method usually involves the use of trays or canisters filled with activated carbon. The primary value of air purification is odour removal. On the other hand experimental evidence as to the effect in retarding ripening and controlling storage disorders is far from conclusive. In any case ethylene is not removed by activated carbon.

The use of ozone to eliminate ethylene in fruit storage has been repeatedly suggested. Other alleged beneficial effects are elimination of tainting and control of decay. However, ozone may damage fruits in very low concentration and already for this reason its application in fruit stores appears highly questionable. Moreover, experimental evidence available to date indicates that ozone has little, if any value, in controlling decay of fruits in storage.

A review of some problems in ventilating fruit storage spaces is given by EMILSSON (1961)

3.7. Mixed storage

Sometimes it may be desirable to store different kinds of fruits together. This is, of course, only possible when the temperature requirements are the same for the kinds of fruits involved. Risks encountered are cross-transfer of odour and harmful action by ethylene.

Cross-tainting between various kinds of fruits has been observed but appears to have little practical importance. Nuts, however, are very sensitive to tainting and should always be stored separately.

As already stated the ripening effect of ethylene is negligible at temperatures below +3°C. Fruit stored in this low range, e.g. apples and pears, therefore may be safely mixed in storage. At higher storage temperatures, however, the risks for ethylene effects must be taken into account very seriously.

3.8. After-effects of cold storage

It is sometimes believed that cold storage predisposes fruits to rapid deterioration upon transfer to ambient temperatures. However, there is no evidence to support this viewpoint except in cases where chilling damages have been induced during cold storage. Of course, it would not be reasonable to believe that cold stored fruits should keep as long as freshly harvested ones, the reason being that some of the potential life has been used up in storage.

On removal from cold storage care should be taken to prevent as far as possible condensation of water on the cold surface of the produce. Condensation will occur when the dew-point of the air is higher than the surface temperature of the produce or of its packaging material. The package may act as a barrier to condensation on its contents. Sometimes it may be good practice to cover a pallet-load of packages until it warms to above the dew-point of the surrounding air, thus avoiding heavy condensation.

Condensation may favour decay, particularly in the more tender fruits. Such produce must be handled with extreme care following sweating and it is generally wise to dispose of it as soon as possible. Otherwise, the damage risks from condensation should not be overestimated and they should not deter anybody from using recommended storage temperatures.

4. AIDS TO REFRIGERATION

4.1. CONTROLLED ATMOSPHERE STORAGE

4.11. Introduction

Storage of fruits in controlled atmosphere (CA-storage) is founded on the possibility to decrease respiration, thus retarding ripening and prolonging the storage life, by adjusting the concentration of oxygen (O_2) and/or carbon dioxide (CO_2) in the storage atmosphere.

Our knowledge about the CA-method has increased greatly in recent years. This applies to fundamental physiological aspects as well as to methods of creating the atmosphere desired and to application in practice.

4.12. Physiological aspects

4.121. The rate of respiration is roughly speaking proportional to (O_2). Oxygen intervenes as a reagent with the different substrates of respiration.

Carbon dioxide plays its rôle in reactions of carboxylation and decarboxylation. It also seems to affect a number of enzymatic reaction systems.

4.122. When (O_2) decreases below 21 % there is decrease in respiration intensity and a delay of the climacteric. The effect of decreased (O_2) becomes less pronounced when the temperature is lowered.

Below a certain (O_2) - generally 2 - 3 % at low storage temperatures - anaerobic processes may complicate the picture. These lead to formation of alcohols and aldehydes with consequent taste distortions. Disturbances in ripening may also occur - acids and chlorophyll remain, solubilization of pectins is retarded.

With decreasing (O_2) such physiological diseases as scald, core flush and low temperature breakdown in apples often become less severe.

Decreasing (O_2) down to 2 - 3 % appears to have very little effect on attacks of fungus diseases.

4.123. Increasing (CO_2) generally decreases respiration intensity, especially at higher temperatures. Lemons are an exception, respiration being stimulated by increasing (CO_2) to 10 %.

Higher (CO_2) may create grave disturbances in metabolism such as inhibition of respiratory and pectolytic enzymes and of production of substances creating the characteristic fruit aroma.

High (CO_2) may aggravate core flush but decrease scald in apples. (CO_2) above 10 % may induce brownheart in apples.

(CO_2) above 20 % often inhibits spore germination and fungal growth. On the other hand, a stimulating action may appear at lower concentrations.

4.124. The combined effect of (O_2), (CO_2) and temperature is complicated and follows different patterns in different kinds of fruits. Thus, in bananas, the effects of decreasing (O_2) and increasing (CO_2) are synergistic. On the other hand, in apples there is no interaction between (O_2) in the range 1.5 to 16 % and (CO_2) 0 - 5 %.

4.125. The choice of the optimum combination of (O_2), (CO_2) and temperature is complicated by the occurrence of limiting factors. Taking apples as an example, the use of a low storage temperature is limited by the risks for physiological disorders and fungal attacks. Similar conclusions are reached if (O_2) or (CO_2) are chosen as limiting factors. It is necessary to make the best possible use of all three variables and consequently apples should be stored

a) at a temperature of 0^{o} - 4^{o} depending on the variety

b) in an atmosphere containing about 3 % O_2;

c) in 2 - 5 % CO_2, provided that this concentration is tolerated and risks for scald and fungal attacks decreased.

Evidently the balancing of these factors is much complicated by the special susceptibilities of each variety, which it is necessary to know very well. As an example, the variety Golden Delicious is fairly insensitive to low temperatures but quite sensitive to increasing (CO_2), while Cox's Orange presents the opposite picture.

4.126. The following conclusions may be drawn as to the practical application of CA-storage

a) Cooling, decrease of (O_2) and increase of (CO_2) concurrently influence the metabolism of the fruit and their individual effects may be added.

b) It is advantageous to operate at low (O_2) but above the limit for anaerobic respiration. In this way ripening is retarded and certain physiological diseases controlled.

c) Cooling is indispensable but dangerous zones (freezing, physiological disorders) must be avoided. By cooling the storage life is prolonged and fungal diseases controlled.

d) It may also be favourable to increase (CO_2), thereby decreasing the risks for certain physiological disorders, checking fungal diseases and delaying ripening. On the other hand, too high concentrations may have toxic effects.

e) No all-embracing, optimum recipe can be given as the ideal conditions depend on

- the sensitivity of the kind and variety of fruit to low temperature and to (CO_2);
- the conditions of cultivation and the degree of evolution at harvest;
- the length of storage envisaged.

4.127. An authoritative and up to date review of physiological problems in CA-storage is given by ULRICH (1967).

4. 13. Techniques in CA-storage

4. 131. Principles

Initially, in the commercial application of CA-storage the atmosphere wanted is created by the fruit itself through the normal respiration process when placed in a suitably tight and well filled room. When a low oxygen atmosphere is desired, equipment for carbon dioxide removal is added. This type of CA-storage may be described as "product generated atmosphere".

Today several methods are available for producing the atmosphere desired by supply from the outside. We call these "externally generated atmospheres".

4. 132. Product generated atmospheres

For this method the storage space must fill high demands on gas-tightness. A number of more or less sophisticated techniques have been developed for this purpose - many of them are described in Annexe 1966-1 to Bulletin de l'Institut International du Froid.

In a sufficiently gas-tight space fruit respiration gradually lowers (O_2) from the normal level to the desired concentration. Once the desired (O_2) is obtained fresh air from the outside must be added periodically to maintain it.

As O_2 is used in respiration, CO_2 is given off. It must be removed from the atmosphere; otherwise injurious concentrations would soon build up. This is generally done by atmospheric washers (scrubbers) using water, caustic soda, monaethanolamine or dry hydrated lime. A quite new technique envisages the use of an exchanger-diffuser based on the special permeability properties of silicon rubbers. This is stated to be simple to operate, to consume no material and to require very little energy (MARCELLIN & LETEINTURIER 1966).

4. 133. Externally generated atmospheres

There are two main alternatives for this kind of CA-system:

a) to replace continuously the atmosphere in the storage space with an atmosphere with the desired composition - flushing;

b) to circulate the atmosphere through special equipment to remove O_2 and CO_2.

The flushing method may use liquid or compressed nitrogen to create the atmosphere desired. Alternatively, the atmosphere is generated by a hydrocarbon fuel burner system. For a detailed description and discussion of different systems reference should be made to PFLUG & GUREWITZ (1966).

In circulation systems so far only equipment working on the burner principle has been used. Volatiles may create problems in systems of this kind and could necessitate the introduction of special absorbers.

Nitrogen flushing systems have several advantages but are expensive to operate. Burner systems are cheaper but have other disadvantages. Probably, several systems will find future practical application.

[illegible]

[illegible]

[illegible]

4.13. Modified atmospheres

Modified atmosphere storage [illegible] in a beneficial atmosphere [illegible] ventilation. Examples of this technique are the use of polyethylene box liners for apples, pears and cherries or the addition of dry ice [illegible]

With box liners the change in the atmosphere is created by using films with different permeability to O_2 and CO_2. [illegible] (1957) reports that gas concentrations of [illegible] % CO_2 and [illegible] % O_2 were obtained in boxes of pears and apples stored [illegible] using various kinds of film.

