DEVELOPMENTS IN FOOD PRESERVATION—2

STUART THORNE

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Edited by

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PREFACE

Preserved foods have a bad public image and an unjustified reputation for being inherently inferior to 'fresh' foods. Comments such as 'the soup was obviously not canned', 'peas straight from the freezer' and 'how different to man-made foods' are the common vocabulary of the popular press. These three statements were, incidentally, culled from a single Sunday magazine, but typify the public's attitude to food preservation. But is this reputation deserved; is the quality of preserved foods really inferior? I believe that it is not, but several factors have combined to create this reputation and the food industry is, at least partly, to blame for its reputation.

The first reason for public distrust of preserved foods is historical. In the mid-nineteenth century, A. H. Hassall exposed widespread adulteration of foods and these revelations were coincident with scandalous adulteration of the Royal Navy's canned provisions. The seeds of discontent were sown. By the late nineteenth century, canned meat from Australia was established as a common item of diet in Britain. But it was essentially a cheap alternative to fresh butcher's meat. Although it was safe and nutritionally satisfactory, the processing methods of the time ensured that it was of poor sensory quality. The reputation of preserved meats as cheap alternatives for fresh meats has endured and spread to many other preserved products.

There are today many preserved products of exceptional quality. With modern processing techniques, preserved foods can compete favourably with their unpreserved counterparts in many areas. But the poor reputation persists and it is often difficult to find a market for superior quality preserved foods. At the upper end of the market, in particular, there is considerable snob appeal attached to 'unprocessed' foods. Developments in food preservation are creating the potential for even better preserved foods, but much of this potential will not be realised until we can convince our accountants and consumers that processed and preserved foods can be very good indeed and need not be a cheap substitute for 'fresh' products.

Another constraint to improvements in preserved foods is the ready acceptance of the quality deficiencies and characteristics of some preserved foods. Canned peas are often preferred because of the texture and flavour imparted by canning. One major canner, a decade or so ago, introduced an aseptic canning line for tomato soup. The product was splendid, with a marked flavour of fresh tomatoes, but the process was discontinued after considerable consumer criticism that the product did not taste like tomato soup!

Unlike other industries, where quality can be defined solely in terms of operational characteristics of the product, quality in food includes unquantifiable parameters of consumer appeal, which vary from consumer to consumer. Major quality parameters are indeed nutritional adequacy and microbial safety. But these alone are not enough and it is in the area of sensory quality that quality in processed and preserved foods is sometimes deficient. At the risk of making wild generalisations, I assert that it often suits the food industry to produce products of bland flavour and indifferent texture. These do not actually offend any consumers and satisfy the need of large manufacturing organisations to produce few products that can be widely distributed. Traditional staple foods—beer, cheese, bread—have suffered most, but there does appear to be a resurgence of consumer demand for more strongly flavoured, traditional products. Beer drinkers, presumably a vociferous group, were the first to demonstrate in Britain that industry could be made to heed their demands. Some recent products of food technology—notably Lymeswold cheese in Britain—have demonstrated that modern production and processing methods can produce products of outstanding quality and that there need be no conflict between modern industrial processing and outstanding sensory quality.

It is a great loss to our industry and to the consumer if developments in food preservation do not realise their full potential because preserved foods are considered second-rate alternatives to 'fresh' foods. Modern preservation techniques are capable of producing safe and nutritious foods of excellent sensory quality. We must educate not only the consumer, but also those who formulate policy in the food industry, to realise this.

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Chapter 1

CONTROLLED ATMOSPHERE STORAGE OF FRUITS AND VEGETABLES

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SUMMARY

Controlled atmosphere (CA) storage utilises carefully regulated levels of increased carbon dioxide and decreased oxygen in conjunction with low temperature to prolong and extend the storage and market life of fresh fruits and vegetables. Much research has been directed to determining the optimum CA conditions for a great number of crops, yet the method has been employed commercially almost exclusively for apples and to a limited extent for pears and cabbage. Such variables as crop species and cultivar, the different organs used for food purposes and the complex physiological and biochemical processes of the tissues, together with the absence of a marked inhibiting effect of CA on pathological infection and decay are responsible for the limited application of the CA process. Most fruits and vegetable products have critical tolerances to low oxygen and high carbon dioxide levels which vary with the conditions under which the crop is grown, the stage of maturity when harvested and stored, and the storage temperature employed.

