CONTROLLED AND MODIFIED ATMOSPHERE STORAGE OF FRUITS AND VEGETABLES

MEYVE VE SEBZELERİN KONTROLLÜ VE MODİFİYE ATMOSFER KOŞULLARINDA DEPOLANMASI

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ÖZET: Bu derlemede, kontrollü ve modifiye atmosferde depolamanın olumlu ve olumsuz yönleri ile uygulama şekli üzerinde durulmuştur. Kontrollü atmosfer uygulamasında önemli yeri olan karbondioksit, etilen ve oksijen gibi gazların meyve ve sebzeler üzerine olan etkileri iyi bilinmektedir. Kontrollü veya modifiye atmosferde depolama süresince taze meyve ve sebzelerin solunum ve olgunlaşma oranları, depolanma süreleri, etilen üretim miktarları, arzu edilmeyen tat ve kokular ile birlikte bazı fiziksel bozulmaların oluşumu ve ayrıca kimi bakteriyal gelişmeler, ortamda bulunan fazla miktardaki karbondioksit ve düşük orandaki oksijen düzeylerinden önemli bir şekilde etkilenmektedir. Etkili bir kontrollü atmosfer sistemi, uygun bir çevre ve gaz emici sistemlerin varlığı ile mümkün olabilmektedir.

SUMMARY: In this paper controlled and modified atmosphere storage and their application, advantages and disadvantages are reviewed. The effects of oxygen, ethylene and carbon dioxide on fruits and vegetables are well known. Respiration and ripening rates, storage life, production of ethylene, formation of undersirable flavours, development of some physiological disorders and fungal growth of fresh fruits and vegetables are affected by high carbon dioxide and low oxygen levels during controlled or modified atmosphere storage. Effective controlled atmosphere requires an adequately specified gas removal systems and storage environment.

INTRODUCTION

Refrigeration and the use of low temperatures is the fundamental technique used to retard deterioration and to maintain fruits and vegetables in the freshest condition for as long as possible or as long as required after harvest (GEESON, 1984). However, in some cases low temperature alone may be insufficient to retard the ripening of fruits or prevent deterioration such as leaf senescence, loss of flavour or texture and microbial attack which can occur during the storage (ANONYMOUS; 1979). Furthermore low temperatures are inappropriate for many crops because of their susceptibility to chilling injury. Commodities such as banana, beans cucumbers and tomatoes have relatively high optimum storage temperatures of 7-14°C, below which they are physiologically damaged, although the symptoms of this injury pitting, discoloration, poor and/or uneven ripening and increased susceptibility to microbial infection often become apparent only when are transferred to higher temperatures (BISHOP, 1990).

Perishing, is primarily over-ripening, and ripening is a consequence of cell metabolism. In normal metabolism, low levels of O_2 inhibit respiration (GEESON et al, 1985). Extension of the storage life o fresh plant produce is dependent on applying techniques which reduce the rate of cell metabolism without causing injury to the produce itself. Refrigeration is the most important technique but a compromise minimum safe temperature has to be accepted (BISHOP, 1990).

Under these circumstance, Modified or Controlled atmosphere used either at ambient temperature or in conjunction with refrigeration, may provide an effective means of retarding deterioration, maintaining the quality or extending the storage life of crops (GEESON, 1984).

Controlled atmosphere (CA) storage could be the most important innovation in fruit and vegetable storage since the introduction of mechanical refrigeration. This method involves is controlling the levels of certain gases in the storage atmosphere as well as controlling the temperature. When CA is combined with refrigeration, it markedly retards respiratory activetiy and may delay softening, yellowing, quality changing processes by maintaining an atmosphere with more CO_2 and less O_2 than in air (SALUNKHE and WU, 1974). CA storage is used to extend the storage life of seasonal perishable products. This technique can be used for many fruits and vegetables, but it is primarily used for apples and pears (HARDUEBURSG et al, 1986).

