Dienst Landbouwkundig Onderzoek
Instituut voor Agrotechnologisch Onderzoek

(CA) Storage of Horticultural Crops

Drs Simon P. Schouten

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Introduction

In many countrie's farmers still bring their harvested crops to the market to sell them directly to the consumer. In this case distribution is very simple and keepability of crops may be limited. Sometimes however distribution is much more complicated and keepability demands may be up till weeks or even months. Storage is necessary on several places in distribution chains because of the nowadays worldwide distribution. For example Dutch fruits and vegetables are stored for days or weeks at auctions and after selling they are transported and stored again on for example a wholesale market somewhere. After selling again storage takes place in a cold room of a shop and finally the crop may be stored in a refrigerater of a consumer. Storage is necessary to make possible this worldwide distribution of almost all harvested crops.
Storage at the farm of the grower has off course another background. He wants to spread his deliveries, especially in cases of one harvest per year including tree fruits, carots, potatoes. Storage will enable the grower to spread his deliveries and this may lead to better prices. Therefore apples are sometimes stored during almost a year in CA Controlled Atmosphere stores. A second goal of storage may be aspreading of deliveries to the factories of the processing industry. French fry and potato chips production take place during the whole year, made possible by storage of the tubers in big air cooled stores, in which sprout growth is controlled chemically.

Stored crops suffer however from deterioration, ripening and quality loss, depending on many pre- and postharvest factors. This quality loss must be inhibited as much as possible during storage and here we need post harvest technology and fysiology. We need to know the fysiological and biochemical backgrounds of deterioration, ripening and quality loss. Further we need the technical knowledge of how deterioration, ripening and quality loss can be inhibited in practice.

The major part of this syllabus will be devoted to the influence of post harvest factors (Temperature, Relative Humidity and Air Composition) on quality aspects (firmness, colour, growth, chemical composition etc) of several crops. The second part will be devoted to aspects of storage technology.

Factors influencing Keepability

A definition of keepability or is: the time, during which a described minimum quality level is maintained under defined conditions (1). In this definition the "described minimum quality level" is a problem. The "quality" of a crop is determined by many quality aspects (colour, firmness, pathological breakdown) and if one of these aspects becomes "minimal" keepability must be considered at its end. However this minimum is seldom described in exact terms for example: 4 kg firmness for apples. Crop experts frequently have the difficult task to integrate several quality aspects to an assessment above or beneath the "minimum".
In keepability research this problem is avoided by following relevant quality characteristics, which preferably are determined by instrumental analysis.

Factors influencing keepability can be divided into 4 categories:
1. Preharvest factors. These factor include the whole complex of growing conditions such as wheather conditions, soil, crop protection and manuring. Alle these factors can influence keepability.
2. Varieties. Within a certain crop great differences may exist among the varieties. For example the differences among potato or apple cultivars may be very big.
3. Harvest moment and - method. These factor may influence very strongly keepability for example great differences may be present between morning and afternoon harvest of beans and tomatoes. Mechanical harvest methods also have a great influence on keepability (2).
4. Post harvest conditions. This category includes temperature, relative humidity and air composition. These factors are very important for quality retention.

Temperature

Life processes of perishable commodities are regulated by the catalytic action of enzymes. Enzyme activity is temperature sensitive and increases two or four times for each 10°C temperature rise. This can be illustrated with respiration activity (or heat production) (3) of several crops. Also visual quality aspects are influenced in the same way. In other words: the lower the temperature, the longer the storage life.

The best moment for cooling is when possible after harvest. This can be illustrated with a reduction in marketable strawberries (4) because hours delay of cooling after harvest of strawberries. Similar effects can be shown for mushrooms or Conference pears.
A consequence of these effects is, that the best way of lowering tempereature is to cool as fast as possible. This is true not only for quality retention but also for minimizing water losses. Water losses occur, because water evaporates from the surface of a warm crop into cold air especially if the relative humidity is low. Then a big water vapour pressure deficit (driving force for water loss) is present and moisture loss will be high. If the cooling proces takes only little time, water loss will be minimized.

Many crops can be stored very near to the freezing point of their tissue for example many vegetables (5). The best quality retention is realized at the lowest possible temperature. For practical purposes however some precaution has to be considered to prevent freezing damage, which destroys the product completely, since ice cristals penetrate through the cell walls.
Exceptions on this rule are many. For example apples, red beets and chinese cabbage (6) must be kept at temperatures between 1 and 5°C to avoid damage characterized by skin or flesh browning, pitting. This chilling damage is most extensively found in fruits from tropical origin. They are characterized by discolorations, pitting, failure ro ripen, a strongly increased sensitivity to the development of decay and an increase in respiration rate at suboptimal temperatures. Cyclic changes of temperature between 0°C and 18°C however prevented chilling damage in bell peppers.

Relative Humidity

Too much water loss will result in wilting, which means not only loss of wight but also loss of attractive appearance and loss of texture. This quality loss may result in an

unsalable condition. As already said: water loss depends on differences in temperature and relative humidity. Since a difference in water vapour pressure deficit exists, water will be lost from the crop.
Horticultural crops do not loose water at the same rate. Important aspects are:
- protective surfaces such as a waxy skin (apple, mango).
- Surface volume ratio; leaves loose much more water than fruits.
- Specific characteristics for example the dry outer leaves of onions, the corky skin of potatoes and the water loss of tomatoes only through the stylar scar.

An advantage of a very high relative humidity may be a longer storage life. Many vegetables show indeed a better keepability in a high possible R.H. Storage of cichory roots in very high humidity causes a better forcing yield than roots from a lower R.H. A disadvantage of a minimum loss of water is illustrated by apples (8). Breakdown and decay may be higher during storage in a maximally high R.H.

Air Composition

Air consists of about 79% nitrogen, 0.03% carbon dioxide and 21% oxygen and changes in this ratio during storage are indicated as MA (Modified Atmosphere) or CA (Controlled Atmosphere). In a gastight room accumulation of CO2 and a depletion of O2 will occur. These changes may influence greatly quality loss in horticultural crops, since respiration rate is suppressed both by an increase in CO2 and a decrease in O2.

