BUL 1098

Potato Packaging:

Quality Maintenance and Extending Shelf-Life After Harvest

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Introduction

THE POTATO INDUSTRY uses various materials to conveniently package potatoes. After harvest and/or storage, packaging enables convenient transport, provides information on nutrition and cooking recommendations, appeals to consumer ease, and effectively protects clean potatoes from external conditions. Packaging also potentially shields potatoes from the light to prevent greening, to reduce respiration, and to lower weight loss and transpiration (evaporation) losses.

Putting potatoes into some packaging material such as plastic or paper bags, film box liners, wax, or coatings is referred to as modified atmosphere packaging (MAP). This technique changes the atmosphere or conditions around the potatoes within the packages, which is beneficial for maintaining the potatoes' quality and extending their shelf life for up to thirty-five days. However, faster deterioration of potatoes can occur if proper temperature and relative humidity are not properly managed, leading to sprouting, dehydration, and disease development. This bulletin discusses what MAP is, the benefits of using it, how it works, and the various ways to use it when packaging potatoes.

Principles of Modified Atmosphere Packaging (MAP)

The term MAP refers to the modification of gases in the atmosphere within the package, which creates an atmospheric composition different from normal air. Normal air is composed of 78.08% nitrogen (N_2), 20.95% oxygen (O_2), 0.04% carbon dioxide (CO_2), and 0.93% of other gases, including noble gases and ethylene (C_2H_4). Water vapor is also present in the air. The respiration of potatoes, however, reduces O_2 levels and increases CO_2 concentrations within a package, creating an atmosphere different from normal air, a modified atmosphere (Figure 1).

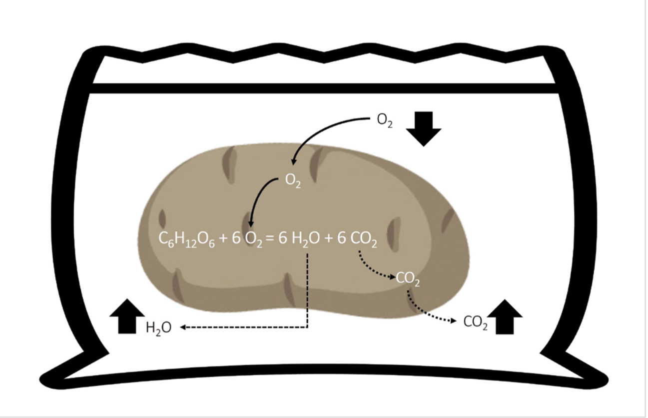

Figure 1. Modification of the atmosphere within a potato package due to a potato's respiration process. Packaged potatoes consume sugars (glucose [$C_6H_{12}O_6$]) and oxygen (O_2), thus reducing the O_2 level inside the package. The process generates carbon dioxide (CO_2) and water (H_2O) due to carbohydrate oxidation. These compounds accumulate inside the package or deplete, depending on the package's permeability to gases and water vapor.

The atmospheric composition in the package is not precisely controlled with MAP, because it depends on several factors: the potato's initial quality, the gas mixture, the storage temperature, the microbiological load or disease presence, the gas/product volume ratio, the physical barrier properties of the packaging material (permeability), and perforation.

One of the two main benefits of using MAP is that it reduces the respiration rate of packaged potatoes. The rate reduces because O_2 is a substrate and CO_2 is the product of respiration and both regulate, directly or indirectly, the activities of the respiratory system and a large number of enzymatic systems. The scientific explanation is that low O_2 limits key regulatory steps of glycolysis (breakdown of sugars) and, consequently, respiration. Using MAP, O_2 can simply be reduced around the packaged potatoes and CO_2 increased. Similarly, O_2 concentration below 8% (80,000 ppm) reduces ethylene production and its metabolic action. Main glycolysis enzymes can also be inhibited when CO_2 levels are about 10% (100,000 ppm). Furthermore, levels of CO_2 above 1% (10,000 ppm) can reduce the sensitivity of the potato to the effects of ethylene and inhibit the activity of key regulatory enzymes.