Respiration

respiration is the oxidative breakdoxn of the more complex substrates is normally present in the cells, such as starch, sugars, and organic acids, to simpler molecules (CO_2 and H_2O), with the concurrent production of energy. The overall equation can be written follows:

$$C_6H_{12}O_6 + 6O_2 + 38ADP + 3Pi \longrightarrow 6CO_2 + 44H_2O + 38ATP$$

Respiration plays a major role in the postharvest life of fresh fruits especially vegetables due to loss of substrate, oxygen requirement, carbon dioxide production (KADER, 1987). An adequate O_2 concentration must be available to maintain aerobic respiration. On the other hand, reduction of O_2 concentration less than 10 % provides a total for controlling respiration rate and slowing down senescence (KADER, 1987). He also reported than in fresh vegetables, if O_2 concentration drops to less than 2 % an aerobic respiration rate and total CO_2 production increase.

Controlled And Modified Atmosphere Storage

Controlled and modified atmosphere (CA/MA) storage is a way of extending the life of products like apples, pears and cabbage where refrigeration alone is not enough to quarantee long term quality (ANONYMOUS, 1990). In thetechnique of CA/MA, the O_2 and/or CO_2 concentration inthe atmosphere surrounding the produce are modified.CA storage is based on removal and/or addition of different gases into the storage room, effectively creating an artificial atmosphere most favourable for significacntly prolonging the shelf life of the commodity (PELEG, 1985). When the fruit or vegetable has been enclosed within a sealed store or container, a MA can be establish by introducing or generatingthe required gas or gas mixture, by "burning out" O_2; usually by the combustion of propane, or simply by allowing the respiration of the enclosed plant material to consume O_2 to produce CO_2 within the sealed space. ACA is fundamentally the same, but theterm is normally applied where the concentration of O_2 is subsequently maintained at the required level by circulating the atmosphere through an appropriate absorbent (GEESON, 1984). CA storage generally refers to decreased O_2 and increased CO_2 concentrations and implies precise control of the gases (WILLS et al, 1989). Successful application of CA totally depends on accurate control of oxygen and carbon dioxide contents as well as the temperature, relative humidity and storage time (PELEG, 1985).

Historical Background of CA/MA

The initiation of CA is achieved by introducing nitrogen gas into a sealed cold storage room and scrubbing out the oxygen (PELEG, 1985). In 1918 Kidd and West started a thorough scientific investigation on commercial use of CA storage at the Food Investigation Organisation in Cambridge in England. They discovered over 70 years ago that certain varieties of apples remained in better condition in an atmosphere that contained less O_2 and more CO_2 than air (LIPTON, 1975). Kidd and West later moved closer to the fruit-growing industry in Kent, and established the Ditton Laboratory. In 1969 the Ditton Laboratory was incorporated in to the East Malling Reseach Station, which has become the world's leading CA research Instutue. This work has continued until the present day under the guidance of Sharpies who introduced the commercial use of ultra low oxygen (ULO) storage of apples a partial reality in the 1940s and inspired others to test the utility of CA storage with other crops (DALRYMPLE, 1967). In the USA alone about one-third o the apple crop was in CA storage at the end of the 1972 harvest (LIPTON, 1975).

The first commercial CA storage in England was carried out by Mr Spencer Mountain in 1929. He successfully stored 30 tons of Bramley Seedling apples in 10 % CO_2. At the outbreak of war in 1939 the storage capacity in Britain had grown to 30000 tonnes. The British storage capacity in 1987 was approximately 300000 tonnes. In 1965 there was 240000 tonnes of CA storage in the USA, and it was 1.8 million tonnes by 1987. CA storage started much more later in other European countries. Apples and pears remain the predominant crop stored in CA conditions, but other produce is also successfully stored (BISHOP, 1990). It has been also shown that CA conditions can increase the storage life of green bananas (McGLASSON and WILLS, 1972). In 1977, work was started at the Food Reseach Institute in Norwich (England) by Geeson and others on the storage of Cabbage (GEESON, 1984).

Beneficial and Detrimental Effects of CA/MA

Preventation of ripening and associated changes in fruits is one of the main benefits of CA/MA (KADER, 1980). Oxygen concentration has to be lowered to below 8 % to have a significant effect on fruit ripening, the lower the O_2 concentration, the greater the effect. Elevated CO_2 levels (above 1 %) also retard fruit ripening and their effects are additive to those of reduced O_2 atmosphere (KADER et al, 1989). Use of CA/MA may allow handling of ripening, especially climacteric type, fruits at temperatures higherthan their optimum temperature. This is especially beneficial for chilling sensitive fruits such as tomatoes, melons, avocodes, bananas, and mangoes, to avoid their exposure to chilling temperature (KADER, 1980).