Possibly 10% of all commercial apples grown for fresh market purposes are CA stored. Optimum conditions range from 0–8% carbon dioxide, 1–7% oxygen and from −1 to 4·5°C. Specific recommendations based on regional determinations and experience must be followed. Pears and cabbage have highly localised requirements and no general recommendations are available for these crops.

Buildings properly constructed and equipped for cold storage are modified for CA storage by the addition of an airtight internal lining and sealed doorway. Airtight linings of sheet metal, plywood panels and foam-in-place polyurethane insulation are commonly used. Special equipment needed to regulate the temperature and atmosphere includes external thermometers and thermostats, a gas analyser and a carbon dioxide scrubber. An atmosphere generator may be employed to assist the natural respiration process of the stored product to develop and maintain the controlled atmosphere.

Another means for providing CA is by application of low pressure so as to adequately reduce the partial pressure of the oxygen in the storage room or chamber. It is a costly, but possibly feasible, technology for transport of produce under CA conditions.

1. INTRODUCTION

Controlled atmosphere storage, commonly known as CA storage, utilises the regulation of the oxygen and carbon dioxide of the storage room atmosphere in conjunction with low temperature to extend the storage life of products. It is considered to be beneficial to numerous horticultural crops, including fruits, vegetables, cut flowers, ornamental plants, seeds and tree nuts. Also, it has been demonstrated to facilitate the storage of other agricultural products, including meat, alfalfa meal and corn ensilage. Even so, the commercial use of CA is almost exclusively limited to the storage of fresh apples. A few other crops are CA stored to a minor extent, namely pears and cabbage.

The history and development of CA storage for apples is well documented by Dalrymple,[1,2] who attributes the initial scientific examination of it as a means of lengthening the storage life of fruit to Berard in France in 1819, although active research on its value and possible use for commercial agriculture did not take place until the work initiated by Kidd in England approximately 100 years later. Extensive use of the CA method by the apple industry has been made in the United States and Canada since 1930. Subsequent refinements in its application to apples have resulted from the efforts of numerous researchers throughout the world. The more recent developments have concerned the use of gas-fired generators to create artificially low oxygen atmospheres, the development of new methods for scrubbing carbon dioxide, and the application of new construction methods and materials to provide adequately airtight structures. Improvements in the technology of applying CA are now opening the way for the use of very low levels of oxygen. Although the practical developments have dealt primarily with the storage of apples, much research has been directed towards the possible benefits and requirements for the commercial CA storage of many other horticultural products.

2. STORAGE ATMOSPHERES

The composition of an ordinary cold storage room atmosphere varies in the range of 19–21% oxygen and 0–2% carbon dioxide depending on the temperature, kind and quantity of produce stored and the degree of airtightness of the structure. The balance of the atmosphere is nitrogen plus minute quantities of numerous other gases evolved by the stored crop, disease organisms and other possible sources such as gas-powered equipment. Atmospheres with greater than normal modifications in oxygen and carbon dioxide levels are sometimes developed intentionally by increasing the airtightness of the structure or by enclosure of the commodity within containers or packages that are partially or completely sealed.

Under these conditions the oxygen may be depleted to near 0% and carbon dioxide may accumulate in excess of 20%. Since there is little or no control or regulation of these atmospheres, the term of modified atmosphere, rather than controlled atmosphere, is appropriate. In contrast, a controlled atmosphere is one in which the oxygen and carbon dioxide are regulated to predetermined levels known to be beneficial and non-harmful to the product. The balance of the gases, in addition to oxygen and carbon dioxide in a CA atmosphere, are considered to be inert and serve as filler as is true for normal air.