The other main benefit of using MAP is that it reduces water loss. The packaging or coating creates an atmosphere with higher water vapor due to its relative impermeability to water vapor (Figure 1). Water transpired and evaporated from washed potatoes adds to the water vapor in the air within the package, which creates conditions of high relative humidity, but also those favorable for disease. Packaging should have some capacity for ventilation or means for air movement to allow water vapor to escape and for the potatoes to dry. Examples include plastic bags with perforations, mesh paper with mesh, or boxes with vent holes.

Types of MAP

The atmosphere within the package can be modified in two ways:

a) Passive modified atmosphere. If a potato's characteristics and the packaging's permeability are adequately combined, an appropriate atmosphere can be passively produced inside the packaging through the consumption of O_2 and the production of CO_2 by the respiration process. Passive MAP is the common packaging technique used in the potato industry. Packages can be perforated or not.

b) Active modified atmosphere. To quickly adjust the atmosphere inside the packaging, actively establish and adjust it as needed. Simply remove (vacuum) and replace the atmosphere with a desired gas mixture, which also requires knowing the respiration rate of the potatoes being packaged.

Packaging Materials

Fresh potatoes are commonly packaged in transparent, perforated low-density polyethylene (LDPE) plastic/bioplastic bags, Kraft paper bags with mesh, or cardboard boxes. Many plastic films are available to use as packaging, but relatively few have been used for MAP purposes and few possess gas permeability suitable for use in storage under modified atmospheres. Since the O_2 content in MAP typically decreases from 21% in normal air to 2%–5%, there is a risk of CO_2 increasing from 0.04% to 16%–19% inside the package. Indeed, there is a relationship between O_2 consumption and CO_2 production. Since high levels of CO_2 can be harmful, an ideal packaging material (film) should allow greater CO_2 output in relation to O_2 input. The CO_2 permeability should be 3–5 times greater than the O_2 permeability. Similarly, plastic packaging should have a relatively high coefficient of permeability to O_2 to avoid the formation of an anoxic atmosphere (low O_2 levels) inside the package.

The permeability of package materials should not be too permissive (high permeability), since changes in the atmosphere around the packaged potatoes are insufficient and benefits to extend the shelf life will not develop. Alternately, if the permeability of the packaging is too restrictive (low permeability), changes in the atmosphere will be too intense and the O_2 levels too low to maintain aerobic respiration, which can generate undesirable odors and flavors, produce the disorder blackheart, and cause the packaging to swell (Figure 2).

Plastic films are generally more permeable to CO_2 than to O_2, so the rate of accumulation of CO_2 from respiration is lower than the rate of depletion of the corresponding O_2. Polyethylene, although quite permeable, is not suitable for use in sealed packaging. More permeable films, such as cellophane and polyvinyl chloride (PVC), may have inadequate permeability when used to package products that have high respiration rates at high temperatures.

Low-density polyethylene is the most widely used plastic material to promote MAP. However, other plastic films are commonly used for this purpose, such as high-density polyethylene, polypropylene, polyvinyl chloride, polystyrene, etc. Polypropylene is relatively permeable to many volatile compounds and gases but is comparatively impermeable to water vapor, which can cause the appearance of free water and condensation in the packaging. Polyvinyl chloride has high permeability for water vapor, as well as to O_2 and CO_2. The high permeability of PVC may, in some cases, be more efficient in extending the shelf life of products than other plastic films.

Paper is commonly used to pack fresh potatoes. Various types are used for packaging, including sulfite paper, Kraft paper, grease-resistant paper, paperboard, and laminated paper, among others. Both paper and paperboard are valued for their flexibility, mechanical strength, biodegradability, and suitability for printing. However, they have limitations, such as low resistance to water vapor and oxygen due to low porosity, lack of heat sealability, and greater risk for tearing.