<u>Oxygen</u>
Lowering the oxygen content has a great influence on respiration rate. The lower the O2 content will be, the greater the inhibition of respiration (9). This process has however a limit about 1%. The crop will turn to ferment and produce ethanol. Increase in CO2 content will further strengthen this effect.
Also deterioration and ripening are inhibited in low oxygen contents. For example skin browning and flesh browning of apples is strongly inhibited in low oxygen conditions. Even a great difference between 1 and 3%O2 can be observed (10).
Other effects of lowering the oxygen content are a better retention of chlorophyl and an inhibition of carotene and lycopene synthesis in chinese cabbage, broccoli (11) and tomato repectively. Firmness loss is inhibited in many fruits including apples, pears, olives and papayas. Because of inhibition of deterioration the crop will suffer less from pathological breakdown.

However not all crops do react in the same way on lowering the O2 content of the storage room. For example carrots (12) show an increase in decay in low O2 conditions and potatoes show a stimulated sprout growth (13).

The same procedure as indicated for cooling (= "when possible after harvest and as quick as possible to the desired level") should be followed for the low oxygen condition. This so called Rapid-CA has a better quality retention than a slow way of establishing CA conditions.

As already indicated typical CA disorders may develop is some crops and if the oxygen content drops too low ethanol will accumulate in the tissues, which is accompanied by browning of the skin and flesh for example in apples or hollow and black hearts in potatoes.

Carbon Dioxide

An increase in CO2 content will slow down respiration rate to a certain extent and this will result in a better quality retention. These effects are known from the colour retention of broccoli, Brussels sprouts and white cabbage. Also pathological breakdown is inhibited in several fruits and vegetables including cabbage, black currants (14), strawberries and sweet corn. A specific effect is known from asparagus: less fibrousness (15).
Off course there are limits in the application of CO2 elevation. For example onions may develop watercore and softness above 5%CO2 and this will result in big storage losses (16). CO2 may be dangerous to Conference pears especially in relation with a late harvest. This may result in an increase of the occurrence of hollow hearts (17).

The combination of CO2 elevation and low oxygen is often applied for fruits and vegetables for example apples and white cabbage (18).

Ethylene

Ethylene (C2H4) is considered the natural aging and ripening hormone of plant parts. It is physiologicaly active in trace amounts (less than 0.1 ppm). It is produced by all living tissues of higher plants and by some microorganisms. Production rate is however very different ranging from less than 0.1 ul.kg.hr (cabbage, potato, carrots, asparagus) to 10.0-100.0 ul.kg.hr (apple, pear, passion fruit, papaya).

Many undesirable effects of ethylene are known for example accelerated senescence and ripening and abscission of leaves, which results in an abbreviated storage life.
Combined storage of fruits and vegetables may therefore cause problems for example storage of tomatoes (high production rate) and cabbage (very low production rate) may result in accelerated yellowing and abscission of cabbage leaves.
Ethylene is also allowed to accumulate during storage in gastight rooms and this may also influence the crop itsself for example in apple storage (19).

The production rate of ethylene is lowered by a low temperature, low oxygen conditions (<8%) and CO2 (>2%) elevation. Also ethylene action is also inhibited by these circumstances and this means, that under CA conditiona at low temperature crops are protected against ethylene action however not completely.

During distribution ethylene may harm crops because distribution often takes place at high temperatures and without the protection of CA conditions.

Storage Technology

Crops are stored in the field or stores (air or mechanically cooled and CA rooms).
It is possible to leave the crops in the field in countries with a moderate climate. The crops are simply left, where they are for example Brussels sprouts in the Netherlands or in protecting constructions (against freezing damage) as heaps or pits (carrots, potatoes (20),

beets).
The protection of the crops is much improved in air-cooled stores. Protection against low temperature is reached by isolation in the walls, removal of respiration product is controlled by ventilation and air is distributed through a system of channels in very big rooms, which may contain for example 1000 tons of potatoes (21).

Cold stores

Temperature in a mechanically cooled room is controled by a heat exchanger. The evaporators are equipped with fans to spread the cold air over the whole room. The temperature does not fluctuate very much in cold rooms, which results in a more stable R.H. The biggest advantage of mechanical cooling is off course, that keepability is no longer limited by the storage system.
The most important parts of a mechanical refrigeration equipment are the evaporator inside the room, condensor and compressor outside the room and the expansion valve, controlling the liquid refrigerant brought into the evaporator (22).

Cooling of harvested crops is done in different ways. The cold air from the evaporators can be blown simply in the room, which is filled with boxes. In this situation it is difficult to get a quick drop in temperature, because there is no direct contact between the cold air and the warm crop. Using so-called forced air cooling (23) solves this problem by creating a difference in pressure between the air in the room and the air in the boxes. This pressure difference forces the cold air to enter the boxes to carry away the heat from the crop by flowing around the individual fruits or vegetables or flowers.

Relative humidity in a cold room is determined by the stored crop. In priciple R.H. should be 100%, but moisture from the crop freezes on the lamellae of the evaporator and in this way water is extracted from the air in the room. R.H is lowered in this way.
Since water losses from the crop should be small, systems were developed to control water losses during storage. A so-called "wet cooling system", in which the air from the room is brought in an opposite direction with cold water, is possible of maintaining 98-100% R.H. (24).

CA storage

A simple way of creating CA conditions is to apply an extra gas barrier around the crop. Respiration of the crop will cause an elevation of CO2 and a decrease in O2. This principle is still applied in rooms, liners and MAP (Modified Atmosphere Packaging).
MAP is a technique based on permeable plastic films, in which the individual fruits or vegetables are wrapped. After wrapping a balance will develop between CO2 elevation and O2 decrease (25).