This method has been the subject of much experimental work during the last decade. While some authors report excellent results with a considerable retardation of ripening, especially for pears, others maintain that no dependence can be placed on improved storage life because of great variability between different containers in the composition of the atmosphere.

One definite drawback of the method is that the liner must be opened in some way as soon as the fruit is taken out of cold storage. Otherwise, when the temperature rises and the rate of respiration of the fruit increases harmful effects may arise through a too low concentration of O_2 and/or a too high concentration of CO_2. Therefore, if pears or apples are to be carried in sealed liners by ocean transportation an unbroken cold chain from the land store into the ship's hold appears to be indispensable.

4.14. Evaluation

Until quite recently commercial use of CA-storage has been mainly limited to apples and pears. For this purpose, however, the method has found extensive application, especially in the United States, Great Britain, Italy and France. It must be considered as virtually indispensable for efficient, long-time storage of most apple varieties.

The introduction of the externally generated atmosphere technique is opening the way for new and highly interesting applications of CA-storage. Many fruits which appear to offer attractive possibilities for world marketing from the areas under special consideration in this paper have a notoriously short storage life. These fruits are unable to develop a product generated atmosphere before serious deterioration takes place but may benefit materially from CA-treatment. Moreover only the introduction of this technique has made ocean transportation of fruits under CA-conditions a practical proposal.

It should not be forgotten that CA-storage is more expensive to install and operate than regular cold storage. Also it requires a more advanced technique for running and supervision.

Our knowledge about the behaviour of most kinds of fruits under CA-conditions is far from complete. Fruits of the same kind but with different origin often react differently. Consequently much more research is needed to make optimal application of the CA-technique possible.

4.2. IRRADIATION

4.21. Introduction

Post-harvest treatment of fruits by irradiation has attracted considerable interest because of several possible beneficial effects. Most important of these is the possibility to control storage diseases through the fungicidal properties of radiation. A second tempting application is opened by the delay in ripening induced in certain kinds of fruits.

Up to date reviews of current status and problems in fruit irradiation are given by SOMMER & MAXIE (1966) and DIEHL (1967).

4.22. Control of diseases

The greatest potential advantage of irradiation for control of fungus diseases is that the treatment penetrates the fruit tissues. Thus, the pathogen growing within the host may be inactivated or inhibited. With chemicals generally little or no penetration is achieved.

To obtain a satisfactory fungicidal treatment the pathogen must be killed or inhibited by a dose that does not induce any practically important, adverse effects in the fruit. Unfortunately, only quite few commodities withstand satisfactorily the doses necessary for disease control. For this reason considerable attention has been devoted to techniques for improving the fungicidal effect, reducing host damage or both. Among methods studied the following may be mentioned: oxygen sensitization, shallow irradiation, combination of radiation with chemical treatments or with heat treatment. The last mentioned approach appears to be the most promising one, as in many cases a strong interaction between the two treatments is obtained.

Obviously, fungicidal treatment of fruits by irradiation is still in its infancy but in some cases practically promising results have already been obtained. This applies particularly to strawberries. In this fruit a dose of 0.2 Mrad may prolong refrigerated storage life with several days, mainly by controlling Botrytis cinerea.

Brown rot and Rhizopus rot in stone fruits may be controlled by irradiation soon after harvest, but unfortunately the doses required soften the fruits to such an extent that normal handling is made impossible. This difficulty may eventually be resolved by using a combination of heat treatment and irradiation.

So far irradiation of citrus fruits has not looked particularly promising due to poor disease control with doses non-injurious to the host and to the availability of fairly efficient chemical fungicides (cf. section 4.32.). Recently, however, DIEHL (1967) has reported promising results from the combined effects of coating the fruits with a synthetic polymer irradiating with 1 MeV electrons and subsequent cold storage. The polymer coating serves to minimize reinfection after irradiation and to reduce water losses. Lemons treated in this way were in excellent condition even after 3 months and showed better juice yields and higher vitamin C contents than diphenyl treated lemons kept at the same temperature.

Radiation may control pathogenic or non-pathogenic storage diseases in apples and pears. It appears unlikely, however, that such treatment will become of practical interest in the foreseeable future. On the one hand reasonably satisfactory and cheap chemical treatments are available; on the other there are definite risks for delayed irradiation injury in storage.

4.23. Physiological responses

The metabolic state of the fruit at the time of treatment has a decisive influence on the physiological response to irradiation. In fruits of the climacteric type irradiation before the onset of the climacteric rise will initiate effects markedly different from those obtained by treatment later than the midpoint of the rise. Preclimacteric fruits show no consistency in ripening response to irradiation. Bartlett pears will either fail to ripen or ripen abnormally. Peaches and nectarines will ripen prematurely. In bananas ripening is temporarily inhibited and is normal once initiated spontaneously or by treatment with ethylene. Mangoes show a delay of ripening with up to 6 days. In all these fruits ripening proceeds normally if irradiation is done after the climacteric rise in respiration has progressed to a measurable degree.

Our understanding of the effect of radiation on ripening of fruits is far from complete. In some fruits the endogenous production of ethylene is inhibited, in others it is stimulated. In addition the sensitivity of the fruit to ethylene may be changed.

It has been established that irradiation will intensify many physiological disorders of fruits such as chilling injury and high temperature injury.

4.24. Evaluation

Irradiation so far shows limited promise only for prolonging the storage life of fruits. Much more research is needed until reliable conclusions may be drawn as to the feasibility of this technique for any kind of fruit. Attention should be focused on ways of maximizing disease control and reducing adverse host responses.

Investment costs for irradiation are generally quite high. The technique will only be economically applicable where large volumes of produce are handled in a centralized way. It will have a good chance only where conventional methods of preservation are unsatisfactory. One example of this may be control of fungus diseases in fruits, as chemical methods generally leave residues in the foods, which are regarded with rapidly increasing suspicion.

It is sometimes believed that food irradiation is a panacea and this is the main reason why it has been discussed here at some length. The obvious conclusion is that irradiation will not replace conventional methods of fruit preservation - but possibly supplement them in a few special cases.

4.3. DISEASE CONTROL WITH CHEMICALS ETC.

4.31. Background

As already indicated attack of micro-organisms, especially fungi is probably the most important cause of loss in storage of fruits. Methods to control these diseases include spraying in the field to reduce infection and good storage practice such as rapid cooling and correct storage conditions. In some cases application of fungicidal and/or fungistatic chemicals after harvest may be useful.

Before a chemical treatment is used several factors have to be considered. It must be effective for the purpose for which is intended, it must be reasonable in cost, it must be non-toxic to the fruit and, most important of all it must not be harmful to humans.

In order to illustrate the problems of control of storage diseases these will be reviewed for two important commodities in the subsequent sections.

4.32. Rotting of citrus

Citrus fruits are very liable to attacks during storage by a number of fungi, especially Penicillium sp. The possibilities to control rotting by using low storage temperatures are limited due to the fact that such temperatures may induce physiological skin disorders.

The possibilities to check rotting using fungicidal chemicals have been studied extensively (MUNOZ DELGADO 1966). The treatment may be performed by immersing the fruits in fungicidal solutions, by wrapping in paper or packing in cartons impregnated with active chemicals or by in other ways exposing the fruits to a fungicidal atmosphere.

A great number of chemicals have been examined but very few have been found useful for application in practice. Apart from efficiency the most important limiting factor is the strict demands on non-toxicity to human beings. In earlier years much use was made of boric acid and related compounds. Recently more efficient chemicals have been introduced, e.g. sodium salt and esters of ortophenylphenol as well as diphenyl.

Some countries have more strict food laws than others and do not allow the use of the chemicals mentioned above. For this reason studies have been initiated in Spain to develop an efficient thermic treatment to replace the chemical method. (MUNOZ DELGADO loc. cit.). Promising results have been obtained by immersion of the fruit in a hot water bath (temperature 53°C) for five minutes followed by cooling in cold water.

4.33. Grey mould in grapes

Grey mould caused by Botrytis cinerea is a most troublesome disease in grapes, often causing severe losses in storage and transportation. So far the only efficient control method available is to expose the grapes to an atmosphere containing sulfur dioxide. Other chemicals are being studied and promising results have been obtained but they are not yet available for application in practice.

Unfortunately the use of sulfur dioxide is encumbered with certain difficulties and inconveniences. Thus, it is difficult to determine the optimum concentration and time of treatment as these are affected by a number of factors, e. g. variety, degree of maturity, temperature and condition of the skin of the grapes. Moreover, one fumigation is generally not sufficient, the treatment having to be repeated every 7th to 10th day. The stowage of the fruit must be arranged in such a way that sulphur dioxide is evenly distributed throughout the stow. Finally, sulphur dioxide is extremely corrosive against metals and it is necessary to protect all metallic components in the store room against this.