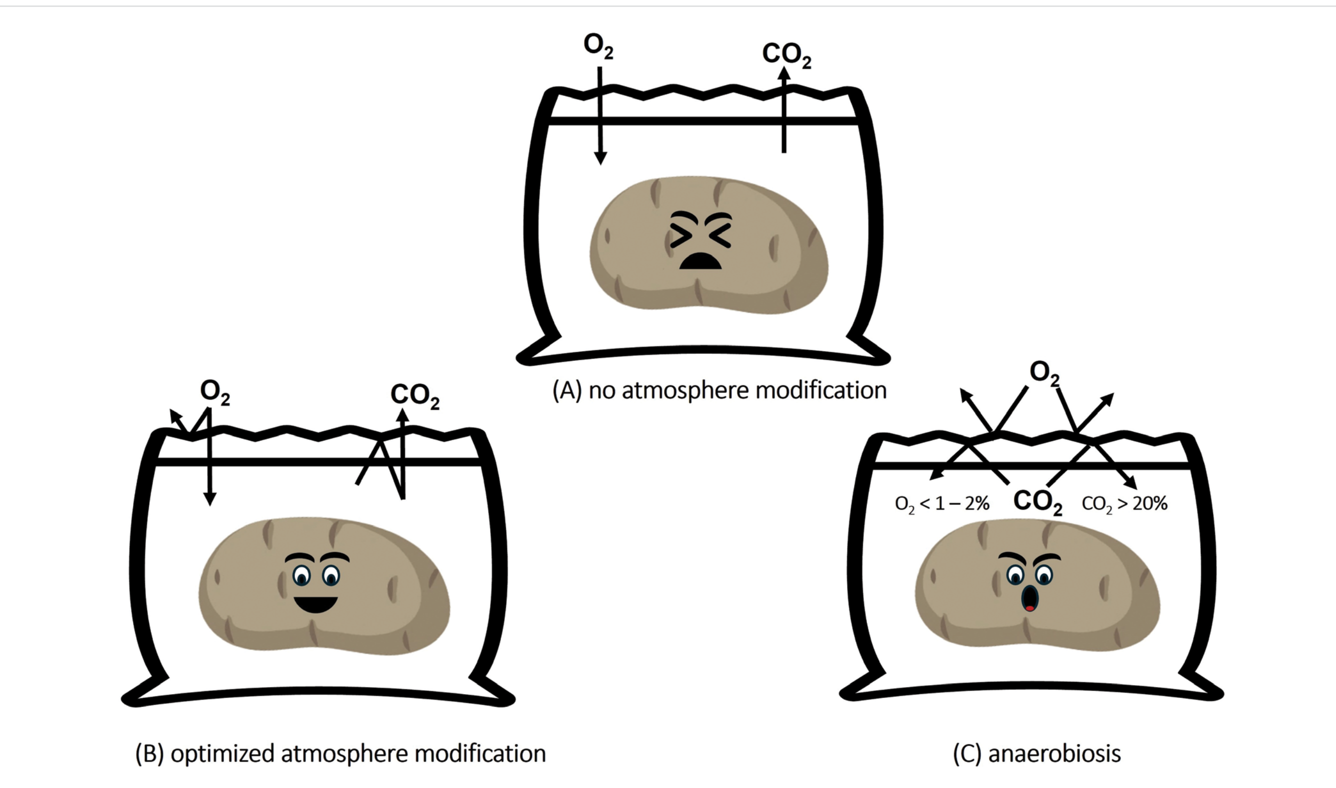

Figure 2. Interaction between package material and products. **A**, too permeable (no atmospheric modification), **B**, adequate permeability, and **C**, too low permeability (aerobic respiration [anaerobiosis]).