Controlled atmospheres suitable and possibly beneficial for extending the storage and market life of fruits and vegetables have been extensively researched with much of the work having been done since the classical studies of Kidd *et al.*[3] Bibliographies compiled at the University of California, Davis,[4–7] list over 3000 titles of interest to students of the general subject of handling, storing and marketing commodities under modified or controlled atmosphere conditions. Recently published excellent reviews on the CA storage of fruits[8] and vegetables[9] summarise the current scientific knowledge relating to numerous crops. The Proceedings of the First National Controlled Atmosphere Storage

Research Conference (USA) in 1969[10] presented a summation of experimental results obtained with various atmospheres for numerous vegetable crops. A more complete compilation of research recommendations for fruit and vegetables was made in 1973 by Stoll.[11]

2.1. Beneficial Effects

The primary purpose of CA is to extend the storage life of the product by retardation of the various catabolic processes that result in eventual senescence and loss of food value of the crop. The CA effects are readily measured by the slowing of respiration, a physiological process common to all living plant tissue. It may be reduced by CA to one-half of that in air at the same temperature. Both low oxygen and increased carbon dioxide levels are effective either alone or in combination on tissue metabolism, but in variable degrees depending upon the crop and cultivar. Most recommended levels and mixtures of gases have been found by research to be beneficial, yet not harmful, for a particular cultivar of fruit or vegetable as grown under specific regional climatic conditions.

The total length of the storage life of a fresh fruit or vegetable is dependent on the inherent storage quality characteristics present at the time the crop is harvested and placed in storage. Strawberries that might normally have a limited cold storage life of 2 weeks could be expected to be marketable possibly after 4 weeks of CA storage, but there is the moot question of whether or not the costs involved can be economically justified. Apples, on the other hand, that can be cold stored for 5 months are more likely to be profitably stored for 10 months through the use of CA. Although apples have been stored for as long as 2 years in CA, it is questionable if fruit of this age would be of competitive quality and value to crops produced more recently.

Since an abundance of stored carbohydrates are essential to an acceptable eating quality for many products, their conservation as a result of the reduced respiratory activity in CA storage, even though the overall storage period may not be lengthened, is beneficial. In other cases, CA storage may delay the ultimate exhaustion of the substrate so that the product remains useful during an extended market period.

Another benefit of CA storage is the residual effect that remains through the post-storage period. This was demonstrated by Smock[12] with McIntosh apples, whereby the lower respiratory activity of the fruit in CA never returned to a normal level once the fruit was removed from CA. It is frequently observed that CA apples have to be conditioned in air for a short period of time in order to develop a suitable level of flavour and aroma.

Although CA does not serve as a substitute for refrigeration, it has proven to be extremely useful in conjunction with the application of intermediate temperatures for cultivars that are susceptible to low temperature injury. The early commercial development of CA for apples in England and the United States was based on benefits obtained at temperatures of 4–5 °C for the Cox's Orange Pippin, Bramley's Seedling, Yellow Newtown and McIntosh cultivars.[8] It was found that when low temperature storage was avoided, overall storage life was markedly enhanced with CA. The development of such storage disorders of apples as Jonathan spot and various breakdown disorders associated with senescence is retarded.

Another important value of CA is that it facilitates the storage of a commodity under higher, more ideal conditions of relative humidity than are normally obtained in cold storage. This is possible because the requirements for developing and maintaining the proper gas levels, particularly a minimum of air space within the room and little air exchange with the outside atmosphere are conducive to developing and maintaining a 90–95% relative humidity condition. Crops stored under these conditions retain a high degree of crispness and may lose only 1–2% of their original fresh weight due to water loss during an extended storage period. The Golden Delicious apple that is highly susceptible to water loss can be stored for 8–10 months in CA without excessive wilting or shrivel.