However, the picture may be changed by a quite new technique for applying sulphur dioxide to grapes, which is now being developed (PAULIN 1966). A polyethylene bag is used to stabilize the emission of sulphur dioxide from a metabisulfite solution. This contraption is called a "generating bag". The permeability of the polyethylene film to sulphur dioxide provides a nearly constant gas discharge rate during the whole storage period. This rate is determined by the film thickness and surface area and the quantity of metabisulfite introduced into the bag. Grapes are stored in a perforated polyethylene package. Generating bags are placed in contact with and between bunches of grapes and the upper surface of the package. An equilibrium condition is reached between the quantity of sulphur dioxide continuously discharged by the generating bag and that diffusing out of the package

4. 34. Antibiotics

The possibility to use antibiotics to control microbial attacks on stored commodities has attracted much attention in recent years. Notable progress has been achieved, especially with meat, poultry and fish, while with fruits the prospects look much less promising. Experiments have been made with peaches and strawberries in which some fungistatic effects have been registered.

5. COLD STORAGE OF FRUITS - COMMODITIES

5. 1. Deciduous fruits

5. 11. Apples

More apples are stored on a tonnage basis than any other fruit. Also, the average storage period is longer. The literature on storage physiology, storage diseases and storage practice is immense (cf. U. S. AGRICULTURAL RESEARCH SERVICE 1965).

The optimum storage temperature for each apple variety should

- retard ripening as far as possible;
- control decay organisms as effeciently as possible;
- not cause low temperature disorders to any economically important extent.

Against the background of these criteria it appears that

a) Provenance, variety, picking time etc. play a very important rôle in the choice of the optimum storage temperature.

b) Many kinds of apples are best stored at quite low temperature, i. e. around -0. 6°C to ±0°C. This applies for instance to most varieties from the North Pacific Coast of the U. S. A. , from Argentina and from South Africa.

c) A number of varieties of apples are subject to a disorder know as "low temperature breakdown". This may become apparent at temperatures below +4° to +5°C, its incidence and severity increasing with lower temperatures and longer storage periods. In most cases apples grown in a more temperate climate are more sensitive to this type of disorder. For this reason apples from New Zealand and Tasmania are often stored and carried at temperatures between +1. 1°C and +3. 3°C and from the mainland of Australia at +3. 3°C. Most apples grown in Europe should not be stored at a lower temperature than +2°C; for some varieties the optimum temperature is as high as +5°C.

d) Apples from Chile are generally stored at the same low temperature as those from Argentina. However, there are indications that some Chilean apple varieties are fairly sensitive to chilling damages and that a slightly higher storage temperature might be preferable. Experimental studies of this problem appear warranted.

The storage life of different apple varieties varies between a few weeks up to 8 months. Early varieties generally are more perishable than later ripening ones.

CA-storage of apples may prolong the storage life very considerably, sometimes even double it. For modern long-time storage of apples the CA-technique must be regarded as indispensable.

The optimum CA-conditions vary as much with provenance, , variety etc. as the requirements on storage temperature (cf. section 4. 12 6).Generally (O_2)

is kept at 2 - 3 %, (CO_2) between 2 % and 8 %. The most striking benefits from CA-storage are obtained with those varieties which develop low temperature disorders in regular cold storage.

Scald is probably the most important storage disorder of apples. The classical control method is the use of mineral oil paper, either shredded or as individual fruit wraps. More effective chemicals are now available, e.g. diphenylamine and ethoxyquin. These are applied as post-harvest dips or sprays or impregnated in wraps.

Generally, scald is less severe in CA-storage than in regular storage. The disease is frequently not visible in storage but develops rapidly when the fruit is moved to warm temperatures.

5.12. Pears

With few if any exceptions it is essential to store pears at a temperature as close to the freezing point of the fruit as possible. It is also of primary importance that pears are precooled to this temperature immediately after harvesting and kept closely to this level during the entire storage period. The optimum storage temperature generally is -1.7 to -0.5°C.

Pears differ from most other kinds of deciduous fruits by having both an upper and a lower limit for normal ripening after storage. As already stressed the ideal storage temperature for pears is very close to the freezing point of the fruit. It must, however, be specially noted, that there is an upper critical temperature level, above which pears lose their ability later to ripen in a normal way. This "dangerous temperature zone" varies between varieties, but is generally between +2°C to +10°C. The obvious conclusion is that keeping pears in this "dangerous" temperature interval during any phase of handling, storage and transportation must be most carefully avoided.

The storage life of pears varies very much between varieties - from 2 - 3 months for Bartlett up to 6 - 7 months for Packham and Winter Nelis.

Polyethylene film liners may extend the storage life of several varieties of pears by 1 - 2 months (cf. section 4.135). It has been realized for many years that pears may benefit from CA-storage. However, so far this type of storage has been used only on a fairly limited scale, but now a rapid increase appears to be taking place in several countries.

The literature on pear storage is extensive. A large number of important references are found in U.S. DEPT. AGRICULTURE (1968).

5.13. Grapes

Largely because of their high sugar content most varieties of table grapes have freezing points that are lower than for any other important kind of deciduous fruits. Although for most varieties there is no danger of freezing injury at temperatures as low as -2.2°C, they are usually stored at temperatures between -1.1° to ±0°C.

Unlike apples and pears, grapes do not ripen further after harvest. They should be picked at optimum maturity.

Good keeping varieties such as Emperor and Almeria may be stored successfully for up to 6 months. Other varieties have a much shorter life-span.

The most important cause of deterioration of grapes in storage is attacks of gray mold (Botrytis cinerea). Methods of control are discussed in section 4. 33.

For a comprehensive review of the problems in storage of grapes reference should be made to RYALL & HARVEY (1959).

5. 14. Stone fruits

Stone fruits - apricots, cherries, peaches, nectarines and plums - generally have their optimal storage temperature at -0. 6° to 0°C. Some exceptions are discussed below.

These fruits have a comparatively short storage life. Mostly it is not sufficiently long to allow transocean shipment by sea without difficulties and complications.

Most stone fruits appear to benefit from CA-storage. Commercial application, however, is so far on a limited scale. More experimental evidence about optimal CA-conditions is needed.

Apricots may keep well for 1 to 2 weeks, or possibly even 3 weeks if stored at -0. 6°C. They are subject to internal breakdown at temperatures above 0°C.

Cherries keep for about 2 weeks at -1. 1° to -0. 6°C. The use of sealed polyethylene liners will extend the storage life by at least an additional week. With a suitable film thickness atmospheres containing 7 - 9 % CO_2 and 3 - 5 % O_2 will be generated within the packages These must be opened when fruit is removed from cold storage as off-flavours may develop at higher temperatures. CA-treatment will also extend the storage life of cherries but benefits obtained are no greater than those by polyethylene liners.

It is difficult to store peaches for extended periods. Most freestone varieties keep for 2 weeks and some freestone and most clingstone varieties for 3 - 4 weeks at -0. 6°C to 0°C. With longer storage peaches lose their flavour and natural bright colour. Their flesh may become dry and mealy or wet and mushy. Internal browning often develops. In some varieties mealy breakdown (wooliness) may be reduced by keeping the fruit at fairly high temperature (18° to 25°C) for 2 - 3 days before lowering the storage temperature to -0. 6°C.

Nectarines have the same storage requirements as peaches.

Plums are very sensitive to cold injury internal breakdown when stored at temperatures from 0. 5° to 6°C and this temperature range must be carefully avoided. Most plum varieties can usually be stored satisfactorily at -0. 6°C for 3 - 4 weeks. If storage at this temperature is extended too long difficulties may be encountered in ripening the plums. To master this problem a "dual temperature" technique has been developed for the transportation of plums between South Africa and Europe. The plums are carried at -0. 6°C for part of the voyage. Then the temperature is rapidly raised to +7° to +10°C, depending on the variety, for the rest of the voyage. By varying the periods of either shipping temperature the plums may be landed overseas at the most desirable stage of maturity for ripening.

5.2. Citrus fruits

5.21. General considerations

The two main causes of loss in storage of citrus fruits are fungal rotting and physiological skin disorders. The lower the storage temperature the better is rotting kept under control. On the other hand, physiological disorders usually are aggravated by low temperature. Successful storage depends to a very large extent on an intelligent balancing between these two risks.

A great many factors influence the optimum storage temperature, e.g. variety, nature of soil, cultural practices such as irrigation and spraying, size of fruit, time of harvest, degree of maturity. This may well explain why so many different temperature recommendations are encountered in the scientific literature as well as in practice.

When fruit from a given region is known to be liable to rotting and has not been given any fungicidal treatment, it is often better to accept some risks of injury to the skin by storage at a somewhat lower temperature and in this way minimize losses from rotting.

Results with CA-storage of citrus fruits have not been encouraging.

Citrus fruits are very liable to attacks during storage by a number of fungi, especially *Penicillium sp.* Control methods are discussed in sections 4.22. and 4.32.

The application of wax or wax emulsion preparations to citrus fruits has been practiced for many years. Waxing reduces moisture loss and thus retards shriveling. It may also give an improved glossy appearance.

For a more detailed discussion of citrus storage reference should be made to MUNOZ DELGADO (1966) and ROSE et. al. (1944, 1951).

5.22. Oranges

The optimum storage temperature for oranges varies between 0° to 5°C. The economical storage life generally amounts to 8 - 16 weeks.

5.23. Clementines, satsumas, mandarines

The European recommendation for these citrus fruits is to store at 4° to 6°C. (MUNOZ DELGADO 1966). Under such conditions storage life is stated to be around 8 weeks.