Potato Response to MAP

Atmospheric Composition

Differences in using a passive and active modified atmosphere can be seen in a demonstration trial (Figure 3). In this example, when Russet Burbank potatoes were packaged in perforated bags, little gas modifications were observed. The O_2 and CO_2 levels remained constant at a level of 16% and 0.08% (800 ppm) during nine days at 73°F and 15% relative humidity (RH) (Figure 3). Using a passive modified atmosphere bag without perforation and less permeability, the O_2 levels decreased from 16% to 2.3% and CO_2 levels increased from 0.04% (400 ppm) to 5.6% (56,000 ppm) after four days at 73°F and 15% RH. Thus, achieving constant O_2 and CO_2 levels using a passive nonperforated bag required four days. In addition, the weight loss of potatoes kept in the perforated bags was higher (1.1%) than in the closed plastic (passive) bag (0.13%) during the same period.

Using the active modified atmosphere approach, O_2 levels in the package rapidly decreased to 5.7% on the first day (Figure 3). This is why it is called active packaging—it quickly and actively changes concentrations of the gases inside the packaging by managing gas diffusion through the packaging material. Yet, the CO_2 levels had a similar accumulation pattern as the passive nonperforated approach (Figure 3). The use of active MAP is a more expensive packaging material compared to passive MAP.

Quality

Potatoes have very low respiration rates at storage temperatures (42°F–48°F). However, the respiration rate tends to increase after handling and at ambient temperatures (68°F–72°F) in retail situations. Higher temperatures result in greater potato deterioration, especially if low O_2 (<1.5%) or elevated CO_2 (>10%) levels develop inside the packaging.