2.2. Limitations of CA

Many fresh fruits and vegetables are highly susceptible to pathological decay, and unfortunately, the levels of low oxygen or high carbon dioxide that inhibit the growth and development of the fungal and bacterial organisms that attack plant tissues are generally toxic or otherwise damaging to the commodity. Oxygen at less than 1% will inhibit the growth of some organisms, but sub-oxidation injury as a result of the occurrence of an excessive amount of anaerobic respiration (fermentation) may destroy the product. Carbon dioxide levels of at least 10% and usually 15% or higher are needed for decay control. Some crops tolerate these levels and although control of mould growth has been reported for grapes, peaches, citrus fruits, papaya, sweet cherries and strawberries,[8] high carbon dioxide has been employed to a limited extent only for strawberries and sweet cherries, usually under transit conditions. These two crops have consistently demonstrated a high tolerance to carbon dioxide. Such vegetable crops as tomatoes, peppers, asparagus and celery that have been shown to be physiologically benefited by CA, do not tolerate levels of carbon dioxide needed to reduce the growth of pathogens to which they are readily susceptible.[9]

Fruit rots that affect apples and pears under CA and low temperature conditions are generally negligible and adequately controlled by low temperatures. One benefit of CA for these crops is that it markedly reduces the spread of the organism from one fruit to another. The control of decay on cabbage in CA has been inconsistent, but successful when good sanitation practices are followed. Fruits and vegetables of tropical or subtropical origin, plus a few others from temperate climates, are often susceptible to low temperature or chilling injury when exposed to temperatures slightly (3 °C) to well (10 °C) above their freezing point. An early anticipated benefit of CA storage was that it would alleviate or prevent chilling injury of susceptible crops so they could then be stored at temperatures low enough to retard normal degradation processes as well as the growth of pathological organisms. However, with few exceptions, CA does not prevent low temperature disorders. Instead, benefits have been realised only as a result of the other CA effects obtained at the non-chilling temperatures. The early successes for CA storage with McIntosh, Cox's Orange Pippin and Yellow Newtown apples were achieved by storage at the intermediate temperatures of cold storage needed to avoid low temperature disorders.

Breakdown disorders associated with advanced ripening or senescence of tissues have been observed to be increased rather than decreased for some crops, as for example pears,[13] under CA conditions. There is evidence[14] that within the confines of a CA storage room there can be an accumulation of enough naturally occurring ethylene to stimulate the onset of ripening and senescence of apples, especially at temperatures of 4 5 °C and higher. This accumulation of volatiles is thought to be a source of difficulty in the CA storage of citrus fruit[15] since ethylene may stimulate pathological decay as well as senescence. In other instances, low oxygen or elevated carbon dioxide levels may interfere with the normal ripening processes essential for the development of acceptable flavour, texture, juice and appearance characteristics needed for market acceptability.[16] Off-flavours and off-odours may develop in vegetables[17] as a consequence of the disruption and imbalance of one or several of the biochemical processes involved.

Kader and Morris[18] presented charts (see Table 1) of the possible tolerance of fruits and vegetables to elevated carbon dioxide and reduced oxygen levels which would be useful in the continuing research to establish suitable CA conditions. The tolerance to low oxygen levels is more or less

TABLE 1

MAXIMUM LEVELS OF CARBON DIOXIDE AND MINIMUM LEVELS OF OXYGEN LIKELY TO BE TOLERATED BY FRESH FRUITS AND VEGETABLES (ADAPTED FROM KADER AND MORRIS[18])