According to U.S. recommendations mandarine type citrus fruits should be stored at 0°C. Because of their perishable nature they should not be kept longer than 2 - 4 weeks and they should be marketed promptly after removal from storage.

5.24. Lemons

The optimum storage temperature for lemons is 12° to 14°C. Under such conditions they may keep up to 6 months. Lemons that are of proper size and dark-green colour when picked have the longest storage life. Tree-ripened fruit does not keep well in storage.

5.25. Limes

Limes may be stored satisfactorily at 9° to 10°C for 6 to 8 weeks. Some loss of green colour, however, often becomes apparent after 3 to 4 weeks' storage. Green colour is retained better at temperatures around 5°C, but limes are subject to pitting if kept below 7°C. This condition develops soon after removal from storage.

5.26. Grapefruits

Grapefruits are more sensitive to low temperature injury than most other citrus fruits. Generally, recommended temperatures range between 10° and 16°C. Sound fruit that has been carefully handled and is not overripe can usually be stored 4 to 6 weeks, even up to 12 weeks without serious spoilage.

5.3. Bananas

The most important application of refrigeration to bananas is in overseas transportation. Generally bananas are picked at a stage of development which should permit their arrival at destination without ripening. At unloading the bananas must still be in the preclimacteric phase, i.e. quite green and hard. In this condition they can be handled with relatively small risks for mechanical injuries and bruising.

Although there exist over 500 edible banana varieties only a few have significant commercial value. These include Gros Michel, Cavendish, Lacatan, Poyo and Valery.

Bananas have to be in transit for periods up to 24 days. Especially for long-range transportation it is necessary to maintain optimum conditions throughout e.g. in selection, overland transport, packing, loading, cooling, carriage at sea, during discharge and finally ripening.

The keeping quality (transportability) of the banana is influenced by a great many factors, some of which are difficult or impossible to control. Most important among these is the degree of development at harvest. Others include fertilization, diseases, parasites and climatic conditions.

The greater the degree of development (fulness) at harvest, the shorter is the time the banana may be kept in the preclimacteric stage. On the other hand, the more developed fruit is generally considered to be superior in quality and consequently is in higher demand on the consumer market. The choice of the correct fulness for a specific trade demands considerable diligence and experience.

Various criteria have been proposed for an objective determination of the degree of development. These include number of days after emergence of the flower bud, pulp/peel ratio, hardness and colour of the pulp, size and shape of the individual fingers. In practice almost only the last mentioned criterion is used.

In recent years the technique of handling bananas has changed drastically. Earlier bananas were invariably shipped on the stem. This practice still continues in a few trades but today by far most bananas are cut from the stem, sectionalized and packed in cardboard boxes before loading. This is a most important advance as boxing eliminates many sources of handling damage previously encountered in shipping stems.

Below a certain temperature, which differs between varieties, bananas are liable to chilling damage. Chilling is mainly a peel injury in which certain cells are killed. The dead cells darken and give the peel a characteristic smokey or dull-yellow appearance after ripening. In chilled fruit there is a tendency for the onset of the climacteric to be delayed and if the damage is severe full flavour and normal consistency may not develop. Chilling is generally considered to have a simple time-temperature relationship but this has been questioned.

The following carrying temperatures are generally recommended for bananas

Gros Michel	11.4° - 11.7°C
Cavendish, Lacatan, Valery, Poyo	12.8° - 13.3°C

This recommendation is subject to slight modifications as a result of stage of maturity, packaging used, length of voyage and air-circulating system employed.

Bananas are very sensitive to ethylene in the unripe state. Even 0.5 part per million, if maintained in the atmosphere, will eventually initiate the onset of the climacteric phase. When that is entered they are no longer sensitive to ethylene and are in fact producing small quantities of it themselves. The presence of fruit, in and after the climacteric phase presents a danger to the unripe, preclimacteric fruit in a cargo space. Ethylene must not be allowed to accumulate but must be removed by fresh air ventilation. So far only very approximate data on the ethylene production at different temperatures and stages of development of the fruit are available. There is also little knowledge of which concentration can actually be tolerated. Consequently, the fresh air ventilation capacity can so far only be decided on the basis of practical experience. Figures up to 3 complete changes per hour are common.

The air circulating system is of prime importance in the carriage of bananas. With boxed bananas vertical systems are generally considered to be superior to horizontal systems, which require the use of some form of dunnage to operate satisfactorily. The rate of air circulation necessary is still an open question; 60 - 80 changes per hour is accepted standard for modern banana carriers some have even more.

The ripening of bananas requires a well developed technique and special equipment with adequate possibilities for the control of temperature and relative humidity. The temperature range employed is generally between 14° and 20°C with high relative humidity of 90 to 95 %. Within certain limits, the period required for ripening green fruit can be extended or shortened to meet trade demands by adjusting the temperature. Under average conditions, the ripening period may be as short as 4 days with higher temperatures or it may be extended to 8 - 10 days with lower temperatures. The addition of ethylene in a concentration of 0.1 % to ripening rooms is recommended to stimulate ripening in certain cases, e.g. Valery boxed in the production area. Such treatment assures uniform colouration on a predetermined schedule and allows use of lower than normal ripening temperatures, which will result in increased shelf life.

For more detailed information on bananas, their handling, transportation and ripening reference should be made to I. I. R. (1962), DEULLIN (in press), SIMMONDS (1959), STANDARD FRUIT AND STEAMSHIP COMPANY (1964), UNITED FRUIT SALES CORPORATION (1964, 1965), VON LOESECKE (1949).

5.4. Tropical fruits except bananas

5.41. Pineapples

Flavour and aroma are most attractive in pineapples fully ripened on the plant. Such fruits, however, are unsuitable for extended storage and transportation and for such purposes a less mature grade must be selected. It is necessary, though, that a certain stage of maturity has been reached at harvesting. Otherwise normal ripening may not take place and the final quality will be poor.

Generally, the colouring of the skin is used for judging the maturity of pineapples. This criterion, however, is far from infallible. At the same stage of maturity of the fruit flesh, the colour of the skin varies with the weight of the fruit, the climatic conditions during maturation and the variety. Thus, the heavier the fruit, the less is the colouration. During cool and dry periods the fruits take on much more colour than during hot and humid weather. Varieties with white flesh generally colour very little even on full ripeness. Therefore, additional criteria have been sought allowing a more reliable determination of the stage of development. In the fruit flesh the arrival of maturity generally manifests itself by the formation of translucent zones around the "eyes" with less marked colouration than the rest of the flesh. The maturity is more advanced the higher the percentage of the cross section area occupied by translucent zones. The development of the crown, slips, eyes and bracts may also assist in assessing maturity. Local study and experience is indispensable to determine precisely the most suitable harvesting maturity for particular requirements.

It is extremely important to protect the pineapples against mechanical damages during harvesting and packing operations. Bruising is quickly followed by inroad of soft rots. Various methods using special equipment have been developed to facilitate these operations (PY & TISSEAU 1965, who give further references

The optimum storage temperature is 7° to 8°C. In this range ripening proceeds very slowly and fungal decay (mainly caused by Thielaviopsis paradoxa) is kept in check. Lower temperatures cause chilling damages - the fruits take on a dull hue, develop water soaking of the flesh and darkening of the core and are particularly subject to decay when [illegible] cold storage. At higher temperatures ripening proceeds rapidly [illegible] optimum conditions pineapples may be stored 4 or even 6 weeks.

CA-storage of pineapples has been little studied. It appears, though, that this method might open possibilities for [illegible] shipment of fruits harvested at a more developed (coloured) stage. [illegible] way an improvement of quality might be obtained, an important prerequisite for expanding the markets for fresh pineapples.

There is some evidence that the storage life may be prolonged by dipping the fruits in a wax emulsion. As a control measure against Thielaviopsis paradoxa a fungicide, e.g. 2, 3, 5, 6-tetrachloronitrobenzene, may be included in the emulsion.

Precooling as soon as possible after harvest and always within 24 hours is essential for obtaining optimum storage life.

Pineapples must be packed in such a way that they are very well protected against mechanical damages. A wide variety of package types have been developed; the more important ones are described by PY & TISSEAU (1965), who give further references. One attractive solution is vertical packing in cardboard cartons with special inserts to fix the fruits in position. In some trades, e.g. Puerto Rico - New York and Hawaii - New York pineapples are shipped in refrigerated containers, loaded at the plantation and carried unbroken all the way to the wholesale dealer. Under such conditions a much simplified packing may be adequate.

5.42. Avocados

There are three main races of avocados - the Mexican, the Guatemalan and the West Indian. The Mexican type is the hardiest and has small fruits with a very thin skin. The Guatemalan race is less hardy but considerably larger than the Mexican avocado. Its skin is thick. Well known varieties are Fait, Wagner, Taylor, Linda, Dickinson and Tass. The West Indian type is the least hardy of all avocados and includes the varieties Trapp, Waldin and Pollock. A number of hybrids between the races have became very important and popular. This is particularly so for the Mexican - Guatemalan hybrid Fuerte. Also worth mentioning are the Guatemalan - West Indies hybrids Collinson and Winslowson.

