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Modified Atmosphere Packaging: A Future Outlook

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Abstract. **All development is on a continuum that began in the past and should proceed on a time line incrementally deriving its bases from previous information. Modified atmosphere packaging emerged from the research and findings of controlled atmosphere storage and distribution with relatively little concern about external environmental controls which were axiomatic with controlled atmosphere. Unfortunately, a virtually universal paucity of control over environmental variables such as product sanitation and temperature led to a need to address issues of anaerobic respiration within sealed packages. Overcoming potential anoxia directed development towards more gas permeable package materials and structures at the expense of research on more comprehensive solutions to quality retention. Even as the oxygen permeabilities of plastics are not ignored, new directions are towards integration of multiple technologies to retard both microbiological and physiological deteriorations. Primary among these are the rapid reduction in temperature using cryogenic, air impingement or related techniques followed by careful maintenance throughout distribution. Corollary is the more refined control over process operations to ensure initial quality. Complementing these controls might be the introduction of gases and techniques such as noble gases and internal package humidity control that have been demonstrated to enhance the effects of oxygen reduction and carbon dioxide elevation. Almost as important is the assembly of all the added value elements in a balanced manner to deliver what should be regarded by consumers as a complete quality eating experience.**

In the United States, the fruit and vegetable delivery systems are shifting from fresh whole to minimally processed; from distribution packaged in lined or unlined corrugated fibreboard cases, wooden crates and bins to consumer/other end user, i.e., hotel/restaurant/institutional packaged—after all, consumers use pieces, trimmed and cleaned and not whole lettuce heads; from air packaged to altered total system environment packaged; to integrated environment processing and distribution; and from modified atmosphere to nearly controlled atmosphere packaged. The future of packaged fruit and vegetables will be found in the integration of multiple technologies—which now may be designated hurdle technologies; integration with distribution, i.e., comprehensive integration throughout the system; and a shift towards prolongation of initial quality retention rather than avoidance of anaerobic respiration as an objective.

How might the future of fruit and vegetable preservation be forecasted? The first element in forecasting is to comprehend the history of fruit and vegetable preservation with particular reference to its drivers. A second basis is thorough knowledge of science and technology. A third foundation is knowing and understanding the current drivers such as research and development findings; product characteristics and needs; and distribution channels and technologies. It is imperative that the forecaster apply reasonable probabilities and not hopes and dreams to the forecast. Finally, it is critical to extrapolate from the past through today into the future. Nothing springs from a zero base. The future is almost invariably an extrapolation from today—and should contain no surprises for the professional who is immersed in the discipline. Because the future derives from yesterday and today, it is important to understand the relevant history of fruit and vegetable preservation. Prior to the 1930s, ice and mechanical refrigeration were employed to help move food from the growing to the consuming areas. During the 1930s/1940s, New Zealand meat and New York State apples entered the first controlled atmosphere storages. During the 1950s/1960s, Whirlpool Corporation's Tectrol process represented the first Total Environmental Control:

- Temperature control was absolute and basic—because Whirlpool was in the refrigerator business.
- Respiratory and microbiological anaerobiosis were not considered because it was controlled by the presence of oxygen. Gas concentrations were precise.
- Water vapor content was deemed to be critical and so was overtly controlled to 85% relative humidity.
- All test products were freshly harvested, cleaned, and brought to the laboratory within minutes of peak quality: asparagus, beans, peaches, strawberries, etc.

The critical objective of the Whirlpool research was to optimize quality retention. Within four years of the first experiment, the Tectrol process was commercially applied for apples. During the 1960s, for business reasons only, the Tectrol process was transferred to a new spin-off joint venture organization—Transfresh—which later was totally divorced from Whirlpool Corporation.