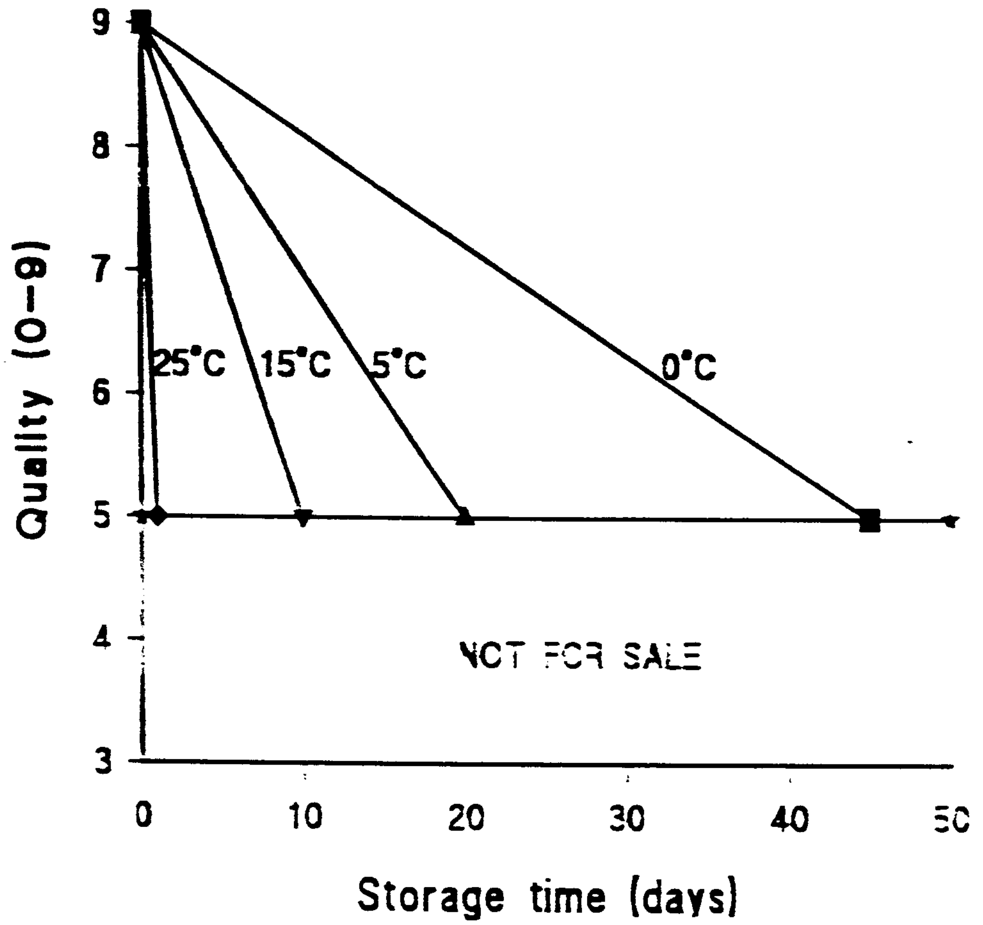
In many rooms the system generates and controls the CA conditions. In such a room we need a special buiding, some apparatuses such as a scrubber for CO2 and eventually for C2H4, a nitrogen generator and the analysers for measuring gas conditions.

Rooms are often built from somposite panels, which consist of two thin metal layers with a thick isolation plate between. The panels are used for walls and roofs, while floors are mostly made from concrete, which must also be isolated to prevent heat leakage from the soil. The door of the room must be a special one to prevent air leakage and this is the same for inspection windows (26). The room must be equipped with under/over pressure safety valve to prevent problems because of cooling (shrinking air) and wheather conditions. This safety is often completed with a lung, which is a plastic bag in open connection with the room and containing air from the room. A small fan, bringing in air into the room if necessary, is built in the wall of the room. All gas pipes, in and out from scrubber, N2 generator and analysers, pass the wall of the room.

For a quick establishment of CA conditions several apparatuses are used. We know burners, which bring burnt air (poor in O2) into the room (27). There are also so called ammonia cracking systems, which poroduce nitrogen by cracking ammonia. Finally air separation systems are becoming popular. These systems separate air in its componets and the N2 rich air is used for flushing the CA room.
Also CO2 removal can be done in different ways. The most simple way is placing lime on top of the bins. The CO2 is absorbed in lime, which can also be place outside the room. Only a fan is necessary to bring thee air from the room to the scrubber. This principle is also used in the activated charcoal scrubber although this is more complicated because of the regeneration (= removal of CO2 from the charcoal). Ethylene scrubbing is realised by chemical absorbance on KMnO4 or by catalytic oxidation of ethylene.

CA conditions are controlled by measuring CO2 and O2 contents in for example infrared and paramagnetic analysers and adjusting the contents with switching on or off the scrubber, ventilator or N2 generator. A development based on air separation is a system, with which complete control of CA conditions can be got. The wanted CA condition is created and maintained continuously by adjusting CO2 and O2 contents.

1.
Influence of temperature on keepability or storage life.



2.
Influence of harvest method and harvest time on brown colouring of beans (after Embrechts)

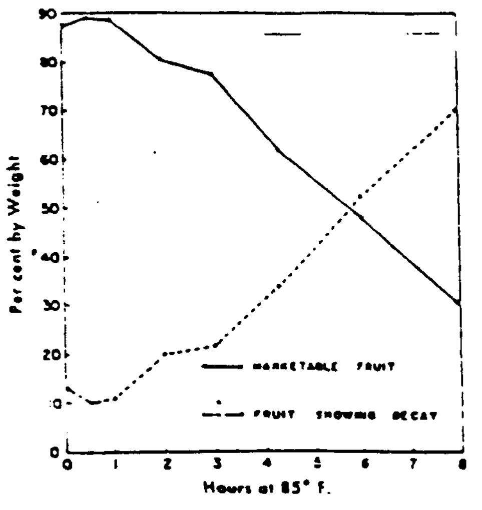
Harvest time	Harvest time	Washing	Not washing	Average
morning	by hand	7.0	7.1	7.1
	machine	6.1	5.9	6.0
afternoon	by hand	7.5	7.7	7.6
	machine	6.6	7.5	7.1

