Microperforated Packaging: Optimising Micro Holes for Shelf Life

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Abstract

Microperforated packaging features microscopic pores (50–200 µm) in polymer films, offering precise control over gas and moisture exchange to perfectly match the respiration needs of fresh produce. This innovative approach significantly extends shelf life while preserving key quality attributes such as texture, colour, and flavour. Unlike active modified atmosphere packaging, it passively regulates the internal atmosphere, minimising the risk of anaerobic fermentation and spoilage. Microperforated films are crafted from materials like polyethylene, polypropylene, polyethylene terephthalate, and biodegradable polymers. These films are tailored to specific product requirements and produced using advanced techniques, including cold needle process, hot needle process and laser perforation. Microperforated packaging is broadly used for various perishables such as fruits, vegetables, baked goods, seafood, and flowers. It helps minimise weight loss and senescence while significantly contributing to food waste reduction and sustainability by lowering dependence on energy-intensive cold chain systems.

Keywords: Microperforation, Shelf life, Respiration, Gas exchange, Food waste, Packaging

Introduction

Fresh fruits and vegetables continue to respire even after harvest, consuming oxygen and releasing carbon dioxide, water vapour, and ethylene. The continual metabolic changes in produce lead to physiological degradation, increased transpiration losses, and hastened senescence, particularly in high-respiring produce such as leafy vegetables, berries, and tropical fruits. Conventional packaging methods tend to restrict gas exchange, resulting in the accumulation of respiratory gases and hastening spoilage of the produce. To overcome the difficulty, the food packaging industry has adopted a smart and scalable solution called microperforated packaging. Microperforated films facilitate the formation of a naturally regulated internal atmosphere. These packaging films contain small perforations (usually 50 – 200 microns in diameter) that allow controlled gas exchange between the interior and exterior environments. This aids in maintaining an interior environment that closely fits the produce's respiration requirements. With increasing demand for fresh, highly respiring, minimally processed produce and a greater emphasis on environmentally friendly packaging options, optimising microperforated packaging has become more important than ever.

What is microperforated packaging?

Microperforated packaging employs microscopic perforations in the packaging material to enhance the permeability of gases and airflow. Microperforated polymer films help maintain optimal gas concentrations within the package by allowing similar diffusion rates for both oxygen (O_2) and carbon dioxide (CO_2). Microperforated films, with perforation diameters smaller than 200 µm, are often used in modified atmosphere packaging (MAP) for fresh foods that have high respiration rates, such as minimally processed fruits and vegetables (González *et al*., 2008). It uses tiny holes in materials to improve air flow and moisture control for fresh produce and perishables. These holes allow gas exchange and moisture release while keeping a mostly sealed environment to reduce contamination and extend shelf life.

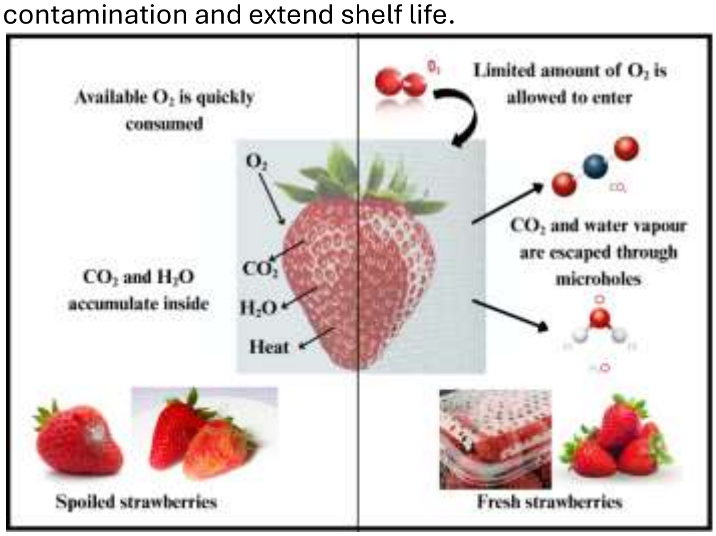

Fig. 1. Respiration mechanism of A) Non-perforated packaging and B) Microperforated packaging in strawberries

Science behind microholes

The principle of microperforated packaging is to optimise gas exchange and moisture regulation through micro holes (50 – 200 µm) to extend fresh produce shelf life. It creates a modified atmosphere by balancing O_2 influx, CO_2 efflux, water vapour transmission, slowing respiration and ethylene-driven ripening.

Table 1. Micro hole size selection

Category	Hole size	Example
Small holes	50–100 µm	low-respiring produce (e.g., apples)
Large holes	150–200 µm	high-respiring produce (e.g., berries)

The density of micro holes, which typically ranges from 10 to 50 per square meter, controls the gas flow rate through the packaging film, thereby affecting the transmission rates of oxygen (O_2) and carbon dioxide (CO_2). The micro holes reduce the risk of anaerobic conditions by preventing excessive CO_2 buildup, which can lead to off-flavours or fermentation.