Because the new parent was a Salinas, California, lettuce grower, Tectrol was applied to head lettuce transport. Lettuce trucking represented the first application of plastic film boundary to retain the atmosphere within a confined space. Because of the plastic and nitrogen gas injection only at the outset, the system now represented a compromise from the optimum—it was really modified atmosphere. Nevertheless, Tectrol became commercially functional for bulk in spite of imprecise control of anoxia and the first example of imprecise control of temperature.

Transfresh's results later were translated into plastic film-packaged intact fresh produce products.

Prevention of respiratory anaerobiosis within the package was critical to quality and became the principal focus of research and development among the produce industry technical staffs. Mechanisms to defer anaerobiosis included high gas permeability films, which really did not exist during the 1970s; thinner films, which were physically undesirable because they were not sufficiently resistant to impact, abrasion, or puncture; windows of gas-permeable films, which appeared to function well; and high surface-to-volume, i.e., package material-to-contents packages, which were used extensively. Transfresh's results further were translated to consumer-sized packages by employing passive rather than active atmosphere, i.e., rather than injecting appropriate gas mixtures, the produce respiration generated the required equilibrium at atmosphere—a "less expensive" approach. Packages began either with air or vacuum. Both required product respiration to achieve the required equilibrium CO_2:O_2 environment. Water vapor, however, was not controlled. One result of passive atmosphere control was (and is) the loss of 1 to 2 days' quality life. In addition, by using commercial distribution channels, temperature control was lost. One result has been that symptoms of respiratory anaerobiosis still appear in commercial packages of pre-cut produce. As a consequence, research and development focus has been on suppression of respiratory anaerobiosis. This chronology demonstrates the evolutionary process that propelled the original controlled atmosphere to a modified atmosphere packaging—not a scientifically based progression, but rather a series of compromises.

During the mid 1980s, at the behest of academicians, the controlled atmosphere designation was converted to "modified atmosphere packaging" to better describe the in-package environmental situation.

Because of the problems, the focus of research and development was on the suppression of respiratory anaerobiosis. Among the solutions proposed, several with extraordinary publicity:

- Microporous package materials, e.g., FreshHold, developed by Hercules and now marketed by River Ranch.
- Microperforated package materials such as P-Plus from Sidlaw in the United Kingdom, now marketed by Printpack.
- Thinner gauge/high gas permeability films such as Philips K-Resin from many package material extruders and converters.

These alternatives were applied for both intact and fresh-cut vegetables.

Sanitation and temperature control became recognized as being important if not critical to product quality retention.

Published peer-review research results of the 1980s and 1990s did not necessarily support commercial developments. In fact, many literally trailed commercial information by years.

If was evident that commercial and university research objectives were different: the former had immediate problems to resolve; the latter had not been apprised of the issues or results and were still addressing 1960s and 1970s questions.

Commercial sanitation, hardly mentioned in peer review literature, was crucial in factories. As important as it was to product quality, temperature control was begun in processing, but not necessarily throughout distribution. Therefore, retardation of respiratory anaerobiosis by methods other than temperature control became critical. As one result, the issue of quality retention was somewhat less crucial than the respiratory anaerobiosis issue.

Forecasting the future requires not only an understanding of the past—which shows how we arrived at where we are and what we are doing today—but also comprehensive of the current situation.

Current situation with fruit and vegetable preservation. Commercial fresh-cut fruit and veget able processors and packagers are attempting to cope with sub-optimum/poor distribution temperatures and the respiratory anaerobiosis issue. At the same time, they are trying to develop minimally processed fruit. Looming over all of this is the issue of microbiological safety which has generated both headlines and great concern among regulators.

University and independent, etc., research are focusing on microbiological safety, on deteriorative mechanisms, and on developing models to predict gas concentrations under various conditions.

Within commercial fruit and vegetable factories, clean room technology is becoming standard for fresh-cut fruit and vegetables processing.

Future. The target objective in the future must be to retain the initial high quality of the freshly harvested fruit and vegetable. The core feature of quality retention will be integrated technologies or, as often designated today, hurdle technology.