(1 = very much brown colouring spots; 10 = no borwn colouring spots

3.
Heat production of different commodities at various temperatures

	Heat production $Kcal.ton^{-1}.24$ hrs				
	0°C	5°C	10°C	15°C	20°C
potato	380	325	400	575	700
apple	165	355	530	885	1200
tomato	320	425	750	1450	1875
cabbage	340	475	700	1125	2250
cucumber	405	600	1150	2225	3375
asparagus	1275	1650	3150	5000	6750
Brussels sprouts	1200	2400	4075	5630	10400

4.
Influence of delay in cooling on quality of strawberries (after Mitchel)

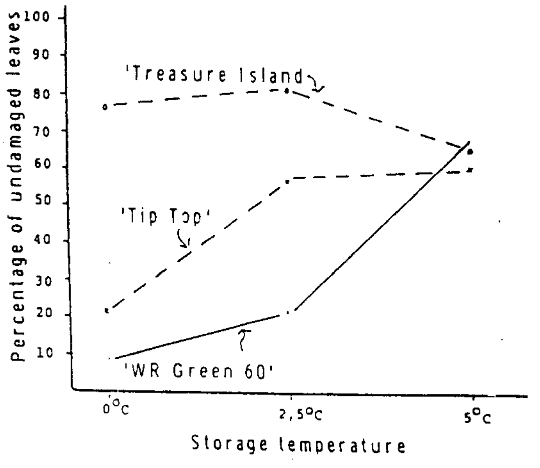


5.
Table 23. Freezing points of Major Vegetable Crops (from Weichmann)

Vegetable	Freezing point range °C		Freezing point range °F	
Artichoke	-1.44	-1.17	29.4	29.9
Asparagus	-0.89	-0.61	30.4	30.9
Bean, snap	-0.89	-0.72	30.4	30.7
Bean, lima	-0.89	-0.56	30.4	31.0
Beet, root	-1.67	-1.06	29.0	30.1
Beet, tops	-0.94	-0.39	30.3	31.3
Broccoli	-1.17	-0.39	29.9	31.3
Brussels sprouts	-1.28	-0.83	29.7	30.5
Cabbage	-1.22	-0.17	29.8	31.7
Carrot	-1.83	-1.39	28.7	29.5
Cauliflower	-1.17	-0.94	29.9	30.3
Celery	-0.67	-0.22	30.8	31.6
Corn, sweet	-0.94	-0.61	30.3	30.9
Cucumber	-0.83	-0.72	30.5	30.7
Eggplant	-0.94	-0.78	30.3	30.6
Endive	-0.78	-0.17	30.6	31.7
Escarole	-0.89	-0.06	30.4	31.9
Garlic	-3.39	-0.83	25.9	30.5
Lettuce	-0.39	-0.17	31.3	31.7
Parsley	-1.28	-1.11	29.7	30.0
Peas	-1.17	-0.61	29.9	30.9
Pepper, sweet	-0.94	-0.61	30.3	30.9
Potato	-1.44	-0.83	29.4	30.5
Radish	-1.22	-0.72	29.8	30.7
Rutabaga	-1.50	-1.06	29.3	30.1
Spinach	-0.50	-0.28	31.1	31.5
Squash	-1.94	-0.50	29.5	31.1
Sweet potato	-1.89	-1.06	28.6	30.1
Tomato	-1.28	-0.50	29.7	31.1
Turnip	-1.39	-1.06	29.5	30.1

Source: Ref. 12.

6.
Fig. 10: Influence of temperature on development of brown midribs in chinese cabbage (after Apeland).



7.
Effect of R.H. on the estimated* storage life of some vegetables (after v.d. Berg)

Vegetable	Temperature (%)	R.H. (%)	Storage time (weeks)
Selery	0-1	90- 95	8-10
	0-1	98-100	10-12
Chinese cabbage	0-1	90-95	8-12
	0-1	98-100	10-14
Brussels sprouts	0-1	90-95	6- 8
	0-1	98-100	10-12
Carrots	0-1	90-95	15-30
	0-1	98-100	30-40
Head Cabbage	0-1	90-95	14-22
	0-1	98-100	18-26

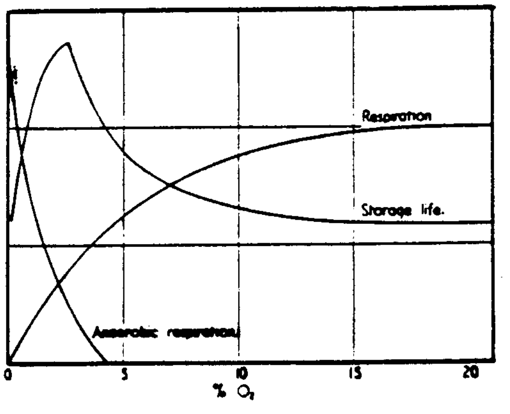
* At storage loss of 20-30 %.

8.
Influence of water loss on storage problems in Cox's O.P. and Bramley apples after storage in air at 2.8°C during 200 and 180 days respectively (after Johnson)

Variety	R.H. (%)	Weight loss(%)	Senescent breakdown(%)	Superficial scald(%)	Necteria rot(%)
Cox's O.P.	95	5.7	17	-	-
	85	9.9	1	-	-
Bramley	95	2.4	26	85	35
	85	6.8	7	35	9

9.

Diagram of the effect of the concentration of oxygen on the aerobic and anaerobic respiration and on the storage life of apples. (after Tomkins).

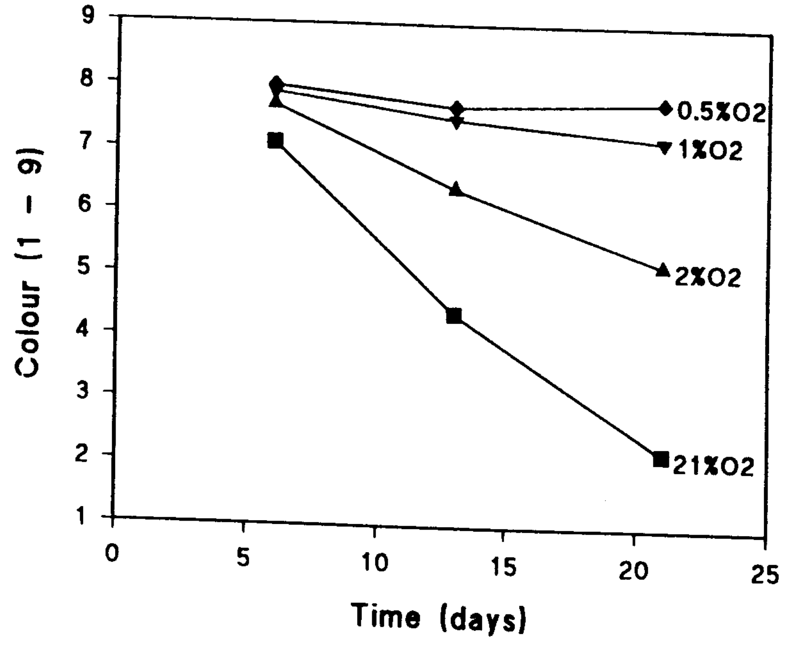


10.