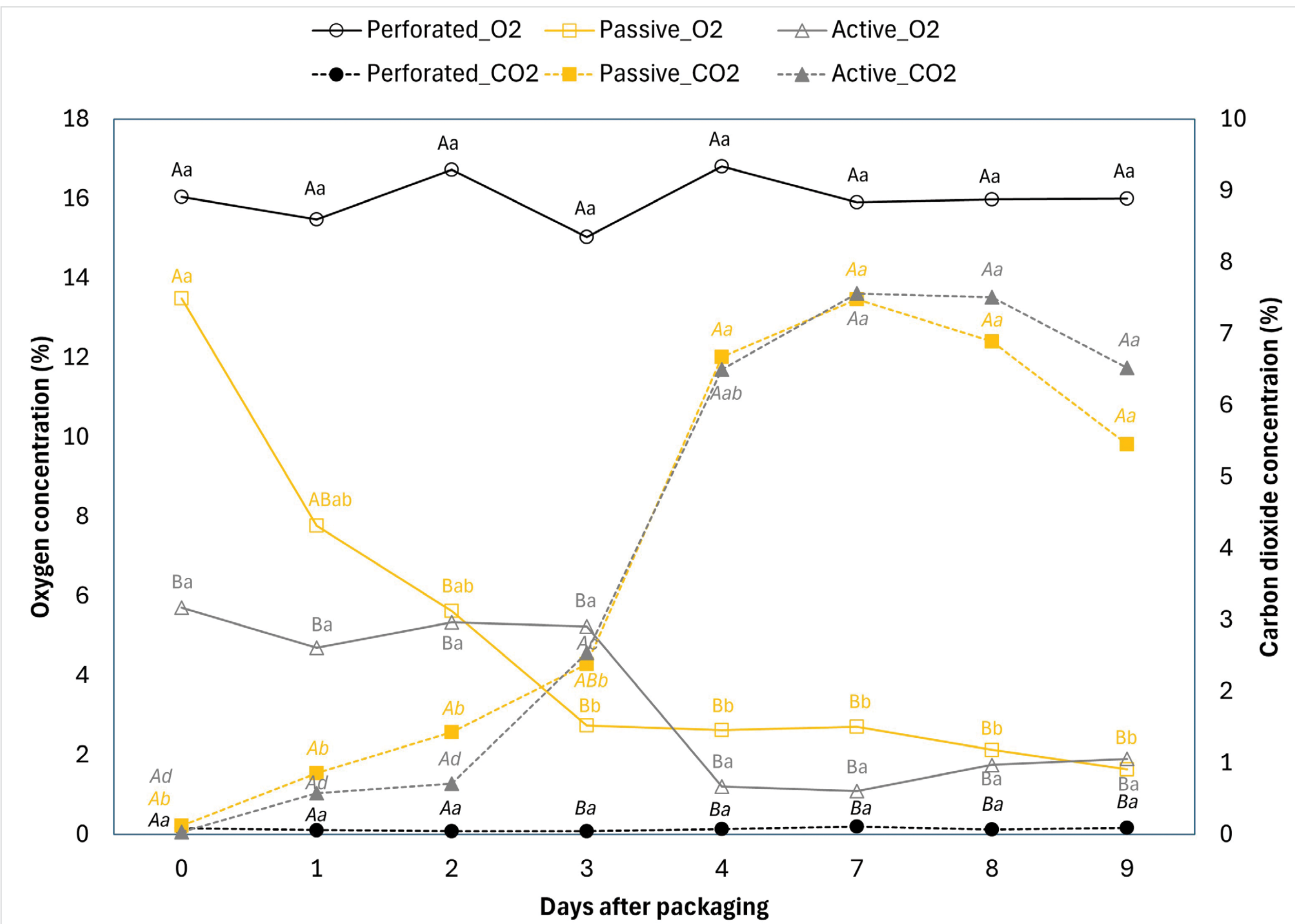

Figure 3. Example of MAP in packages containing Russet Burbank potatoes in perforated bags (-●-), passive 101 µm LDPE bags (-■-), and active 101 µm LDPE bags (-▲-) over nine days at 23°C and 15% relative humidity (RH).

The potato tolerance to O_2 and CO_2 concentrations inside the packaging is important to consider when looking at active and passive packaging. The general recommendation is to keep potatoes in atmospheres with O_2 concentrations that are not too low in order to maintain aerobic respiration (10% O_2) and CO_2 levels not too high that could cause damage to the potatoes (10%, 100,000 ppm CO_2). But O_2 levels as low as 5% and CO_2 levels as high as 15% (150,000 ppm) can be used, depending on the storage conditions and cultivars. Freshly harvested potatoes can have periderm development and wound healing delayed if atmospheres below 5% O_2 develop inside the packages.

Although high CO_2 can be used to reduce the respiration rate and control decay development, potatoes will show CO_2 injury if exposed to levels higher than 10% (100,000 ppm). This will induce off-odors, off-flavors, increased decay, and internal discoloration (Figure 4).

The passive and active use of 101 µm LDPE bags decreased the O_2 and increased the CO_2 content to levels that might have injured potatoes, inducing discoloration (photovoltaic reflectance). Although fry color was affected by 101 µm LDPE bags, packaged potatoes are not routinely fried.

Basic Management Considerations Based on MAP

Consider many factors whenever using MAP. Temperature, humidity, and duration of the potatoes in the package affect the atmosphere inside the package. The type, quantity, and weight of the potatoes are additional factors to keep in mind. The type and thickness of the plastic film and the manufacturing, closing method, and perforation number and size also affect O_2 and CO_2 levels inside the package. Furthermore, each potato cultivar has a certain variation and tolerance to different levels of gases in the atmosphere.

Figure 4. Packaging materials were passive perforated bags, passive nonperforated bags (101 µm LDPE), and active bags (vacuum sealed).

Currently, potatoes are commonly packaged in transparent, perforated LDPE plastic/bioplastic bags, Kraft paper bags with mesh, or cardboard boxes. These packages are too permissive (high permeability) and the atmospheric modifications around the packaged potatoes are not sufficient to reduce the respiration rate and actively manage to extend the shelf life of the products. A better understanding of the dynamics of the potato respiration rate is essential to realize MAP's full potential for potato growers.

Further Reading

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