Hurdle technology. Integration of multiple technologies is required to achieve the quality retention objective. Within hurdle technology, temperature is most important variable, throughout processing and distribution.

Other variables essential to be addressed are:

- Raw material quality—to retain quality, you must have initial quality;
- Sanitation of the product and its processing environment by chlorine, ozone, or other technologies;
- The effective use throughout of environmental gases as in oxygen reduction, carbon dioxide elevation, water vapor control, ethylene removal, etc.;
- Control pH;
- Pretreatment such as mild heat to inactivate enzymes and/or the addition of chemicals such as ascorbic acid to retard oxidation; and
- Post treatments such as UV or pulsed light irradiation might have merit to restrain microbiological growth.

Temperature control. As is well known, temperature is the most critical influencing variable in retaining quality and ensuring safety. But this temperature should be maintained in process as well as distribution operations. Temperature reduction may be achieved in the future by cryogenic and/or air impingement to achieve a level just above the freezing point, -1°C, where the least biological activity occurs without a phase change. Moisture control is also important. It is important that product temperature—and not just air temperature—control be effected in distribution:

- In the production warehouse
- In transport: trucks, containers, rail cars, etc.: prechill the vehicle and maintain its temperature
- In any distribution warehousing—which, of course, should be discouraged in favor of cross-docking or direct delivery
- Retail display today constitutes the major challenge but even here, the concerns over microbiological safety are driving towards better control—which is achievable technically
- Temperature in the consumer site is important—and will be better controlled in the future

Temperature control may be achieved by air temperature and engineered cold air circulation. The defrost and refrigeration cycles are of consequence since the product's temperature should not increase. Compartment thermal insulation is, of course, important.

Ice with a temperature of -1 to 0°F and a fusion heat can be considered as a secondary refrigerant. Temperature control should be throughout the entire system, and not just in warehousing—which should not even be part of the system.

Temperature control at less than 3°C eliminates the *Clostridium botulinum* Type E toxin formation problem. 0°C significantly reduces *Listeria*, *Salmonella*, etc. problems. There are no known effective means today of coping with *E. coli* O157:H7 beyond the initial product quality and sanitation discussed above. The use of -1°C slows enzymatic and biochemical activities; and the growth of spoilage microorganisms. Low temperatures reduce physical moisture loss if steady temperatures are employed. Reduced temperatures maximize the beneficial effects of CO_2 because CO_2 solubility at 0°C is 40% higher than at 10°C, 20% higher than at 4°C.

Thus, temperature control effectively doubles shelf life or, conversely, permits a two-times quality enhancement for each 10C° reduction to -1°C.

Processing. In the future, sanitation will be improved to virtually eliminate microbiological pathogens—no technology known today can guarantee the absence of pathogens, despite the Federal government pronouncement of this objective. Sanitation, of course, reduces the total spoilage microbiological count. Sanitation is achieved through clean room technology, building good facilities, constantly cleaning the facility, keeping the "dirty" isolated from the clean, isolating each station, ensuring clean workers and practices, and maintaining the areas cold—"clean and cold."

Gas Involvement. Numerous gases are used and more will be considered to aid in product quality retention. Reducing oxygen, of course, reduces oxidative and aerobic pathways. Carbon dioxide remains as the major microbistatic agent.

In a new concept, the appropriate gas mixtures should be incorporated throughout processing operations, and not just as package headspace gas:

- Cutting
- Conveying
- Cleaning
- Packaging

Incorporation of gas throughout the system can effect quality enhancement of greater than 50% over air handling; chlorinated water washing; and conventional mechanical conveying. Gases whose increased use can enhance quality retention include ozone, carbon dioxide, and noble gases.

Ozone. Ozone—now in the process of becoming Generally Recognized as Safe (GRAS)—is an effective sanitizing agent at 0.1 ppm in water. Ozone is microbiocidally more powerful than chlorine. Ozone reduces problems associated with chlorine, such as:

- Residual odor
- Possible adverse secondary effects such as organochlorine reaction products which have been implicated in public health issues.
- Ozone is being proposed to replace chlorine.