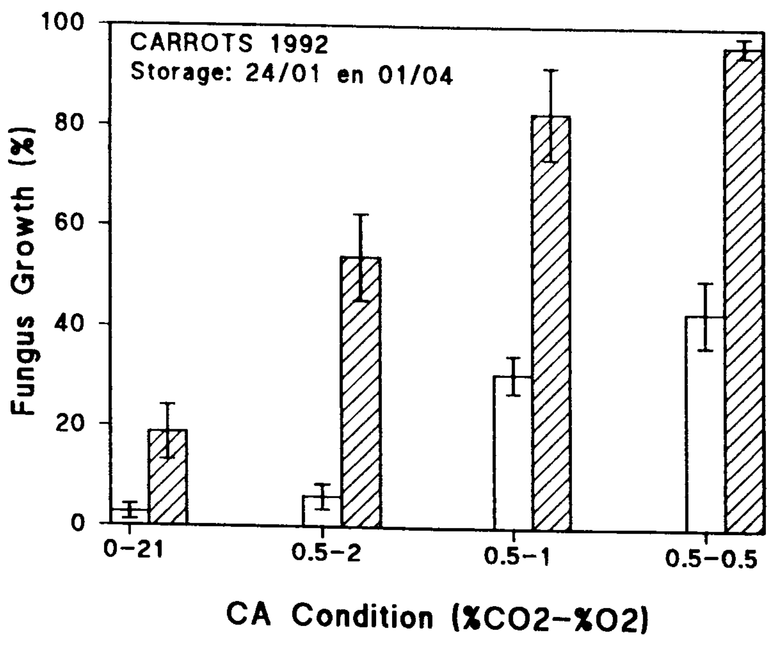
Influence of oxygen concentration on the quality of Boskoop apples after long term storage.

O_2 (%)	Harvest date	Superficial scald(%)	Coreflush (%)	Flesh browning(%)
3.1	24/09	44.3	41.2	0.0
	01/10	41.3	34.8	0.2
	08/10	19.6	15.5	0.7
2.4	24/09	37.5	14.0	0.3
	01/10	25.4	10.2	8.0
	08/10	22.9	2,8	0.5
1.7	24/09	9.1	8.2	0.3
	01/10	6.4	4.2	0.2
	08/10	1.7	1.3	4.5
1.0	24/09	0.0	0.8	0.7
	01/10	0.0	0.7	1.7
	08/10	0.0	0.0	5.7

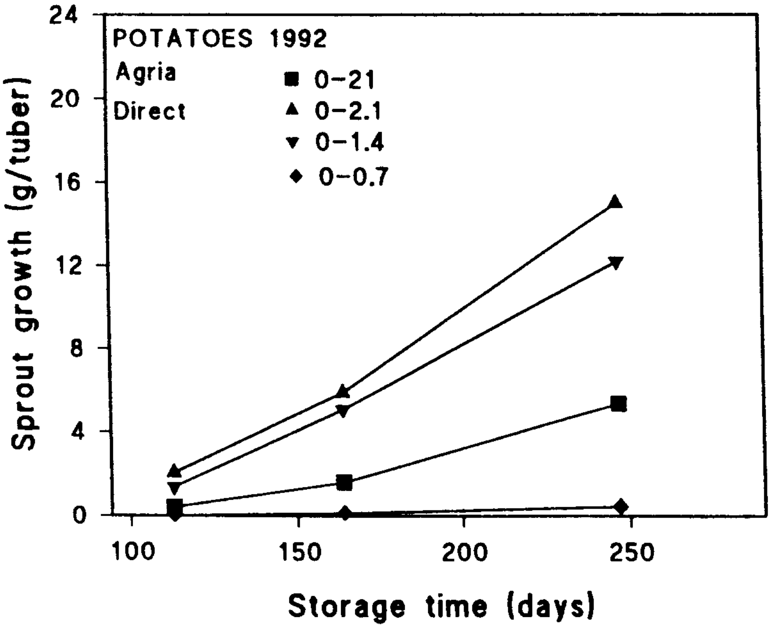
11.
Influence of oxygen content on the colour of broccoli (after Lipton and Harris).



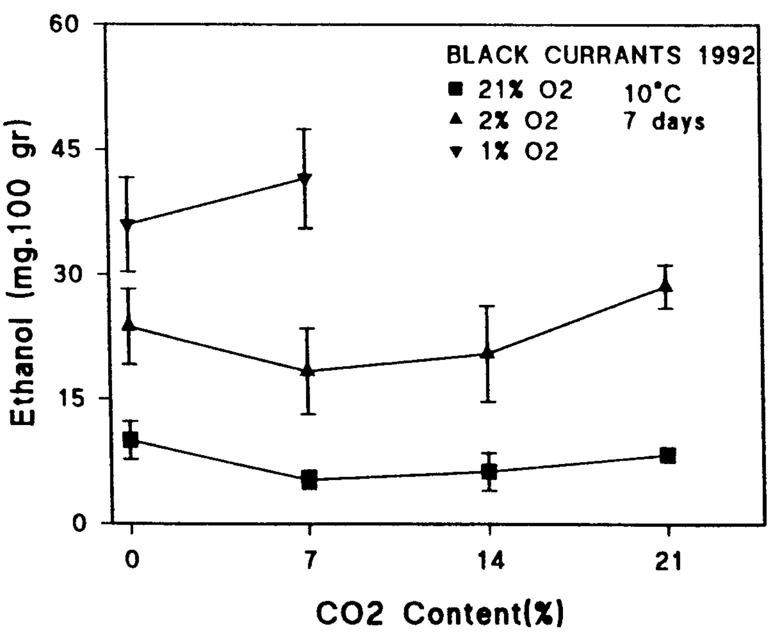
12.
Influence of oxygen content on decay of carrots.