Fruit: cultivar	*% CO_2*	*% O_2*	*Vegetable: type*	*% CO_2*	*% O_2*
Apple:			Artichoke	2	3
Delicious	2	2	Asparagus (at 5°C)	10	10
Rome Beauty,			Asparagus (at 2°C)	15	10
Stayman, Winesap	3	2	Bean, snap	10	2
McIntosh, Jonathan,			Broccoli	15	1
Cortland	5	2	Brussels sprouts	5	2
Yellow Newtown	7	2	Cabbage	5	2
Apricot	2	2	Carrot	4	3
Avocado:			Cauliflower	5	2
Fuerte	5	3	Celery	2	2
Lulu	14		Cantaloupe	10	2
Banana	5		Cucumber	10	3
Citrus fruit		5	Eggplant	7	
Fig	20		Kale	20	
Mango	5		Lettuce: head, leaf	1	2
Nectarine	5	2	Onion, bulb	10	1
Olive	10	2	Pea, green	7	5
Papaya	5	2	Pepper (at 13°C)	5	3
Peach	5	2	Pepper (at 5°C)	10	3
Persimmon	5	3	Potato: market	10	10
Pear:			Spinach	20	
Anjou, Bosc	1	2	Summer squash	10	2
Bartlett	5	2	Sweet corn	20	
Pineapple		2	Tomato	2	3
Prune, Italian	20				
Strawberry	20	2			
Sweet cherry	10	3			

predictable and accountable because of the direct effect of oxygen on the type of respiration taking place, with anaerobic respiration becoming excessive when molecular oxygen is deficient. The adverse effect of carbon dioxide on plant tissues is more likely to be a matter of toxicity in that carbon dioxide, being an end product of respiration, has little direct effect on the respiration process. There are many variables that affect carbon dioxide toxicity: and elevated temperature, for example, increases carbon dioxide production by respiration, but decreases the solubility of carbon dioxide in the cellular contents. Lipton[19] suggests that the multitude of differences in the biochemical processes, within as well as between plant tissues, could account for the extensive array of disorders of vegetables induced by a wide range of carbon dioxide conditions.

Variable responses of different fruits and vegetables in CA are not unexpected because of the different kinds of tissues and organs involved (e.g. roots, stems, leaves, fruits). The marked variations in requirements for cultivars within a species, however, are less expected and it is probable that these differences have greatly hindered the widespread development and acceptance of CA storage. This is particularly true for vegetables in that many are grown as annual crops which enables frequent variety changes and the use of cultivars specially selected for production in different regions and seasons throughout the year. It is not unusual for varieties to change more rapidly than new CA storage recommendations can be developed. A less dynamic situation exists for perennial vegetable crops such as asparagus and artichokes which produce numerous crops without replanting. Cultivars are relatively stable for tree fruits from which crops are possibly produced on the same plant for 50 or more years. There is the further advantage that the cultivars of apples suited to cold storage conditions tolerate 1–3% oxygen and 2–12% carbon dioxide. Over the years it has been possible to determine and accommodate the CA requirements of the relatively few apple cultivars that account for the bulk of fruit in world trade. Usually five or more years of research are required before an apple recommendation is adequately tested for commercial use.

The economics of CA storage may not be particularly favourable for some of the crops that are physiologically benefited. The season of production, market value, competition from other production areas or other products, and inherent storage potential are considerations. The yearly cost of CA storage is greater, perhaps up to two times the cost of cold storage, due to the greater investment cost, the increased labour and servicing requirements of operation, and the longer storage period.[1] Such highly perishable crops as strawberries and asparagus may increase sufficiently in market value during a few weeks of CA to justify the cost, yet be unprofitable if the facility stands idle the rest of the year. Other crops such as artichokes, witloof chicory, and sweet cherries that are benefited by CA[8,9] may be of inadequate volume to justify the development and operation of a suitable facility. The storage of commodities together, even for such similar fruits as the apple and pear, has not proven practical because of the finely tuned requirements of temperature and atmosphere for each crop. Cultivars of apples are not completely compatible due to differences in temperature needs and variations in the times of harvesting and marketing. Some crops that may be otherwise suitable for storage together are incompatible because of the likelihood of odour transfer.

Isenberg[9] foresees a greater potential for the employment of CA in the transport rather than in the storage of such vegetables as artichoke, asparagus, broccoli, Brussels sprouts, cauliflower and spinach. However, CA conditions are extremely difficult to maintain in transit except possibly aboard ship or by the use of highly sophisticated highway equipment such as the Dormavac® low pressure container.[20] Shipments of strawberries,[21] in sealed packages or other enclosures to develop or retain a modified, rather than a controlled atmosphere, have been commercially successful.