Carbon Dioxide. In addition to its "headspace functions," carbon dioxide is effective as a conveying gas when dissolved in wash water to reduce pH, and also exerts some microbiocidal effects.

Noble Gases. The potential for noble gases to replace nitrogen must be prefaced by a brief description of nitrogen's role. Nitrogen is effectively inert and is used to displace oxygen and blanket the product.

All noble gases such as argon, krypton, xenon and neon display biological effects up to twice those of nitrogen in retardation of enzymatic activity, microbial growth, and biochemical activity. Being more widely present in the atmosphere and therefore commercially available, argon has been most studied.

The mechanisms by which noble gases exert their actions is not known; some scientists have postulated it to be related to an atomic size difference from N_2. This size difference leads to significantly more effectiveness than N_2 in purging O_2 from environments—and is probably the most important effect.

Argon is twice as soluble as nitrogen in water. At least one scientist believes argon may interfere with enzyme sites in lock/key theory of enzyme activity.

Argon. Argon is being used commercially as a conveying gas, and with CO_2 dissolved in wash water in fresh-cut vegetable processing. Argon offers a 1.5 to 2 time enhanced effect over CO_2 alone. The argon/CO_2 water can replace chlorinated water with a 1 to 1.5 time enhanced effect over the chlorinated water.

Argon is being used as a blanketing gas and headspace gas throughout the system to achieve a quality enhancement effect up to two times over CO_2/N_2.

Argon may contribute to ultra-low O_2 levels, which may exhibit quality retention effect.

Argon should be employed only in total processing, packaging, distribution systems context to optimize its effect.

Elevated Oxygen. A gas concentration much greater than the 20.9% of air, i.e., > 60% O_2, in equilibrium with the contents significantly exceeds optimum O_2 concentration for normal respiration reduction. The effect appears to be both enzymatic and microbiological. Elevated oxygen has demonstrated some significant positive effects in initial quality retention.

Research results to date, however, have not been consistent among vegetables.

Water. Water is an active reactant in the respiration of both produce tissue and microbial cells. The physical gain or loss of water can have adverse results such as: loss results in reduced quality; gain can increase microbiological growth propensity; gain can lead to reduced quality; condensation within the package is undesirable.

Water must be optimized in equilibrium to retain quality. Water vapor in the environment should be in equilibrium with water in the product. Approximately 85% relative humidity is generally considered optimum. Water vapor concentration should be at optimum throughout the system, including processing, conveying, and packaging operations.

Other Gases. Ethylene reduction for selected climateric fruit and vegetable products retards respiration.

Although ethanol production in respiratory anaerobiosis leads to undesirable off flavors, ethanol inhibits microbial growth; blocks cell and tissue metabolism; kills some microorganisms; and reduces a_w. Ethanol is a natural fermentation product which may or may not be desirable.

Ethanol's secondary effects, such as flavor and parent-perceived effect on children, are probably not desirable

Sulfur dioxide is a well-known antioxidant, enzyme inhibitor, Maillard reaction inhibitor, and microbial growth inhibitor. Sulfur dioxide's secondary effects are undesirable—with some persons allergic to it. One research proposal suggests treating product with SO_2 and purging SO_2 immediately before packaging so that the beneficial effects are achieved without the adverse consequences.

Nitrous oxide is yet another gas which has been demonstrated capable of delivering desirable results.

Packaging. Packaging is not just a pouch or a tray with a headspace—it is a unit operation that is elemental to the total system. The packaging process must be integrated with processing and distribution. The operation of packaging equipment is more than headspace gassing. Packaging must incorporate purge and blanketing prior to the actual marriage of product and material. The package structure must consider: the package material gas permeability; the total package gas transmission as influenced by defects, seal defects, etc.; package moisture permeability/transmission; and the temperature dependence of the package material characteristics—which, in most situations, is non-responsive.