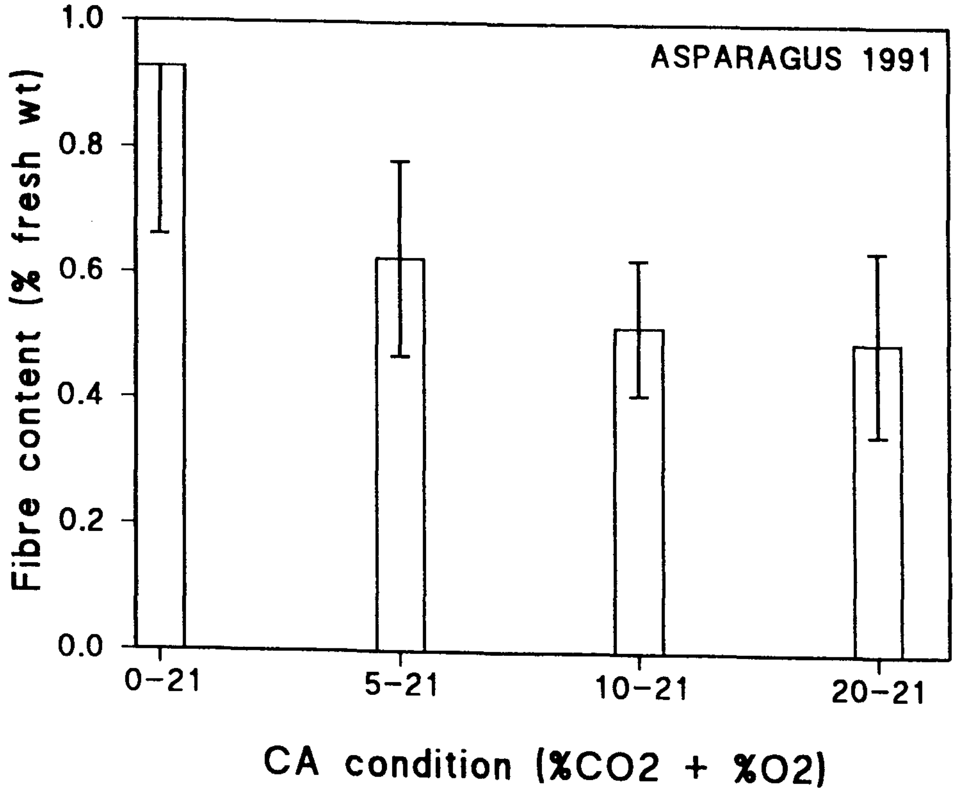
13.
Influence of oxygen content on sprout growth of potatoes at 6°C.



14.
Influence of carbon dioxide content on ethanol accumulation of black berries.



15.
Influence of CO2 content on fibre content of asparagus spears stored at 0-1°C.



16.
CA storage at -2°C and the quality of onions

Storage	Storage loss (%)
0-21	4
1-3	-
5-3	9
10-11	100
10-3	100

17.
Influence of harvest time and CO_2 content in the storage room on the quality of Conference pears.

Storage	Harvest 21/09		Harvest 28/9	
	decay(%)	hollow heart(%)	decay	hollow heart(%)
0.5% CO_2	3.2	0	4.0	1
1% "	1.3	0	5.0	2
2% "	2.8	0	3.6	26
3% "	1.6	0	4.2	45

18.

Table 45: Incidence or rots caused by the fungus Botry cinerea and recovery of trimmed cabbage after long-tern storage in air or a controlled (CA)* maintained at 0-1°C, 95% r.h. (after Gerson).

Season	Cultivar	Storage period(weeks)	Botrytis rots(%)		Recovery after trimming(%)	
			Air	CA	Air	CA
1977-78	Hidena	39	86	0	70	92
1978-79	Hidena	36	72	32	66	81
1979-80	Ladena	35	81	13	75	82
	Langedijk 4- Decema Extra	34	54	7	54	71
1980-81	Bartolo	33	63	36	77	84

* CA comprising 5% carbon dioxide, 3% oxygen and 92% nitrogen

19.

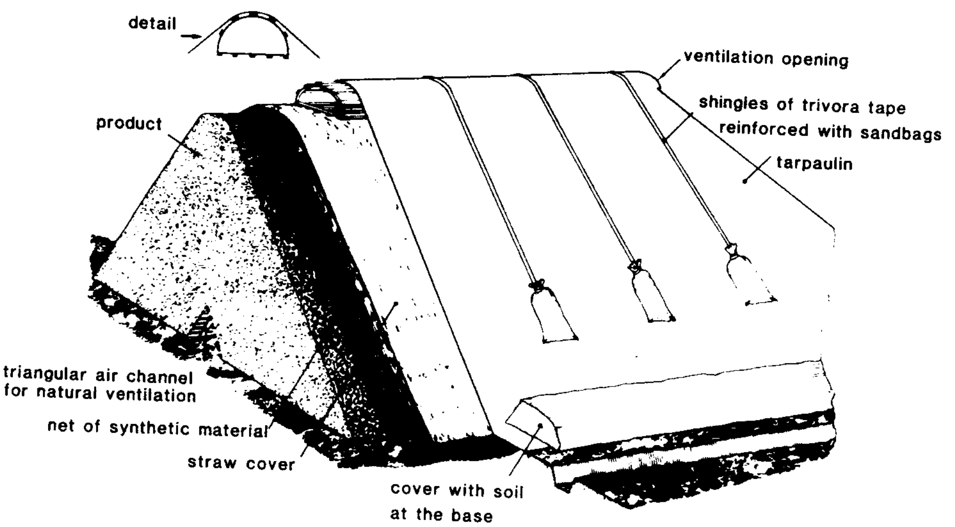
Table 50: Influence of low ethylene concentration and CA storage on the quality of McIntosh and Empire apples (after Blanpied).