CA/MA conditions reduce the respiration rate as long as thelevels of O_2 and CO_2 are within those tolerated by the commodity. Low O_2 and/or high CO_2 concentration can reduce the incidence and severity of certain physiological disorders such as those induced by C_2H_4 and chilling injury of some commodities (KADER et al, 1989). On the other hand, O_2 and CO_2 levels beyond those tolerated by the commodity can induce physiological disorders such as brown stain, internal browning and surface pitting (HERNER, 1987).

CA/MA combination have direct and indirect effects on postharvest pathogens. EL-GROORANI and SOMMER (1981) pointed out that delaying senescence, including fruit ripening, by CA/MA reduced susceptibility of fruit and vegetables to pathogens. On the other hand, CA conditions unfavourable to a given commodity can induce its physiological breakdown and render it more susceptible to pathogens. CA delayed degreening considerably, eliminated abscission and loss of dormancy during storage of produce (BERARD, 1985).

Harmfull effects of CA/MA are intiation of certain physilogical disorders, irregular increased susceptibility to decay when the commodity is physiologically injured by too low-O_2 or too high CO_2 concentration (KADER, 1985b). Another potential disadvantages of small scale CA storage is the possibility of water condensation withing the storage chamber, which may encourage fungal growth and increase decay problems (KADER et al, 1989).

CA Storage Rooms

For the optimum storage condition a store sholud be completely filled with fruit of one varietyor a mix of comatiblevarieties in a matter of one or two days. CA stores are contracted in a similar manner to conventional cold storages. However, a CA storage must be gass-tight. Almost all CA stores now being built in Europe are made from metal-faced insulating panels locked together with proprietary locking systems (BISHOP, 1990). Doors are a common leakage area, and they have to be of substantial construction to allow sealing with a rubber gasket around the perimeter. These are sealed when the door is closed with screw jacks equally spaced around the door (SPEK and ATKINNSON, 1990).

THE EFFECTS OF GASES USED IN CA/MA

The composition of gases in the storage atmosphere can effect the storage life of produce. Alterations in the concentration ofthe respiratory gases, oxygen and carbon dioxide and/or ethylene may extend storage life (WILLS et al, 1989).

Ethylene Effects: Ethylene is produced by fruit as a part of the ripening process and its presence accelerates ripening (McGLASSON, 1985). CA storage reduce ethylene yproduction, but it can still build uyp to significant levels in CA rooms. It has been shown that reduction in these ethylene levels improves the storage life and reduces disorders (DOVER, 1983). It was assumed that ethylene was produced only in climacteric fruits during the ripening phase. The effects of introducing ethylene to the store on climacteric fruits is to initiate them to ripen if the concentration of the gas is above the required threshold. High levels of ethylene in the storage atmosphere can cause undesirable flavours and increased sugar losses in cabbages, and flavour losses in onions (WATADA, 1986). Exposing harvested crops to ethylene can result in the rapid breakdown of chlorophyll. This effect has been shown on a wide variety of green coloured crops (KADER, 1985a). Higher level of decay were also observed in the presence of ethylene for a variety of crops (WATADA,1986).

Oxygen Effects: Many chemical reaction in crops are catalysed by enzymes and the reactions require molecular oxygen. If the O_2 level in the cell is too low there may be undesirable changes in the chemicals which contribute to the flavour and aroma of the crop (BISHOP, 1990). The minimum O_2 level required to avoid fermentation and to ensure aerobic metabolism depends on the kind of crop as well as on duration of exposure. Vegetable crops reacting positively to CA conditions usually require a minimum O_2 content of 1-3 % in the storage atmosphere (WEICHMAN, 1989). At O_2 contents below 2 %, most vegetables react with a sudden increase in CO_2 production (ISENBERG, 1979). Low O_2 and high CO_2 concentration were found to have the same effect in reducing the respiration rate (YANG et al, 1987). KADER (1980) reported that lowering O_2 levels about 2 % can be injurious to fruits because of anaerobic respiration and potential development of off-flavours. If the O_2 level in the cells is low there may be undesirable changes in the chemical which contribute to the flavour and aroma of the crop (ZAGORY and KADER, 1988).