Active Packaging. Active packaging is the nomenclature for a relatively new class of packaging that is overtly responsive to changes in internal or external environment such as temperature, relative humidity, oxygen, carbon dioxide, carbon dioxide:oxygen ratio, ethylene, and microbial presence.

Active packaging can remove components present in excess: oxygen; carbon dioxide; water vapor; ethylene; and aromas, including spoilage odors. Active packaging can permit controlled loss of components such as carbon dioxide and water vapor. It can permit the addition of desired components: oxygen; water vapor; aromas; microbicidal agents, such as silver ions or chlorine dioxide. Active packaging may be an independently functioning package insert, such as a gas-permeable sachet. Such devices are commercially available and used for oxygen control (scavenging), moisture control (either add or subtract), and carbon dioxide control.

Active packaging components may be incorporated into a portion of the package structure as, for example, the closure (lidding on a tray), a window (membrane), or a patch (membrane).

Recently the active component has become an integral component of the package material, such as the wall or tray itself. Such structures are commercial for oxygen and/or moisture control.

High gas transmission package material structures such as microporous or microperforated are not regarded as "active" packaging but, nevertheless, function in much the same manner by removing or adding gases.

Whether or not any of the special mineral-filled structures from Asia function as suggested by their proponents remain an open question. Few, if any, North American, or European researchers have been able to replicate results reported from Asian researchers.

Polyolefin Package Material Technologies. In the area of more conventional packaging, plastic resin today is being produced with very tight physical chemical properties and controlled crystallinities. Films fabricated from the new resins offer more uniform, precise control over gas and moisture permeabilities: these films can offer increased gas permeabilities and can permit thinner gauge films that permit higher gas permeabilities. Thus, film processing technologies with these single site metallocene catalyst resins deliver more uniform films with more precise permeabilities.

In the future, package materials and structures such as those "intelligent" polymers from Landec (and others) offer the potential to foster almost total control over internal package environments and therefore deliver true controlled internal atmosphere packaging.

The implementation of controlled atmosphere packaging can increase shelf life by a factor of 1.5 to 2 over modified atmosphere packaging—or, conversely, deliver significantly better quality during the same distribution time.

None of these technologies is a substitute for good initial product quality, good operational sanitation, comprehensive systems temperature control—i.e., keeping the system clean and cold.

Technology Integration. The integration of product, processing, packaging, and distribution technologies is, in theory, capable of enhancing the quality by a factor of up to 15 times over conventional handling:

	Enhancement Effect
Processing	Up to 2X
Packaging process:	Up to 1.5X
Packaging:	Up to 2X
Distribution:	Up to 2.5X
Theoretical total (if every variable were independent):	Up to 15X

Obviously, a fifteen times increase in shelf life is not really possible, but rather demonstrates that there is a very wide gap between today's practice and tomorrow's possibilities—even by obtaining a fraction of the possible gain.

Future. In the future, both commercial and other interests will necessarily de-emphasize avoidance of respiratory anaerobiosis problems in favor of emphasis on enhancing quality retention. Integrating technologies can improve quality enhancement by a factor of up to 15 times. Realistically we can expect improvement of two to four times. Because of better controls, there will be a diminishment of concern over pathogenic microbiological problems.

To reiterate our vision of the future, fruit and vegetables are shifting:

- From fresh to minimally processed;
- From distribution packaged to consumer/end user packaged;
- From air packaged to altered environment packaged;
- From modified atmosphere to controlled atmosphere packaged;
- To integrated environmental distribution.

These objectives will be achieved through the implementation of integrated control of temperature, sanitation, and the environment faced by products. Active packaging, especially that with sensitivity to temperature, oxygen, carbon dioxide, and relative humidity, will be used. Noble gases will be used. There will be reduced pathogenic risk and significantly enhanced quality retention. Package will become both a distribution and serving implement.