Year	Harvest date	Ethylene concentration in CA: Low ethylene (< 1 ppm)	Normal (500 ppm)	Difference
		McIntosh flesh firmness - lbs [1]		
1977	09/22	15.2	10.8	4.4
1978	09/28	9.1	8.2	0.9
1979	09/18	10.5	8.8	1.7
1981	09/16	15.9	13.9	2.0
1982	09/18	13.5	10.5	3.0
Average		12.8	10.4	2.0
		Empire flesh firmness - lbs.		
1980	10/02	15.3	11.5	3.8
1982[2]	09/29		14.7	1 2 . 5 2.2
Average		15.0	12.0	3.0
		Empire fleah breakdown - %		
1981[2]	09/29		0.5	1 2 . 6 12.1

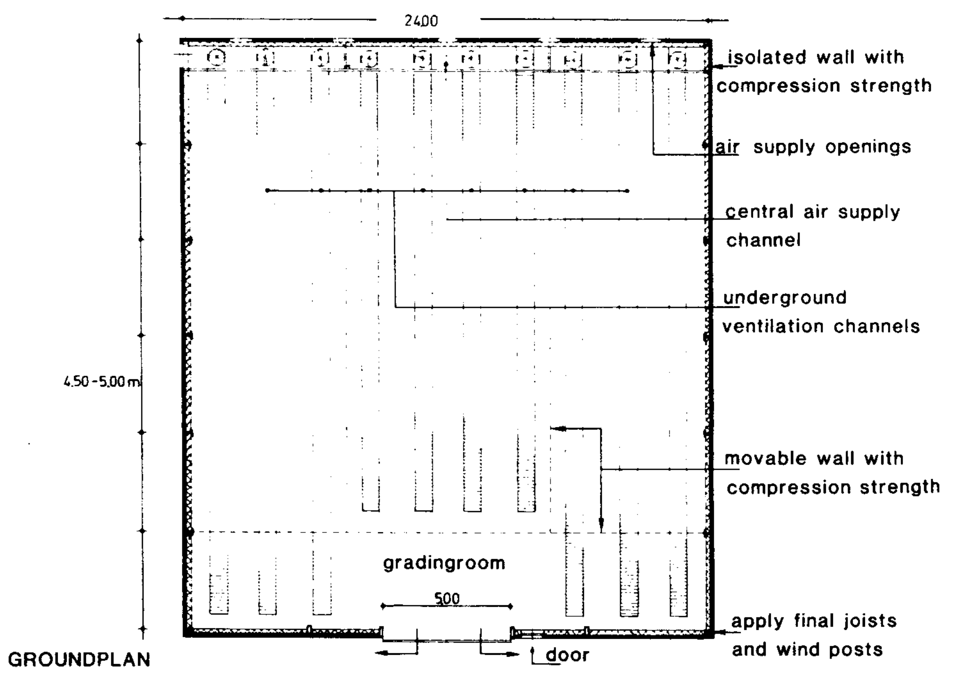
[1] McIntosh data in this table provided by F.W. Liu

[2] Averages for 5 farms

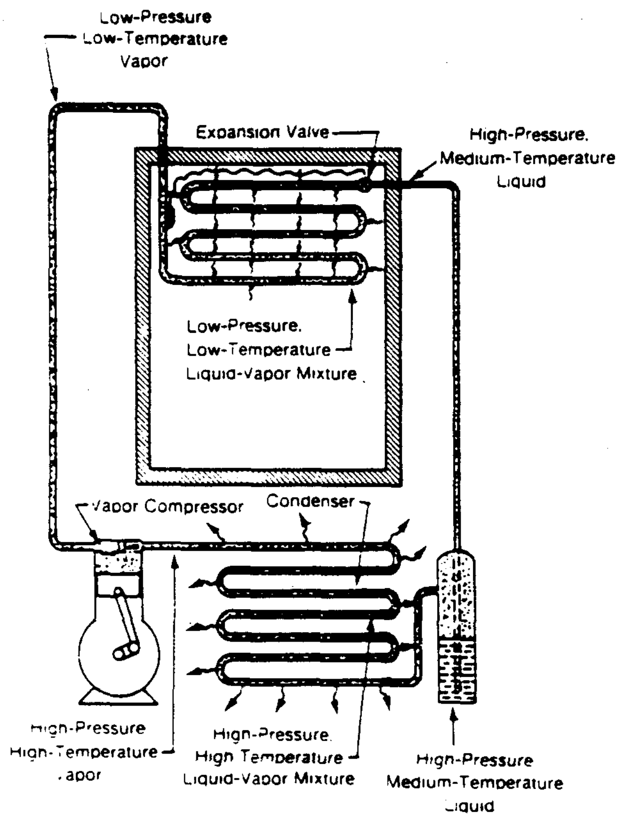
20.
Storage in pits (from Hak).



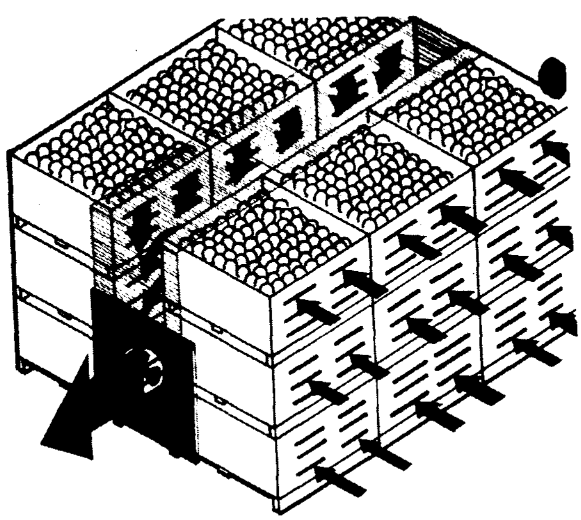
21.
Fig. 36. Air distribution system.