3. RECOMMENDED ATMOSPHERES

3.1. Apple

The vast commercial development and utilisation of CA storage for apples has involved all major apple producing areas of the world. It is believed that possibly up to one-tenth of the total world commercial production of apples may find its way into CA at one time or another. Of the average yearly United States crop of 1 million tons of apples placed in storage for fresh market sales, about one-half are stored in CA.[22] The state of Washington today has 50% of the CA storage space in the United States. About one-third of the 250 000 tons of apples stored in Canada are stored in CA. The development and use of CA storage, together with extensive distribution of apples overseas, has resulted in high quality fruit being readily available throughout the year, particularly the Delicious cultivar.

The conditions recommended for the CA storage of apples vary with cultivars, regions of production, and periods of marketing the fruit. The range of conditions suitable for frequently stored cultivars are given in Table 2. The specific conditions to be employed should be obtained from nearby researchers or advisers familiar with the special regional requirements of the fruit. Without such information, limited trials should be undertaken before an extensive commercial venture is initiated. Furthermore, changes in recommendation occur as additional benefits or difficulties are experienced. The recent utilisation of 1% oxygen, instead of 3%, for Cox's Orange Pippin in England[23] has resulted from an almost continuous evaluation[24] of the changing conditions and procedures that have evolved since the initial recommendations were made. It is now recognised that fruit of suitable maturity and condition can be stored more successfully at this lower oxygen level, particularly with the modern means for monitoring and regulating the atmosphere that assure the avoidance of damage from an oxygen deficiency. Similar trials of lower levels of oxygen for cv. McIntosh in the United States[25] and Canada[26] have indicated

TABLE 2

THE RANGE OF TEMPERATURE AND LEVELS OF CARBON DIOXIDE AND OXYGEN USED FOR THE CA STORAGE OF SOME OF THE LEADING STORAGE CULTIVARS OF APPLES (ADAPTED FROM STOLL[11])

Cultivar	*Temperature* (°C)	*Carbon dioxide* (%)	*Oxygen* (%)
Boskop	3 to 4	0 to 5	2 to 4
Cox's Orange Pippin	3 to 4·5	0 to 5	1·0 to 3·5
Delicious	−1 to 1	0 to 5	2 to 5
Golden Delicious	−1 to 3·5	1 to 5	2 to 5
Granny Smith	0	2 to 5	2 to 5
Ingrid Marie	1·5 to 4	1 to 4	2 to 3·5
Jonathan	0 to 4·5	2 to 5	2·5 to 4
McIntosh	2 to 4	2 to 5	3 to 5
Yellow Newtown	3·5 to 4·5	2·5 to 8	2 to 7

favourable results, with tentative recommendations probable for special applications yet to be fully determined.

Changes in the method of storage operation also may influence the suitability of a given atmospheric recommendation. Our originally successful recommendation[27] for cv. Jonathan of 5% carbon dioxide with 3% oxygen at 0°C proved to be occasionally unsatisfactory due to the development of the brown heart disorder when the atmospheres were quickly established by external generators. The difficulty was overcome by lowering the fruit temperature to 3°C prior to quickly developing the low oxygen atmosphere and by holding carbon dioxide below 3% during the initial month of CA storage.[28] Storage temperature may affect fruit response to a given CA condition and thereby account for some of the variations in the recommended atmospheres. Suitable temperatures vary according to regional growing conditions; 2·5°C is safely used for McIntosh apples in Michigan, but a slightly higher temperature is needed to avoid low temperature injury to McIntosh in New York.[29] Michigan-grown Jonathan apples tolerate 0°C, whereas European Jonathan require a higher CA storage temperature, possibly as a consequence of the cooler growing conditions for the latter.[27]

3.2. Pears

The CA conditions suitable for pears are considerably less well established than for apples.[8] Recommendations for pears are developed only through extensive regional experimentation and experience with the important