Microperforation (MPP) vs. Modified Atmosphere Packaging (MAP)

Microperforated packaging (MPP) is used as part of a modified atmosphere packaging (MAP) system, particularly for fresh produce. Microperforations support atmospheric stability in MAP-packaged produce by enabling controlled gas exchange. It helps to balance the internal gas levels affected by the product's respiration after the package has been filled with a controlled gas mixture.

Modified atmospheric packaging (MAP) effectively reduces postharvest losses, increases shelf life, and ensures food safety. It minimises water loss, improves skin firmness, reduces microbial counts, and reduces fruit degradation. Microperforations in packaging serve as a method to attain the desired gas composition in modified atmosphere packaging for fruits and vegetables. Fruits such as raspberries (Giovanelli *et al*., 2014), figs (Villalobos *et al*., 2018), and sweet cherries (De Paiva *et al*., 2017) have shown that microperforated film packaging is effective in preserving fruit quality. The difference between MPP and MAP is given in the following table.

How is microperforated film made?

There are three main methods for perforating plastic films.

i. **Cold needle process**

Microperforated polyethylene film is commonly produced using the cold needle technique, where fine needles mounted on a roller pierce the film to form small perforations. Due to the flexibility of polyethylene, this process does not deform or weaken the structural integrity of the film.

Table 2. Difference between MPP and MAP

Feature	Microperforated Packaging (MPP)	Modified Atmosphere Packaging (MAP)
Mechanism	Uses microscopic pores (micro-perforations) to allow passive gas exchange.	Actively changes the gas composition within the packaging.
Gas control	**Passive**: Relies on the respiration of the product and micro-holes to reach balance.	**Active**: A gas mix (O_2, CO_2, N_2) is injected during packaging.
Precision	Lower precision depends on produce respiration, temperature, and hole size.	Higher accuracy in measuring and controlling gas concentrations.
Technology required	Simple, laser or mechanical perforation on film.	Advanced gas-flushing or vacuum-sealing machines are needed.
Cost	Low cost	High cost
Shelf-life control	Moderate, better than no packaging, but less than MAP.	Extended shelf life highly controls spoilage and ripening rates.
Suitable for	Fresh produce with moderate and high respiration rates.	Produce with high respiration.
Condensation control	Helps to decrease moisture buildup due to ventilation.	Moisture can be trapped if not paired with moisture control layers.

ii. **Hot needle process**

Hot needles can also be used, but they need more energy. It is normally reserved for usage on hard and brittle films with little flexibility, which are more prone to tear rather than puncture. Heated needles easily glide through more brittle material, leaving a ring of strengthened material, similar to the laser piercing technique.

Both the hot and cold needle processes employ rollers with extremely narrow needles. As the film travels over the rollers, the needles puncture it at precise intervals to produce perforation before winding it back into a roll of film.

iii. Laser perforation

Laser perforation is the process of cutting a highly accurate, tight pattern of holes with hot laser beams. This approach is typically used for smaller parts or patterns that cannot be done using rollers and needles. Running them across an entire breadth is not cost-effective for basic patterns; nonetheless, in other cases, lasers are the only option. This approach can also produce unique perforation patterns and incorporate higher levels of automation. It offers high precision and uniform hole size.

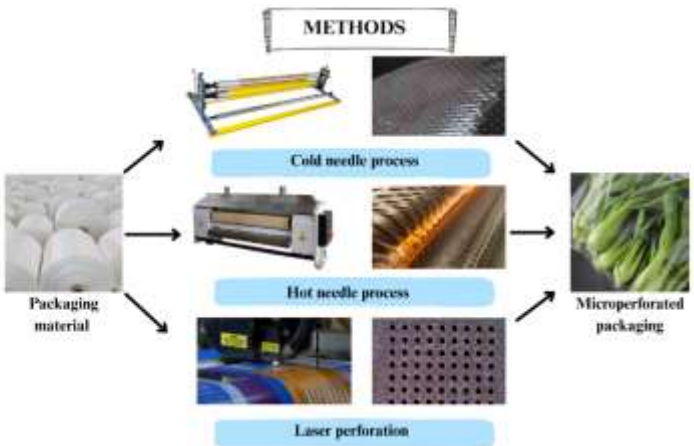

Fig. 2. Methods of preparing microperforated packaging

Packaging materials used

Microperforated packaging is selectively used for the products which need to breathe. The choice of packaging material depends on the specific product being packaged, its respiration rate, desired shelf life, and environmental impact. The size and number of micro perforations are carefully tailored to ensure optimal gas exchange for each product type. Polyethylene (PE) is one of the most commonly used polymers due to its flexibility, durability, recyclability, and low cost. It is frequently used to wrap trays of meat, fresh produce, mushrooms, and various fruits and vegetables. Polypropylene (PP), a commonly used plastic, is applied in both films and woven bags, making it ideal for packaging breathable products such as fresh vegetables and bakery items. Polyethylene Terephthalate (PET) is also utilised in microperforated films for its excellent barrier properties and transparency. As the demand for sustainable packaging increases, biodegradable polyesters are being investigated for microperforated applications, particularly for fruits. One such material is polylactic acid (PLA), a biodegradable, plant-based polymer used to produce eco-friendly microperforated films. Additionally, paper-based materials can be microperforated to meet specific packaging needs.