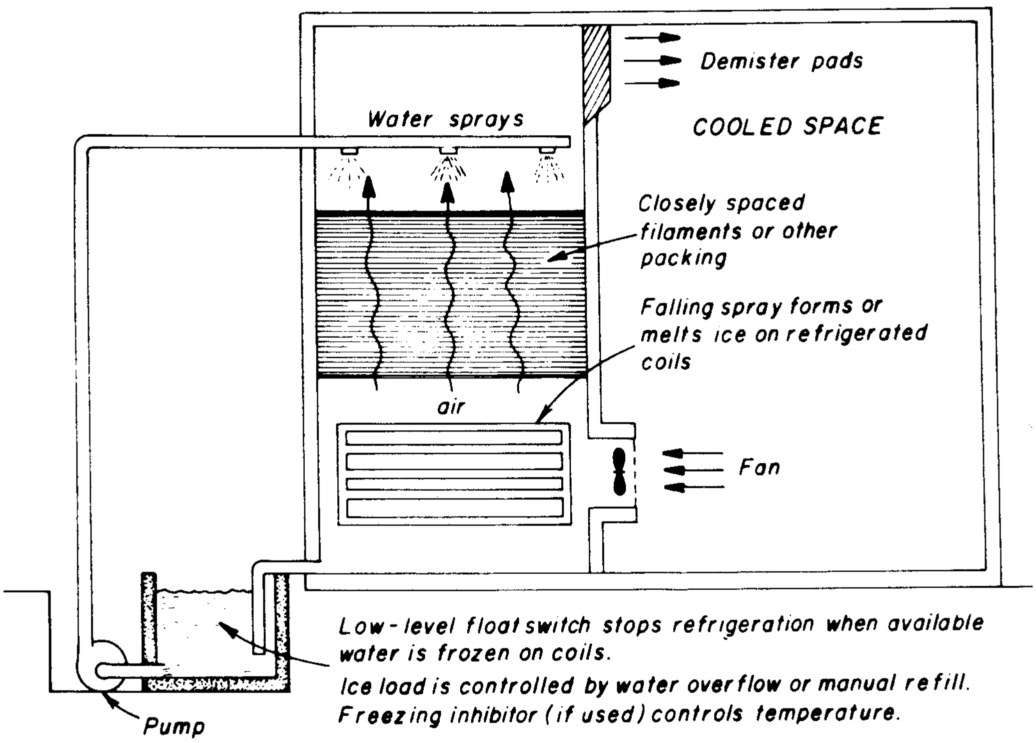
22.
Schematic of a typical recompression or mechanical refrigeration system (from Mitchel).



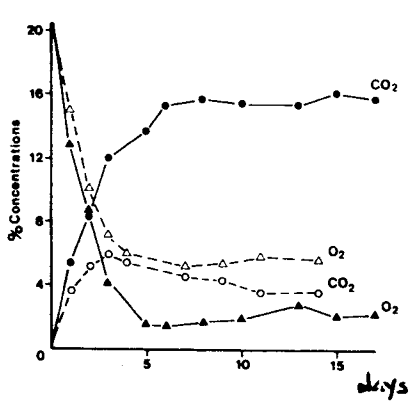
23.
Diagrammatic view of a forced-air cooling tunnel (after Guillou et al).



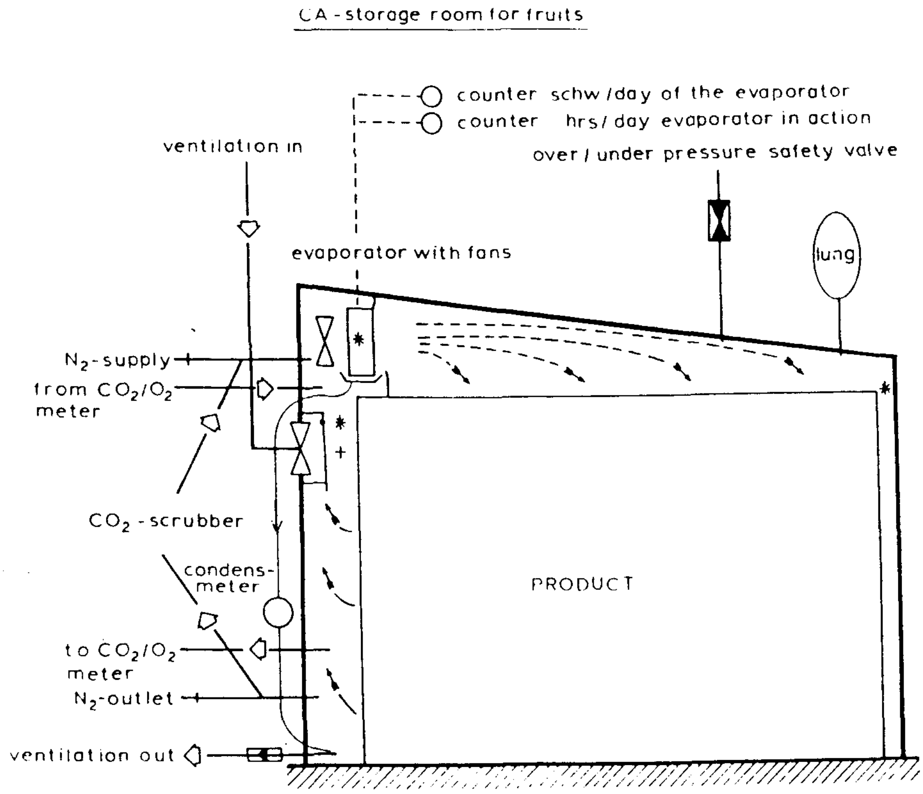
24.
A packed cooling tower in which cold water is sprayed over packing and air counter-flows through tower for cooling.



25.
Changes in the composition of the internal atmospheres within punnet packs of tomatoes sealed with a suitably permeable film (25 μ polystyren-butadiene-hollow symbols) and with an insufficient permeable film (15 μ oriented polypropylene - solid symbols), and held at 10°C (after Geeson).



26.
Overview of a CA-storage room (after Rudolphy).



27.
Diagram of CA storage.