Lesson 43. Controlled and Modified Atmosphere Storage

43.1 Introduction

Controlled atmosphere (CA) and modified atmosphere (MA) storage are technologies for extending the shelf life of foods, especially fruits and vegetables; and for eliminating pests in stored grains and oilseeds. The most important application of CA and MA is for long-term storage of apples, but the shelf life of certain other fruits (pears, sweet cherries) and vegetables (cabbage) can also be extended by these methods. In addition, there is considerable evidence that MA can extend the shelf life of meat, fish, poultry, fresh pasta, sandwiches, eggs, and bakery products. Because grains and oilseeds are more stable than high moisture foods (e.g., fruits, vegetables, meats), CA and MA are used primarily for disinfestation rather than for increasing the shelf life

43.2 Controlled and Modified atmospheres for fruits and vegetables

43.2.1 Principle

The principle behind controlled and modified atmosphere technologies is to reduce the rate of respiration, reduce microbial growth, and retard enzymatic spoilage by changing the gaseous environment surrounding the food product. This is achieved by reducing the concentration of oxygen (O_2), which is required in respiration, or by adding an inhibitory gas such as carbon dioxide (CO_2) or carbon monoxide (CO). The balance between O_2 and CO_2 is critical, and an optimal ratio is required for each specific product. A major difference between CA and MA storage is in the degree of control of the gaseous composition of the storage atmosphere. The CA implies a higher degree of control than MA in maintaining specific levels of O_2, CO_2, and other gases. Also, in MA storage the composition of the atmosphere surrounding the product is generally created and maintained by the interaction of the commodity's respiration with the permeation of respiratory gases through the packaging material. Modified atmosphere conditions can also be established and adjusted by pulling a slight vacuum and replacing the package atmosphere with a desirable gas mixture, which can be further, adjusted through the use of O_2, CO_2, or ethene (C_2H_4) absorbers. In CA storage facilities, both temperature and gas composition of the storage atmosphere are regulated or controlled. The gas concentration ranges encountered in CA storages are 1 to 10% O_2, 0 to 30% CO_2, and the balance is nitrogen (N_2). Air consists of approximately 78% N_2, 21% O_2, 0.03% CO_2, and traces of several other gases that have no physiological significance.

43.2.2 Benefits and limitations of CA and MA storage

The benefits and concerns of CA and MA storage have recently been reviewed by several authors. The benefits can be divided into quality advantages and marketing and distribution advantages. The improvements in quality arise from the general reduction in the rates of metabolic processes, retardation of physiological aging, enzymatic spoilage, and reduction in microbial growth. In fresh fruits and vegetables stored under optimal CA or MA, practical quality advantages include:

1. Reduction in chlorophyll breakdown, with resulting higher color stability.

2. Reduction in enzymatic browning in cut produce, whenever low levels of O_2 are used.

3. Improvement in texture caused by the action of CO_2 on enzymes acting on cellular membranes.

4. Reduction in some physiological disorders induced by C_2H_4, such as scald of apples and pears and chilling injury of citrus fruits, avocado, chili pepper, and okra.

5. Reduction in microbial activity especially molds.

The marketing and distribution advantages of CA or MA technologies include:

1. Reduction in fresh food spoilage and quality loss through the distribution at the retail level.

2. Expanded radius of distribution systems and market area.

3. Improved branding options and product differentiation.

4. Potential for increased profitability in all fresh or chilled food operations.

In considering the above described benefits, a number of potential problems associated with CA or MA storage must be recognized. Above all is the potential health hazard associated with these technologies, especially modified atmosphere packaging or MAP. It has been pointed out that the same principles of atmosphere modification responsible for all the benefits of CA or MA are also the main cause of controversy surrounding the potential health hazards associated with these technologies. Modification of the atmosphere and, in particular, the reduction or elimination of O_2 from the package head space will in many cases disturb the equilibrium of the atmosphere in favor of anaerobic microorganisms. The aerobic bacteria that normally spoil the product, and in so doing warn consumers of any potential health hazard, may find themselves at an atmospheric disadvantage and their growth inhibited. In the absence of competing aerobic organisms, anaerobic nonproteolytic toxin producers, such as Clostridium botulinum, are likely to have the right conditions for optimum growth, but their presence may not be obvious to the senses. The food may appear to be acceptable long after it has become microbiologically unsafe. Other concerns associated with CA or MA technology include:

1. Development of off-flavors due to accumulation of ethanol, acetaldehyde, and other volatiles.

2. Increased softening in products such as cucumbers, cauliflower, celery, and onion.

3. Development of physiological disorders, such as brown stain on lettuce, internal browning and surface pitting of some fruits, and blackheart of potatoes induced by inappropriate modified atmospheres.

4. Increased susceptibility of some products (celeriac, carrot, pepper, Chinese cabbage, and citrus fruits) to post-harvest pathogens.

43.2.3 Methods for creating and maintaining MA

The reduction of O2 levels inside an enclosed space (storage room or polymeric film package) can be achieved biologically through respiration of the food product, or it can be obtained by replacing the atmosphere of the storage space with the desired gas mixture. In the first case, the reduction of O_2 to levels of 2 to 3% may require up to 25 days and depends on the characteristics of the commodity and the degree to which the storage room is airtight or the gas permeability characteristics of the packaging film. When a non-biological or active modification system is used, O_2 can be reduced to levels of 2 to 3% within hours. It has been shown, for some commodities, that a shorter O_2 reduction or pull-down period results in better post storage quality. Rapid O_2 pull-down or rapid CA requires the shortest possible time for crop harvest, room loading, product cooling, room closure, and O_2 reduction. Rapid O_2 reduction is obtained by either N_2 flushing or catalytic combustion. In addition, O_2 absorbers may be used, especially in MA storage. There are a wide variety of O_2 absorbers, e.g., dithionite, ascorbic acid, alkali containing glucose, H_2 gas in the presence of palladium catalyst, and iron-based products. Most commercially available O_2 absorbers utilize iron oxide (FeO), which becomes iron oxides (Fe_2O_3 and Fe_3O_4) and hydroxides ($Fe(OH)_2$ and $Fe(OH)_3$) after absorption of O_2. From the reaction mechanism of the O_2 absorber(s) and volume of the storage space, it is possible to determine the amount of FeO needed to lower the concentration of O_2 to approximate desired pre-chosen values. Modified atmosphere packages are dynamic systems where respiration and permeation occur simultaneously. In order to achieve and maintain a satisfactory atmosphere within a package, the rates of CO_2 production and O_2 consumption by the food product must be equal to diffusion rates of the respective gases through the package at a given temperature. Factors affecting respiration of produce in the package include mass and type of food product, temperature, O_2 and CO_2 partial pressures, ethylene levels, and light. Factors affecting gas permeability through the package include type, thickness, and surface area of the packaging film, as well as temperature, relative humidity, and gradient of CO_2 and O_2 in the sealed package.

43.3 Controlled Atmosphere storage of Cereals and Oilseeds

43.3.1 Principle

In CA storage, an environment that is lethal to stored-grain pests is created by changing the proportions of CO_2, O_2, and N_2 in the atmosphere surrounding the bulk grain in storage structures. Controlled atmosphere storage is different from an airtight storage where gas ratios change naturally, although both are carried out in more or less gas-tight storage structures. In air-tight storage, the depletion of O_2 and the accumulation of CO_2 occur due to the metabolic processes of the insects, microflora, and the stored grain. Because the effectiveness of the air-tight storage is largely dependent upon the build-up of an infestation in the grain, it is not considered a satisfactory method. Controlled atmospheres are attained by introducing CO_2 or N_2 from external sources, possibly prior to the build-up of infestation, thereby preventing damage to the stored grain.