Table 3. Packaging materials used in microperforated packaging

Packaging material	Features	Applications
Polyethylene (LDPE, LLDPE, HDPE)	Flexible and moisture-resistant	Fruits, vegetables, and baked products
Polypropylene (OPP, CPP)	Heat-resistant and good clarity	Snacks, bread, and ready meals
Polyethylene Terephthalate (PET)	High strength, transparency, and a favourable gas barrier	Meat, cheese, and salads
Polylactic Acid (PLA)/ Bioplastics	Compostable and eco-friendly	Eco-conscious products, fresh fruits and vegetables
Paper-based	Natural breathability and printable	Bakery and dry goods

Applications

Microperforated plastics are widely used abroad, particularly in food packaging. Their design is permeable and can significantly extend the shelf life of food.

- Microperforated bags are commonly used to package fresh vegetables and fruits, including broccoli, lettuce, strawberries, and apples. Breathability reduces moisture accumulation and mould growth while yet preserving the freshness and appearance of the product. They can mitigate elevated respiration induced by CO_2 accumulation.
- Microperforated bags are also used for packaging snacks like dried fruits and nuts, as their

breathability helps preserve crispness and prevents moisture-related mould growth.

- In the baking industry, microperforated bags are used to package bread, cakes, and pastries. By regulating moisture, the bread stays pleasantly soft without becoming soggy, while the breathable design helps keep the crust crisp.
- Microperforated bags are ideal for packaging fresh fish and shellfish, helping retain their moisture and freshness while preventing spoilage during transport and storage. This packaging method is especially prevalent in seafood markets and supermarkets.
- In the floral market, microperforated plastic bags are used to package cut flowers, ensuring optimal humidity and airflow to prolong their freshness and lifespan.

Microperforation is the most effective method for controlling the O_2/CO_2 permeability of packaging materials. Additionally, the interaction between perforation density and the amount of produce packaged plays a key role in shaping the modified atmosphere (MA), which significantly influences packaging performance. For instance, senescence spotting in bananas was suppressed at oxygen concentrations between 5% and 10% (5–10 kPa), but not at 15% O_2 (Choehom *et al*., 2004). Micro-perforations provided sufficient ventilation to prevent unpleasant odours, effectively extending broccoli's shelf life in both retail and home environments.

Micro perforations in the polymer film enable significantly greater gas exchange compared to conventional films. In packaging fresh-sliced mushrooms, O_2 levels in the headspace are maintained below 5% but kept above 1% to prevent anaerobic and pathogenic microbial growth. Meanwhile, CO_2 levels are elevated; however, concentrations above 12% can cause physiological damage and browning in mushrooms (Parentelli *et al*., 2007).

Velardo-Micharet *et al*. (2016) evaluated the impact of microperforated films on postharvest quality and losses of 'Angeleno' plums during 65 days of storage at 1°C and 90% RH. The different treatments include macroperforated (control), MA bags, and microperforated films with one hole per 10 mm (M10) and 50 mm (M50). It was observed that M50 film effectively reduced weight loss and firmness decline, delayed titratable acidity loss and pulp pigmentation, and minimised chilling injury. These results indicate that M50 microperforated film is a viable alternative to MA bags for extending plum shelf life.

Rodov *et al*. (2022) evaluated compostable biodegradable polyester packaging for ethylene-treated bananas against conventional petroleum-based plastics. Non-perforated biodegradable packaging induced hypoxic fermentation, causing poor ripening, off-flavours, and excessive softening. Microperforation prevented fermentation and enabled modified atmosphere formation. Higher water vapour permeability in biodegradable films eliminated condensation. Although fruit weight loss was greater than in polypropylene, it remained 3-4 times lower than in open containers. Microperforated biodegradable packaging effectively controlled senescence spotting, maintained firmness and flavour, and reduced crown rot incidence.

Conclusion

Microperforated packaging is emerging as a key innovation in the food industry, meeting the growing demand for sustainability, product quality, and waste reduction. Microperforated packaging is a significant step forward in reducing food waste. Researchers view it as a promising solution for minimising food loss while also emphasising the need for more recyclable materials to align with UN Sustainable Development Goals on plastic pollution. Beyond just extending shelf life, microperforated packaging helps maintain the desirable qualities of the produce, such as its colour, texture, and natural aroma. It can enable longer transportation distances and potentially reduce the need for expensive temperature-controlled environments or rapid delivery. This can contribute to lower carbon footprints in the food supply chain. It prevents the development of unpleasant odours that often accompany spoilage in sealed environments. It acts as a smart, breathable barrier that manages the microclimate around fresh produce.

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