It is of critical importance for successful storage of avocados that they are harvested at the correct stage of maturity. This is influenced by the length of storage intended. Too immature fruits must be avoided as they tend to be inferior in flavour and texture on subsequent ripening. As avocado varieties show profound variations with regard to size, shape, colour, skin texture and other characteristics, only local experience can prescribe the exact picking maturity for any particular variety. In California fruits are tested in the laboratory for their oil content, which increases with maturity. This criterion, though helpful, is not absolute. Colouring varieties grown under West Indian conditions may be picked when they show the first trace of colouring (WARDLAW & LEONARD 1935). Specific gravity tests may be useful in determining picking maturity (STAHL 1933). In South Africa sample fruits are picked during the suspected ripening season and left to ripen in a warm place. As soon as these ripen normally without shrivelling the normal picking season is considered to have arrived.

Avocados are sensitive to chilling but the critical temperature varies very much between varieties. Some varieties are subject to chilling after 15 days at 11.7°C, while others are not damaged by extended storage even at 0°C. Various manifestations of chilling have been observed. The skin may become more or less severely necrotized, but internal chill effects are more common. While still firm, the flesh on cutting is seen to have acquired a slightly dark, smoky or brownish discolouration. In some varieties this is chiefly located next to the stone, in others it may occur in the tissue midway between stone and skin. Chilling of the flesh becomes accentuated with the onset of final maturity and culminates in more or less general discolouration of the entire tissue to a smoky-brown, chocolate-brown or black appearance. In some varieties the vascular strands, running longitudinally through the fruit, acquire a characteristic brown or blackish necrosed appearance. Various changes in flavour are associated with chilling. In some varieties palatability is only slightly impaired whereas in others the nutty quality of the normally ripened fruit may be replaced by a pasty insipid flavour, or more or less acrid flavours may be produced.

Chilling in avocados is a complicated phenomenon in which several factors are involved. In addition to variety, temperature and duration of storage the maturity of the fruit at the time of storage is of critical importance. Fruits stored immature only show chill effects after long exposure to the low temperature, i.e. after a certain stage in ripeness has slowly been reached, whereas fruits of the same variety stored more mature may show chill effects in a relatively short time. The evidence available indicates that fruits are most subject to chilling during the initiation of ripening.

The optimum storage temperature for avocados is largely determined by the critical limit for chilling; generally it should be as close to this as possible. According to recent U.S. recommendations (U.S. DEPT. AGRICULTURE 1968) the best storage temperature for cold-tolerant varieties such as Lula and Booth 8 is 4.5°C. All West Indian varieties, which include Fuchs, Pollock and Waldin, are cold intolerant and store best at 12.8°C. A few varieties, such as Fuerte are best held at 7.2°C. Cold-tolerant varieties can be held in storage for a month or longer, but storage of cold-intolerant varieties is usually limited to about 2 weeks. CONDIT (1919) reports that among Mexican avocado varieties, cultivated in California, the Chaliange variety was stored satisfactorily at 0°C for 6 weeks. Reports from Hawaii (HAROLD 1930, WILCOX & HUNN 1914) indicate that avocados grown there keep well for 6 - 8 weeks at 0° to 2.2°C. Studies in the West Indies by WARDLAW & LEONARD (1935) demonstrated that only a few varieties could be held at 7.2°C for 20 - 25 days without sustaining low temperature injury. On the other hand, a higher storage temperature, e.g. 10°C, was found inapplicable because of the tendency of fruits to ripen before the required storage life had been achieved. The authors recommend that among West Indian varieties only the most cold resistant ones should be considered for extended storage and that a steady temperature of 7.2°C is used for these varieties.

To sum up, the problems of cold storage of avocados are mainly to select varieties well adapted to this purpose and to harvest the fruit at the proper stage of maturity. Provided these [illegible] are mastered it appears [illegible] feasible to carry out successfully large-scale transoceanic shipments of avocados.

There is some experimental evidence that the storage life of avocados may be extended considerably by the application of CA-storage. Fundamental work on this problem has been carried out by [illegible] & LEONARD (1935), who report that the range of tolerance to CA-treatments varies from variety to variety, being comparable though not necessarily parallel to the response of different varieties to low temperatures. In varieties unsuited to CA-storage, external and internal damage may occur without the intervention of micro-organisms. In other varieties, although no direct physiological injury may be apparent, the fruits subsequently prove more susceptible to the inroads of storage pathogens. Others again show surprising tolerance to CA-conditions and the authors consider that such varieties would undoubtedly lend themselves to commercial preservation by this method. It is interesting to note that in this category are varieties subject to chilling and consequently unsuitable for transport at low temperatures. OVERHOLSER (1928) showed that the storage life of the Fuerte variety at 7.2°C could be extended from 4 to 8 weeks by applying an atmosphere of 4 % O_2 and 4 - 5 % CO_2. No doubt, the CA-method merits further studies in its application to avocados. It may well make possible considerable progress in the storage and transportation of this fruit.

5.43. Mangoes

There are about a thousand different varieties of the mango with highly varying characteristics and commercial value. They are, as is thought, derived in the first instance from six distinct species. For descriptions of the more important varieties reference should be made to SINGH (1960).

The choice of stage of maturity at picking is dependent on the duration of storage intended and the storage facilities available. It must be made with great care. Unfortunately considerable difficulties are encountered in finding suitable methods for judging maturity. Criteria useful for one variety may not be valid for others. Generally selection is based on shape, size and colour of fruits. Attempts have been made to use the sugar and acid content, the colour of the pulp, the number of days after blooming, the specific gravity etc.

Mangoes are very susceptible to low temperature injuries, which may manifest themselves as skin blemishes, failure to ripen normally on removal from cold storage and a marked decline in resistance to pathogens. Susceptibility to chilling varies with the variety, maturity on picking, season and duration of exposure to low temperatures. Studies on West Indian mangoes by WARDLAW & LEONARD (1936) indicate that the critical temperature for chilling is around 8.9°C for fruits harvested at a relatively early stage of development. Fruits picked on the point of softening tolerate a slightly lower temperature (7.2°C). Although 8.9°C may cause some chilling damage it is recommended for extended storage in preference to 10.0°C, as the latter temperature permits considerable activity of storage pathogens. Investigations in India (CHEEMA et. al. 1939 and others) demonstrate that the variety Alphonso, picked at the proper stage of development, may be successfully stored at 7.2° to 8.9°C for 7 weeks and subsequently ripened at room temperature. For another variety (Totapuri) the optimum storage temperature was found to be 5.6° to 7.2°C, which gave a storage life of 7 weeks. Studies by AKAMINE (1963) indicate that ripe fruits of the Haden mango (grown in Hawaii) can be safely stored in the wide temperature range of 1.7° to 12.8°C. The expected storage life of these fruits is about 4 weeks at 1.7° or 7.2°C, and only 1 week at 12.8°C. For extended storage mature green and partially ripe fruits can be safely stored only at 12.8°C. They ripen at this temperature and their expected storage life is about 2 weeks.

The above data give some illustration of the wide differences which exist between mango varieties with regard to optimum storage temperature and to storage life. Even though the storage life generally may be somewhat on the short side, it appears feasible to carry successfully mangoes to transocean markets by ship provided that proper care is taken in selection, handling and transportation.

There is some indication (KAPUR et. al. 1962) that mangoes may benefit from CA-storage. Much more experimental evidence is needed, however, before the possibilities of practical application may be evaluated.

The optimum ripening temperature for mangoes appears to be between 18° and 22°C, ripening normally taking 4 - 8 days. At higher temperatures wastage due to decay organisms increases and quality is lessened.

The problem of waste due to microbial attacks is difficult in mango storage. Damage due to wound parasites may be serious but can be successfully controlled by careful handling of the fruit. Apart from this mangoes very often, though apparently sound and unblemished on picking, carry latent infections of several important pathogens. Notable among these are Colletotrichum gloeosporoides causing anthracnose, Dothiorella ribus, causing stem-end rot and Phomopsis sp. and Pestalozzia funera causing lateral rots. Disease incidence during ripening, attributable to such dormant infections, is greatly accentuated by chilling, prolonged cold storage, slow ripening and tardy distribution. As the latent infections become established during the period of growth in the field, it is suggested that disease wastage can be considerably reduced by well-timed spraying operations during that period.

5.44. Papayas

There is a very wide variation between varieties of papaya with regard to appearance, quality, commercial value and storage properties.

Storage trials carried out in Trinidad (WARDLAW et. al. 1934) indicate that relatively immature papayas will not ripen after cold storage. Most of the varieties tested showed evidence of chilling if held at temperatures below 13° to 15°C. Some varieties, however, when picked yellow but quite firm, could be stored successfully at 7.2°C for 20 days. Current recommendations for Hawaiian papayas (U.S. DEPT. AGRICULTURE 1968) is to harvest at the 3/4 ripe colour stage and store at a temperature close to but not below 7.2°C. The storage life under these conditions is 1 - 3 weeks.

Papayas should be ripened at 21° to 27°C. The application of ethylene may be beneficial.