Carbon dioxide effects: The effect of CO_2 in extending the storage life of crops appears to be a reduction in respiration of the crop. Where the level of CO_2 in the store is increased this will, therefore, increase its levels within the crop tissue (BISHOP, 1990). Elevated CO_2 levels reduce aerobic respiration (O_2 consumption). However, at a concentration above 20 %, a significant increase in aerobic respiration occurs and can irreversibly damage the tissue (KADER, 1987). Physiological disorders in fruit, associated with excess CO_2 levels, may be associated with this disruption of the respiratory pathway leading to an accumaliton in the crop cells of alcohol and acetaldehyde (BISHOP, 1990). Depending upon the vegetable, CO_2 concentration, and length of exposure, elevated CO_2 causes various problems during storage or tranmsit. In general, CO_2 build-up to concentration above 5-10 % or more sholud be avoided (HERNER, 1987). At high CO_2 concentrations (15 % or more), off-flavour is usually produced in commodities. In some case, off-flavour may be due to an accumulation of ethanol (ULRICH, 1975).

GAS REMOVAL

The selection of scrubber capacity for a controlled atmosphere installation depends on the rate of CO_2 production of the produce under CA conditions and the characteristic of the scrubber (ANONYMOUS, 1979).

Oxygen Removal: CA storage generally requires a low O_2 level. This condition withing the store sholud be obtained as rapidly as possible to maximise the benefit of CA storage. Store O_2 levels can be reduced quickly by flushing with nitrogen. This can be purchased as liquid or gas on site or used directly from tankers. Used with care this can be an economic and safe way of reducing the store oxygen (YANG and CHINNAN, 1988). A propane burner also can be used for removal O_2 in CA stores. Propane burner uses the combustion of propane to convert the O_2 inthe atmosphere to CO_2 and water. A catalytic-type burner is the most common for of atmosphere to CO_2 and water. A catalytic-type burner is the most common for of reducing store O_2 levels. Disadvantages of this application is there have been problems with safety, due to the accumulation of propane and CO which are produced when the burner is not correctly operated or adjusted. This type of burner also produce a large amount of CO_2 which has to be removed by the scrubber (BISHOP, 1990). Another method of O_2 absorption uses iron powders as themain active ingredient. These products often utilise powdered FeO which becomes Fe_2O_3, Fe_3O_4, and their hydroxide forms after absorption of O_2. It is possible to calculate the right type, size and amount of FeO needed to lower the concentration O_2 to approximate desired prechosen values (KADER et al, 1989).

Carbon dioxide Removal

- **Flushing:** If CO_2 is controlled by flushing with air or nitrogen the flushing gas is switched with a valve or selenoid when the CO_2 increase above a preset level. This is done either manually or automatically (BISHOP, 1990).

- **Carbon Scrubber:** Carbon dioxide can be adsorbed on the surface of activated carbon granules. Once the carbon is saturated no more adsorption takes place. However, if the carbon is than flushed with fresh air the CO_2 is removed and the carbon can be used again. The principle is: The store atmosphere can be blown through carbon beds with a low pressure fan for a presemnt period of time (BISHOP, 1990). Calcium hydroxide and magnesium oxide can also be used for absorption of CO_2 (KADER et al, 1989). Most CA storage facilities use activated carbon srubbers to remove the CO_2 produced by plant material. They are designed and operated to maintain the desired concentration but they are able to reduce ethylene much better than reducing CO_2. The amount of ethylene or carbon dioxide, which is adsorbed per mass of activated carbon, is proportional to the concentration at the input of a column. Because the affinity of ethylene is about three times greater compared to that of CO_2, much more ethylene sholud be adsorbed, when passing additional volume of gas mixture through a column of activated carbon (BAUMANN, 1989).

- **Lime Scrubbers:** The removal of CO_2 or "scrubbing" as it is commonly called can be achieved by using hydrated lime. This still verye common practice and in many instances is preferred to mechanical scrubbers (EKSTEEN and BODEGOM, 1989). The lime that is used sould be fresly hydrated high calcium lime. It is reaction with carbon dioxide is:

$Ca(O)_2 + CO_2$ ———> $CaCO_3 + _2O$ (BISOP, 1990).