43.3.2 Advantages and limitations

The main advantage of CA to disinfest grain is its potential to replace pesticides used in the grain industry. The CA-treated grain does not have any chemical residues which can cause considerable health concerns. In addition to providing an effective control of pests, CA storage prevents mold growth, preserves grain quality, and maintains a high level of germination in the stored grain. However, as with any other method of pest control, CA storage has limitations. The major limitation appears to be the high initial cost of air-tight storage structures, and the cost of sealing existing structures to the desired air-tightness. There is also the cost of the generation and transportation of the gas. The interaction of CA gases with the storage structure can cause some practical problems. The introduction of CO_2 or N_2 into airtight structures has the potential to increase the internal pressure on bin walls, and steps need to be taken to permit pressure equilibration. The only chemical reaction observed with CA involves CO_2 in concrete silos. Carbon dioxide is bound by concrete through carbonation, which can result in reduced pressures developing in well-sealed new concrete bins. Also, carbonation of concrete can gradually extend to a depth where reinforcing steel is exposed and the steel may eventually corrode and weaken the storage structure.

43.4 Quality changes in grain under CA storage

43.4.1 Seed viability

Grain can be stored for relatively long periods without a loss in viability, with a decreasing scale for longevity in oats, rice, barley, wheat, triticale, rye, sorghum and corn. The main factors that affect longevity are moisture and temperature with each 1% increase in seed moisture content (MC) halving the life of seed. This rule applies when seed moisture content is between 5 and 14%. Below 5% MC the speed of aging may increase because of auto-oxidation of seed lipids and above 14% MC storage fungi kill the seed. Also, for each 5°C increase in seed temperature, the life of seed is halved (from 0 to 50°C). The presence of O_2 decreases seed germination, even at low partial pressures in dry grain because of membrane damage caused by the production of free radicals and accumulating chromosome damage.

43.4.2 Nutrient changes in grain

A controlled atmosphere of 97 to 98% N_2, 1 to 2% CO_2, and 1% O_2 slows hydrolytic processes in the lipids of rice grain compared to grain stored in air. Pure N_2 atmospheres at 20°C stabilize protein and amino acids and the cooking properties of rice at 18.4 and 23.2% MC compared to storage in air. Elevated N_2, with negligible O_2, retain higher gluten quality in stored wheat than storage in air and the milling and baking properties of wheat are maintained longer than in air even at high moisture contents. An anoxic environment (N_2) slows the oxidative activity and better preserves the organoleptic properties of grains.

43.4.3 Effect of CA on Fungi and Mycotoxins production

Elevated CO_2 (20 to 60%) inhibits fungi and the production of mycotoxins by fungi in stored grain including T-2 toxin, patulin, ochratoxins, penicillic acid, and aflatoxin. The prevention of aflatoxin production in wet corn is of considerable importance in animal feed grain. Reduction of O_2 is less effective in preventing mycotoxins than the elevation of CO_2.

In dry grain, 20% CO_2 inhibits microflora; in wet grain 80% CO_2 is needed. Some species of Fusarium, Aspergillus, and Mucor are tolerant to high CO_2 levels. In wet grain, at 1 to 2% O_2 and 15 to 40% CO_2, typical microflora were the yeasts Hansenula and Candida (60 to 80% RH) followed by anaerobic fermentation caused by lactic acid bacteria and yeasts (>90% RH). Filamentous fungi gradually disappear during storage. Fungi do not grow at <1% O_2. Yeasts can survive at <0.5% O_2.

References:

1. G.S.V. Raghavan, Clement Vigneault, Yvan Gariépy,N.R. Markarian, and P. Alvo. Refrigerated and controlled/Modified Atmosphere Storage.

2. K.M Sahay and K.K.Singh.Text Book of Unit Operations of Agricultural Processing, Vikas Publushing House pvt ltd.