The problem of wastage in storage is serious. It is principally due to attacks of Colletotrichum gloesporoides (antrachnose), established as latent infections during the development of the fruits in the field. Normally decay becomes apparent only when the fruit is approaching final maturity in storage, but may also occur in less mature fruits which have been held at chilling temperatures. Andrachnose may be fairly well controlled by applying heat by one of two methods, vapour heat treatment or hot water treatment (for details see U.S. DEPT. AGRICULTURE 1968).

WARDLAW (1937) considers overseas transportation by ship and distribution of papayas to be by no means impossible, provided suitable types can be selected. This opinion may be slightly on the optimistic side. In any case, practically all shipments of papayas from Hawaii to the U. S. mainland is now by air.

5.45. Dates

Dates are subject to two general types of deterioration. One is caused by micro biological activity, the other form is physiological and includes darkening and loss of flavour.

Dates with 23 % or less moisture are comparatively safe from microbiological spoilage but become increasingly succeptible as the moisture content exceeds this level. Low temperatures also retard microbiological decay.

Physiological deterioration of dates is influenced by temperature, moisture content and variety. Moisture content is particularly important at higher temperatures. Thus, at 24°C colour of Deglet Noor dates is retained four times as long in fruits with 20 % moisture as in similar fruits with 24 % moisture. Similar relationships occur at cold storage temperatures.

For best retention of texture, colour and aroma Deglet Noor and similar varieties should be stored at 0°C or lower. They can be held for a year at 0°C, somewhat longer at -18°C, about 8 months at 4°C, 3 months at 16°C and 1 month at 27°C. Dates of the soft, invert-sugar type should be stored at -18°C or lower.

5.46. Other tropical fruits

Under this heading a number of tropical fruits will be discussed, which presently do not enter international trade in appreciable quantities. For most of them the storage requirements are incompletely known and there is a definite need for much more critical experimental work on this subject.

Chinese gooseberry (Actinidia chinensis)

The optimum storage temperature is -0. 6° to 0°C and the storage life 6 - 8 weeks. Careful handling is necessary to present fruits from splitting.

Durian (Durio zibethinus)

Maturity is indicated by a slight splitting of the rind. As ripening proceeds the segments of the rind split completely. MATHUR & SRIVASTAVA (1954) state the optimum storage temperature to be 3. 9° to 5. 6°C. In their studies the storage life ranged between 4 and 8 weeks depending upon the extent of splitting of the rind before storage. In fruit without any splitting it was 8 weeks. The problem of marketing this fruit is complicated by several factors, e.g. its large size and prickly exterior.

Figs

The fruits should be picked fully grown but just prior to softening, otherwise they do not ripen properly or develop their full aroma. Immediate precooling is indispensable. The best storage temperature is -0.6° to 0°C. The storage life generally is no longer than 1 - 2 weeks, although cases of successful storage for 4 weeks have been reported. Fresh figs are very delicate and require careful handling and packing.

Guava (Psidium cattleyianum)

The optimum storage temperature is 7° to 10°C with an expected storage life of 3 - 4 weeks. At lower temperatures shrivelling and decay increase. The storage life may be extended by skin coating and/or CA-treatment (SRIVASTAVA et. al. 1962).

Jackfruit (Artocarpus integrifolia)

According to studies in India (SINGH & MATHUR 1955) jackfruits are best stored at 11° to 13°C. The storage life at this temperature ranges between 3 and 6 weeks.

Langsat (Lansium domesticum)

The cold storage of langsats has been studied in the Philippines by SAN PEDRO (1936). He concludes that only ripe fruits are suitable for storage. The best results were obtained at 13° to 16°C, the fruits remaining in good condition for about 2 weeks. At lower temperatures chilling damages occurred in the form of brown blotches with a water soaked appearance distributed over the skin. At higher temperatures the storage life was shorter and the onset of wastage more rapid.

From experiments in India SRIVASTAVA & MATHUR (1955) found the optimum storage temperature to be 11° to 13°C with a storage life of 2 weeks.

Litchi (Nephelium litchi)

The storage life of fresh litchies is limited by darkening of the natural purple colour of the skin, by desiccation and by decay. They can be stored at 0° to 2°C for 6 weeks, according to information from India even up to 11 weeks, provided they are packed in polyethylene bags or similar moisture retentive material to prevent desiccation (HATTON et. al. 1966).

Mangosteen (Garcinia mangostana)

One of the main difficulties in the cold storage of mangosteens is the hardening of the rind which occurs with prolonged storage. This tends to be greater the lower the temperature. In view of this a storage temperature of 4° to 5.5°C is recommended, giving a storage life of about 7 weeks (SRIVASTAVA et. al. 1962)

Passion fruit (Passiflora edulis)

Fruits should not be harvested too immature as they may fail to ripen properly. The correct stage of picking varies with season and climatic conditions. Careful grading and packing is necessary. Desirable types of cases and systems of packing are described by KRONE (1929).

The information on the storage properties is partly contradictory. Australian experiments (ANON. 1934) indicate that passion fruits are susceptible to chilling below 10°C, chilling taking the form of a blood red discolouration of the skin quickly followed by mould attacks. A storage temperature of 10°C is recommended giving a storage life of 4 - 5 weeks. I. I. R. (1967) on the basis of information from India recommends a storage temperature of 5.5° to 7°C and states that fruits will keep for 4 to 5 weeks at this temperature.

Persimmon (Kaki plum, Diospyros kaki)

Persimmons should be harvested when fully grown but firm. Great care should be taken to avoid bruising as injured fruits decay quickly. Persimmons are well adapted to extended cold storage; at -1°C they keep for 2 months or longer. Most varieties have a tendency to shrivel, particularly at the apex. The use of relatively impervious wrappers is therefore advisable.

Pomegranate (Punica granatum)

Because of their tendency to splitting most varieties must be picked before they are quite ripe. Ripening, however, continues in cold storage. According to recent U.S. information (U.S. DEPT. AGRICULTURE 1968) pomegranates keep for 2 to 4 months at 0°C. From India MUKERJEE (1958) reports successfull storage for as long as 7 months at 0° and 4.4°C.

Sapodilla (Sapota, Acras sapota)

Information available on the storage properties of sapodillas is partly contradictory. CAMPO (1934/35) reports that the best storage temperature for green and turning fruits is 15°C with a storage life of 16 - 18 days. Ripe fruits could be held in good condition at 0°C for 12 days. According to CHEEMA & GANDHI (1925) green sapodillas can be stored for 4 weeks at 4.4° to 10°C, after which they will ripen normally on removal from cold storage. SINGH & MATHUR (1954) report the optimum storage temperature for fully grown and hard fruits to be 1.7° to 3.3°C with an approximate storage life of 8 weeks.

Several tropical fruits, not included in the discussion above, may be of interest from the point of view of this paper. So far, however, reliable information on their storage properties is not available.

For most of the fruits treated in this section - Chinese gooseberry, durian, litchi, mangosteen, passion fruit, persimmon and pomegranate - it would appear to be well within reach to carry through successfully transocean transportation by ship. With guava, jackfruit and sapodilla this possibility is questionable, while for fig and langsat air transportation so far affords the only realistic solution.

5.5. Berries

Most fresh berries are extremely perishable. They can be carried to distant markets only by using air transportation.

Strawberries may be stored for a maximum of 5 - 7 days. The best storage temperature is ±0°C. Atmospheres high in carbon dioxide may extend storage life by retarding respiration and reducing the activity of decay producing organisms. Irradiation has shown some promise for controling decay in storage (cf. section 4.22.).

Raspberries may keep for 2 or 3 days at -0.6°C to ±0°C. This temperature retards various forms of decay. Precooling and storage in an atmosphere containing 20 - 25 % carbon dioxide may give a further check to ripening and to the development of fungal rots.

Currants, gooseberries and elderberries also are best stored at temperatures just below ±0°C. They may be stored for 1 to 2 weeks, gooseberries up to 3 weeks.

Blueberries (American type) can be stored at -0.6° to ±0°C with high relative humidity for about 2 weeks. With some loss in quality storage can be extended to 4 to 6 weeks.

5.6. Nuts

Nuts discussed here include almonds, brazil nuts, chestnuts, filberts, macadamia nuts, pecans, pistachio nuts and walnuts.

Nuts are much less perishable than most other fruits. Refrigerated storage is recommended, however, to maintain natural texture, colour and flavour and to retard staleness, rancidity and moulding for extended periods. With optimum temperature, humidity, atmospheric conditions and packaging good quality nuts of several kinds may be successfully stored for up to five years. Chestnuts and to some extent also pecans and walnuts are more perishable than other nuts. Shelled nuts can be expected to keep only half as long as nuts in the shell.

There is no critical temperature for storing nuts. Other conditions being equal, the lower the temperature the longer the storage life. A drop of temperature with 10°C may extend the life span from two to three times. Most nuts withstand freezing and can be stored for years at -18°C. A temperature below 3°C is recommended for nuts to be held from one harvest season to the next.

Nuts (except chestnuts) require a fairly low - 60 to 75 % - relative humidity. If humidity is too high mould growth, rancidity and other quality losses may occur. However, if it is too low, there is undue drying and the nuts may become objectionably hard and brittle. Chestnuts dry out and become hard and bony even at fairly high humidity; hence, protective packaging is needed for them.