The lime can be loaded in a "lime box" external to the store and its effect on the store CO_2 level controlled by regulating the flow through the box (ANONYMOUS, 1979). CO_2 level controlled by regulating the flow throug the box (ANONYMOUS, 1979). Alternatively, Where there is a simple requirement for the CO_2 level in the store to be less than 1 %, the lime can be placed directly in the store with the fruit (BISHOP, 1990). The amount of lime required depends on type of fruit and the respiration rate of them, the length of the storage time required and which deployment method is used (EKSTEEN and BODEGOM, 1989). The recommended scrubber capacity for low O_2 condition is that is sholud hold one 25 kg paper sack of lime for every 1250 kg of store capacity. One kg of lime can absorb 0.59 kg of CO_2 during its conversion to the carbonate (ANONYMOUS, 1979). Activated carbon scrubbers are still occasionally used. Lime is used extensively and gives satisfactory results (EKSTEEN and BODEGOM, 1989).

Ethylene Removal

The concentration of ethylene in storage rooms can be readily controlled (DOVER, 1989). Ethylene removal from a store can have a beneficial effect on the fruit storage life and quality. Undersirable levels of ethylene in produce storage areas can be removed by simple ventilation with fresh air if the air is not required to maintain a low ethylene levels (WOJCIECHOWSKI et al, 1985). Ethylene can be also scrubbed from the atmosphere by trapping and/or conversion to other products when ventilation can not be used for removal (SHERMAN, 1985). A large number of reagents and techniques have been tested over the years (BLANPIED et al, 1982) but only potassium permagnganate is presently in common commercial use (LISTER et al, 1985). To be effective, $KMnO_4$ must be adsorbed on a suitable carrier with a large surface areas and celite, vermiculite, silica gel and alumina have all been successfully used as carries (SHERMAN, 1985). These are successfully used for the transport of fresh produce, but prove uneconomic in long term CA storage (BISHOP, 1990). Boulder-clay powder, the principal component of which is cristobalite (>87 % SO_2, >5 % AlO_2, >1 % Fe_2O_3) with traces other crystals absorbs ethylene and many other gases and is non toxic but it results in a brownish cloudy appearanace on fresh produce (KADER et al, 1989).

Water Scrubbers

Most of the major pathogens affecting the postharvest life of fresh produce need an environment with a water activity of more than 0.80 for their growth (SHIRAZI and CAMERON, 1992). Reduction of humidity to levels below the critical water activity of microorganisim should be an effective way to limit their growth. The general recommended levels of 85 % to 95 % relative humidity (RH) (HARDENBURG et al, 1986) for storage of fresh produce. Compounds, such as sorbitol, xylitol, and NaCl, KCl and $CaCl_2$ can be used for reducing the RH in CA/MA stores (SHIRAZI and CAMERON, 1992). For most perishable commodities, the RH in a storage facility sholud bekept in the range of 90-95 %. Humidity levels below this range will result in unacceptable moisture lost. Humudity close to 100 % may cause excessive growth of micro-organism may cause surface cracking.

Automatic Control of CA Storage Rooms

To maintain a stable atmospheric composition in CA storage rooms it is necessary to remove CO_2 at the rate at which it is produced, and supply O_2 at therate at which it is consumed (BAUGEROD, 1980). It is practice in the UK and other European countries to automatically control low-O_2 CA stores. These controllers can be based either on microcomputers or analogue electronics (LAUGHEED and BISHOP, 1984). The gas levels in each store are periodically measured, and the value compared with the required level which is present into the machine. If the O_2 level is lower than required the store is automatically vented, and if CO_2 control is also fitted the scrubbers automatically operate when the CO_2 level is high (BISHOP, 1990). Automatic control of the gases is more desirable than manual control at these levels and is considered essential at ULO conditions (ANONYMOUS, 1979).

An automatic gas sampling and distribution system can be used for CA storage rooms and chambers. The system is set up to control O_2 and CO_2 levels and to monitor C_2H_4 in all CA rooms and chambers. An atmospheric sample from each CA room or chamber is drawn into the gas control room through copper tubes and pumped into O_2 and CO_2 analyser. If the O_2 levels is higher than the set value, then N_2 is automatically injected into the appropriate room under computer control. If the O_2 level is low, then air is automatically injected into the appropriate room. Similarly, the CO_2 level in a CA room can be adjusted by adding CO_2 or N_2 into the room. The system also has the ability to monitor and displays C_2H_4 levels in each CA rom and CA chambers (CHU et al, 1985).

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