The storage life of nuts may be greatly influenced by the kind of package. When nuts are shelled they become bruised and oil "crawls" over the surface and onto the package in a very thin film. Unless this is retarded by a package that acts as a barrier, contains an antioxidant, or removes oxygen by vacuum or by replacement with nitrogen, the nuts may become stale and rancid. Some packaging materials such as pliofilm and polyethylene should be avoided because they impart an undesirable odour to the nuts.

6. PACKING

6.1. BACKGROUND

A package generally has the following three functions (VAN HIELE & MEFFERT 1966)

- it is a means of transport;
- it separates a given quantity from a larger batch;
- it protects the product.

Demands on package performance are increasing due to longer shipping distances, new methods of selling and of transportation, higher requirements on produce quality etc. On the other hand, new packaging materials, mechanized handling, new refrigeration techniques and the rapidly increasing use of master pallets and master containers have provided possibilities that did not exist previously. Especially the last mentioned factor may well cause revolutionary changes in our present concepts of packaging technique.

The package has an important and sometimes overriding influence on two factors which to a large extent determine the storage life of fruits i.e. mechanical influences and temperature.

6.2. PROTECTION AGAINST MECHANICAL DAMAGES

This aspect of packing will be reviewed with regard to an important, specific problem, i.e. protection of apples and pears against bruising in transocean shipments. (Many of the conclusions presented are relevant for other kinds of fruits too). For many years the predominant method of packing such fruits has been in standard wooden boxes, holding about 20 kg. Especially with today's high quality demands it has, however, become increasingly evident that this type of package has very serious shortcomings with regard to the protection it affords the fruit when transported by road, rail or sea from the producer to the ultimate consumer. The main problem involved is bruising, primarily caused by rough handling during the many re-loadings the packages have to go through.

The last 10 - 15 years have seen the introduction and rapid development of fibreboard cartons as a substitute for wooden boxes. Different types of packages are in use,

a) Cell-pack carton, a type of package in which bruising is negligible. Its main disadvantage is that a number of different carton sizes are needed to pack the full range of sizes of export apples. This causes considerable difficulties in stowage.

b) Tray-pack cartons afford almost the same efficient protection of the fruit as the cell-pack. One advantage is that of uniform size; a disadvantage that it is not as strong and generally cannot be stowed to the same height as the cell-pack.

Palletized packs of cartons have many attractions from the handling point of view. This is no doubt a method which merits very serious consideration for the future.

One interesting alternative to palletized cartons is the use of bulk bins. These are containers with a gross weight running from some 300 kg up to 600 or 700 kg. They are generally made of wood, plywood or masonite.

It is generally agreed that apples are exposed to much less bruising damage when carried in cell-pack cartons, tray-pack cartons or bulk bins than in standard wooden boxes. To illustrate this some figures are quoted from a paper by EMILSSON & CASTBERG (1965), which summarizes experiments with Argentine apples, comparing packing in bulk bins holding about 500 kg with packing in standard wooden boxes. It was found that four of the five varieties tested gave an excellent out-turn when shipped in bulk bins. The amount of bruising was negligible, lesions of practical importance varying from 0.0 % to 0.8 % in the different varieties. The out-turn in wooden boxes differed very much between varieties, the amount of practically important lesions ranging from 2.4 % to as high as 35.9 %. Also the fifth variety, King David, which has a very soft flesh, showed less bruising in bins than in boxes, but the difference was only moderate.

The difference between standard wooden boxes and tray-pack cartons is shown by results reported by GINSBURG et. al. (1965). These authors state that an incidence of bruising above 60 % was common in the old bulge pack in bushel boxes. Tray-pack reduced bruising to less than 5 %. This refers to the use of paper pulp trays but it is believed that still better results may be expected by using trays made of polystyrene.

6.3. COOLING AND STOWAGE

All packaging materials act as a barrier against rapid heat transfer. Unless the fruit is precooled to its proper storage temperature before packing, which is seldom practical, packing may create definite difficulties in achieving the rapid cooling desired.

The shorter the distance from the centre of a package to its free surroundings and the larger the outer surface, the quicker will heat transfer occur. Any packaging material used inside the package such as wrappings, films, liners and trays will slow down heat transfer. On the other hand such additional materials are often very desirable to protect the fruit from bruising, desiccation and disease attacks.

Stacking individual packages closely together will cause a decrease in the outer surface assisting in heat exchange. This effect is illustrated by the following figures quoted from VAN HIELE & MEFFERT (1966)

Pears (individual) in air current	0.1 m^2/kg pears
Pears packed in 20 kg crates	0.04 m^2/kg pears
Pears packed in crates with only one small side exposed	0.004 m^2/kg pears

Practical consequences of better heat exchange on the half-cooling time may be illustrated by the following experimental results reported by VAN HIELE & MEFFERT (1966). The figures apply to pears in 25 kg boxes in an horizontal air flow of 2 m/sec.

Stowage	Half-cooling time hrs
Boxes on pallet (8 - 20 cm air space)	2.5
Boxes in small rows	3.0
Boxes in wide rows	4.0
Boxes in double wide rows	6.6
Boxes in block	7.5

Obviously it is possible to stow cartons much closer together than wooden boxes with bulge. This may create special problems in the cooling of carton-packed fruits. It becomes necessary to apply dunnage in sufficient quantities and in an intelligent way to open up the stack and facilitate cooling.

A question which has attracted considerable interest in recent years has been whether the cooling of fruits in cartons may be speeded up by providing the cartons with holes. The proper size and location of such holes has also been the subject of much speculation. Experimental results at the IVK (unpublished) indicate that the improvement of cooling velocity by holes is moderate only. If holes are used they should preferably be located at the corners of the carton, as they are then not so easily blocked in the stow. This, however, detracts from the mechanical strength of the package. For tray-pack cartons an attractive solution is to put one fairly large hole (appr. diameter 10 cm) in the bottom in combination with a long slit in the lid. Moreover, the trays should be provided with a number of small holes. In this way reasonable facilities are created for the cooling air to pass through the cartons in the stack, even if the stow is not exactly geometrical.

With respect to bulk bins one might expect poorer heat exchange as compared to conventional smaller packages. By providing for adequate air interchange in the bin, however, this difficulty is easily overcome. Thus, according to our experience cooling in a bulk bin with venting to about 5 % of the floor area and slightly raised lid is even more rapid than for wrapped apples in standard wooden boxes.

7. TRANSPORT

7.1. General comments

Transport is a most important link in the marketing of fruits. Except for very short durations (local market, air transport) it is generally necessary to apply refrigeration during the transport - the "cold chain" must not be broken. It is always desirable that the time in transit is kept as short as possible.

Presently sea transport dominates transcontinental trade with fruits completely. However, air transport is rapidly gaining in importance, especially for such commodities which combine short storage life with high price.

7.2. Land transport

Vehicles for refrigerated land transport by road or rail may either be equipped with mechanical cooling or refrigerated by a non-mechanical source (water ice, dry ice, liquid nitrogen, eutectic mixtures).

Land transport vehicles may take the form of rail wagons, trucks, road trailers or semi-trailers, railroad trucks or containers. The design of such vehicles with special reference to conditions in the tropics is discussed in I.I.R. (1965).

No doubt, the mobile units in the cold chain present greater difficulties than the stationary ones. Resources both for rail and road service often are inadequate, allowing only slow and infrequent transport and very light loads.

When ice is used as the cooling medium vehicles have to be charged not only before the commencement of each journey, but if the distance is long, also en route. This is one difficulty; another is that ice availability may be limited. Cooling with dry ice or liquid nitrogen is suitable for frozen goods but not easily adaptable to fresh fruits. Mechanically cooled vehicles are independent of fixed installations but have other serious drawbacks. The equipment is sensitive and liable to breakdown when exposed to a very hot climate or to poor road conditions. It requires regular service by trained personnel. In some cases the use of eutectic plates offers an attractive solution. These are robust and easy to use and require refrigeration installations only at the end-points of the journey. The method, however, is limited to average distances and is better adapted to frozen produce than to fruits.

From some points of view the container would appear to offer special advantages to technically less developed countries. It is highly flexible in use and may be adapted to various forms of transport - rail, road or water. Regardless of the manner of transporting the container, it is less expensive to purchase than say a refrigerated truck. Whilst awaiting shipment the container could serve as a small cold room to provide "refrigerated protection" for perishables, where no refrigerated services are available. However, the container has one very definite disadvantage - special heavy equipment is necessary for handling it. Such equipment is expensive and so far rarely available in developing countries.

7.3. Sea transport

The technique of refrigerated sea transport of fruits has reached a high level. Modern reefer vessels are equipped with efficient installations for maintaining the cargo at optimum conditions with regard to temperature and other pertinent factors. Often this technique can very easily be put at the disposal of a developing country wishing to export fruits overseas. A necessary prerequisite, though, is adequate facilities for inland transportation of the produce to the ship's berth. For most fruits - bananas are a noteworthy exception - it is also desirable to have facilities to precool the produce before loading in the ship's holds. Provided that the time elapsing between harvesting and loading is reasonably short - which among other things implies that the loading place is within easy reach of the production area - it may be acceptable to load warm fruit in the ship. Modern ships may serve as very efficient precoolers - more effective than many land installations. Some loss of quality due to delayed cooling of the fruit must, however, always be expected (cf. section 3.3).

One difficulty with sea transportation, especially in trades newly initiated, concerns quantities. Generally cargo quantities of at least 500 tons, mostly 1000 tons and upwards, are required to induce a modern, fully refrigerated ship, which is not in liner service, to call a port of loading. When liner service is available, quantities necessary may be somewhat smaller. Anyhow, it is always desirable to have enough produce of the same kind available to fill one cargo hold, generally 50 - 100 tons. Clearly this may be an obstacle, when a new market is to be developed. This is especially so for a number of tropical fruits, e.g. avocados and mangoes, which for various reasons - temperature requirements, risks for ethylene damage - may not be carried in the same hold as the big staple items (deciduous, citrus, bananas).

The arrival of the container may well revolutionize several aspects of the refrigerated shipping of fruits. In particular the container offers an easy solution to some of the "quantity problems" discussed above. With containers equipped with autonomous refrigeration special demands on transport conditions may be satisfied even for comparatively small parcels. Also the CA-technique may be easier to apply for containers than for large holds.

Problems in refrigerated shipping of fruits are reviewed by HALES (1963) and EMILSSON (1961, in press).

7.4. Air transport

Air transport is usually of short duration and flights are at an altitude where the temperature of the atmosphere is not very high. Provided that the produce is adequately precooled it would therefore not be necessary to apply artificial cooling during transport.

In order to limit undesirable temperature changes it may be advisable to use insulated containers. Several types of light, collapsible insulated containers are available for use with air transport.

The most serious risk for the occurrence of damaging - too high or too low temperature - is during the transfer of the produce to or from the aircraft rather than during the flight itself. Every effort must be made to protect the fruit against this risk. The problem is complicated by the fact that delays in time tables do occur and that facilities for temporary cold storage are not generally available at airports.

If the aircraft has to wait for some time on a sunny tarmac in connexion with loading, a considerable increase may occur in the temperature of the freight space. This may cause serious deterioration of the produce. In such cases cooling of the freight space by the use of mobile refrigerating units is strongly recommended.

8. MARKETING

This subject will only be considered briefly and with the emphasis on the application of refrigeration in the marketing of fresh fruits.

The marketing chain is composed of all moments included in the handling of fresh fruits from the picking until it reaches the consumer. It should be obvious from the preceeding part of this paper that proper and intelligent use of refrigeration during the entire marketing chain is of paramount importance to prevent waste, to secure that the fruits reach the consumer in optimum condition and, in many cases, to prolong the marketing season. Refrigeration may play an important rôle for stabilizing prices, making it possible to store seasonal surplus quantities until the market is ready to absorb them. The need for refrigeration is especially large in those parts of the world under special consideration here, as they generally have a warm or hot climate.

When production areas are very close to markets the need for refrigeration is less; in some cases it may be dispensed with entirely. On the other hand, when fruits have to be sent over long distances to reach markets, optimum use of refrigeration generally becomes necessary. This means immediate precooling following harvest as well as intermediate storage and transportation under carefully controlled temperature conditions.

In addition to refrigeration a number of other factors have great importance in the marketing of fresh fruits. Thus, it is essential that fruits are harvested at the proper stage of maturity, otherwise they will not reach the consumer with optimum eating quality. The optimum picking stage may vary considerably with regard to the distance to markets, transportation facilities available etc. In many countries it has been found desirable to establish official regulations for picking maturity.

Careful grading to established standards ensures ready acceptance of the produce on the markets and generally gives an improved economical return. Top qualities are essential for entering sophisticated foreign markets.

Packing must be carried out in such a way that the fruits are adequately protected against mechanical damages. Furthermore packages should preferably have an attractive appearance and must allow rational handling. International standardization of package sizes is in its infancy but would bring important advantages.

Even with optimum refrigeration time is often an essential factor in the marketing of fresh fruits. For many kinds of fruits only a very limited number of weeks - in some cases even days - are available before overripening and decay unavoidably make the produce unsaleable. This means that facilities must be available for speedy and uninterrepted transportation from production areas to consumer markets.

For some kinds of fruits ripening is a highly important link in the marketing chain. This is very much so for bananas, which has made necessary the development of a special banana ripening and distribution technique. This need is also apparent for a number of other fruits, e.g. pears, avocados and pineapples but so far little progress has been made. Admittedly the difficulties are considerable, but it is the belief of the author that the marketing of such fruits would benefit materially from finding ways to satisfy the demands of the consumer for optimum ripe fruits with full flavour and aroma.

As evident from the above, the handling of fresh fruit from harvesting until it is brought en route to consumer markets involves a whole series of operations: grading, sizing, sometimes washing and treatment with chemicals (fungicides, waxes etc.), packing, precooling and intermediate storage. There is a trend in many production areas to centralize all these operations to "fruit packing stations". Advantages gained by the creation of such big units are possibilities to mechanize all operations to the fullest extent and to provide optimum facilities for precooling and cold storage. Qualified technical personnel may be employed thus ensuring uniformity and high quality of the produce. Marketing can be made in a much more efficient way then by the small individual grower.

There are several different types of fruit packing stations with regard to their legal status. They may be owned and used by one big grower, a group of growers, a cooperative, a trade organization, a government department etc. The equipment needed varies, e.g. with the kinds of produce to be handled and the distance from the markets. Technical aspects of the design of fruit packing stations are reviewed by ANQUEZ (1966). The International Institute of Refrigeration has recently set up a working party to study problems in this connexion and to work out an operating manual for fruit packing stations.

Some comments on the special problems in developing export markets for fresh fruits may be warranted. Although world consumption and trade show an increasing trend, competition on the markets for the "established" kinds of fruits - deciduous, citrus and bananas - is intense. It can only be met by top quality produce offered at attractive prices and favourable payment conditions. Once again, to achieve this the full and efficient use of modern refrigeration technique is indispensable. It is, however, the author's belief that substantial markets for "new" kinds of fruits may be established within the reasonably near future. Thus a considerable increase of world trade in fresh pineapples appears to be within fairly easy reach. It also appears to be quite feasible to build up a large volume of international trade in avocados and mangoes. Other fruits are on the waiting list - sophisticated taste and increasing buying power in the industrialized countries create marketing possibilities hitherto unknown. It might well be that this possibility is more attractive to many of the developing countries than to enter the fierce competition in the markets for deciduous, citrus or bananas. No doubt, refrigeration must be an essential tool in any scheme for developing export of "new" fruits. Interesting advancements in the techniques of storage and transportation - especially the application of CA-treatment in conjunction with container transportation - are appearing and may well create a major breakthrough of the difficulties hitherto met with in the marketing of such fruits. A promising alternative is offered by air transportation, which undoubtedly will become considerably cheaper in the future.

Finally, a few words about future marketing possibilities for fresh fruits as compared to processed fruits. No doubt the demand for fruit juices will increase in years to come, stimulated by the application of more advanced processing techniques, e.g. freeze drying. Whether this will detract materially from the market for fresh fruits is an open question. As to the competition from other kinds of processed fruits - frozen, dried, canned etc. - it is believed that the fresh fruits will at least hold their present position.

9. OUTLINE OF A PROGRAMME

In this last section a few points are listed which appear to be worthy of consideration for any developing country wanting to make fuller and better use of its potential for producing fresh fruits.

Standardized production under plantation or orchard conditions is a first essential. To achieve this there is generally a need of much research on varieties, production technique, disease control etc. An efficient organization for informing and advising the growers is essential to ensure that the results of such research are utilized in practice to the fullest extent.

Much knowledge is presently available about the handling and storage of fresh fruits but there are certain serious limitations. Firstly this knowledge mainly applies to deciduous fruits, citrus and bananas while there are large gaps in our information about most other kinds of fruits. Secondly, our knowledge is mainly based on experience and research work from the industrialized countries. As has been conclusively demonstrated in preceeding sections, storage and handling requirements for any kind of fruit may vary considerably between different production areas. It is always desirable and often necessary to resort to local experience and experiments to establish the optimum conditions. Consequently there is an obvious need for research - fundamental as well as applied on fruit storage and handling to be carried out in important production areas of developing countries and to include the less well known kinds of fruits. A dream for the future would be to establish a number of adequately equipped research centres, staffed with qualified agronomists, plant physiologists and technicians, at carefully selected locations in different parts of the developing world. Such research centres may well be run as co-operative projects between a number of nations. It appears most desirable that the work of such centres is co-ordinated at a common international level.

The establishment of official rules for picking maturity, grading, quality standards, packing etc. is an important and indispensable tool for developing the fruit industry. These must be based on local research and experience, but in case export is considered, due attention must be given to the demands of international markets.

Lack of adequate transport facilities between production areas and markets very often is a severely limiting factor in attempts to expand and rationalize the fruit industry. Generally, difficulties are especially large with regard to the availability of refrigerated transportation. Although the improvement of transport may involve very heavy investments it is necessary to give this factor most serious consideration.

The establishment of fruit packing stations, strategically located and with sufficient capacity, is a further must in the programme. Such stations must be provided with cooling installations which give resources for precooling and cold storage adequate for the kind of trade envisaged.

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