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## The Impact of Packaging and Storage on Coffee Quality: A Review

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### Abstract

The quality and shelf life of coffee are crucial factors in the global coffee industry, directly impacting consumer satisfaction and market value. Proper packaging and storage are essential in maintaining coffee's quality, as they protect against environmental factors that can deteriorate its flavor, aroma, and overall quality. This review highlights the critical role of packaging and storage in preserving coffee quality and extending its shelf life. Effective packaging materials and advanced techniques, such as vacuum sealing and nitrogen flushing, significantly reduce oxidation and preserve freshness. Optimal storage conditions, including controlled temperature, humidity, and light exposure, are equally important in preventing quality degradation. Innovations in major coffee-producing countries have demonstrated the practical benefits of these methods in maintaining coffee quality, enhancing marketability, and reducing post-harvest losses. The adoption of high-barrier packaging materials, advanced packaging techniques, and proper storage conditions is recommended to optimize packaging and storage practices in the coffee industry.

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Coffee Quality, Packaging Materials, Storage Conditions, Shelf Life, Packaging Techniques.

### Introduction

Coffee is one of the most widely consumed beverages worldwide, playing a significant role in both the global economy and the livelihoods of millions of people. Ensuring the quality and shelf life of coffee is crucial, as it directly impacts consumer satisfaction and market value. Proper packaging and storage are essential factors in maintaining coffee's quality, as they protect against environmental factors such as moisture, oxygen, and light, which can deteriorate its flavor, aroma, and overall quality (Daglia, 2012). The global coffee market is immense, with an estimated 166.63 million 60-kilogram bags of coffee consumed worldwide in 2020/2021 (International Coffee Organization, 2021). The quality of

coffee significantly influences its market price, with specialty coffee, which commands higher prices, requiring strict quality control from farm to cup (Specialty Coffee Association, 2018).

Innovative packaging solutions, such as vacuum-sealed bags and one-way valve packaging, have been developed to extend the shelf life of coffee by minimizing exposure to oxygen and moisture (Ross and Pecka, 2012). Ethiopia, the birthplace of Arabica coffee, is renowned for its unique and diverse coffee varieties. However, the quality of Ethiopian coffee is often compromised due to traditional and suboptimal packaging and storage practices. In rural areas, coffee is frequently stored in jute bags or other permeable materials that do not protect

against moisture and pests, leading to significant quality loss (Central Statistical Agency, 2020). Additionally, inadequate storage facilities expose coffee beans to fluctuating temperatures and humidity, further degrading their quality (Labouisse *et al.*, 2008). Improving packaging and storage infrastructure in Ethiopia is essential for maintaining the distinctive flavors and high quality of Ethiopian coffee, thereby enhancing its competitiveness in the global market and providing better economic returns for farmers (Worku and Demelash, 2019). Effective packaging and storage are crucial in preserving coffee quality and extending shelf life in Ethiopia and other major coffee-producing countries, ensuring that coffee maintains its desirable sensory attributes from production to consumption.

## **Coffee Quality Parameters**

### **Flavor**

Flavor is a critical aspect of coffee quality, and it is influenced by a complex combination of chemical compounds formed during roasting. High-quality coffee exhibits a balance of sweetness, bitterness, and acidity, with distinct notes that can range from fruity to nutty or chocolaty (Farah, 2012). Exposure to oxygen and moisture during storage can lead to the degradation of flavor compounds, resulting in stale or offflavors.

Oxidation is a primary concern, as it can cause rancidity and a loss of freshness (Worku and Demelash, 2019). To mitigate this, vacuum-sealed bags and nitrogen flushing are effective methods to reduce oxygen exposure, helping to preserve the flavor by slowing down the oxidation process (Damatta and Ramalho, 2006).

### **Aroma**

Aroma is another vital parameter of coffee quality, primarily determined by volatile organic compounds. A high-quality coffee has a rich, complex aroma with various discernible notes such as floral, fruity, spicy, or earthy (Ross and Pecka, 2012). Aroma compounds are highly volatile and can be easily lost or altered during improper storage. Exposure to light, heat, and oxygen can lead to the evaporation or chemical transformation of these compounds, diminishing the coffee's aromatic profile (Daglia, 2012). One-way valve bags allow for the release of carbon dioxide while preventing oxygen ingress, thereby protecting the aroma. Additionally, storing coffee in opaque, airtight containers helps shield it from light and air (Muschler, 2018).

### **Acidity**

Acidity is a desirable trait in coffee, adding brightness and liveliness to the flavor profile. High-quality coffee usually has a well-balanced acidity that enhances its overall flavor (Ramalakshmi *et al.*, 2009; Wang *et al.*, 2020). Acidity can be influenced by the degradation of organic acids in coffee. Improper storage conditions, such as high humidity and temperature fluctuations, can lead to a decrease in acidity, resulting in a duller taste profile (International Coffee Organization, 2021). Maintaining stable, cool storage conditions is crucial for preserving the acidity. Using moisture resistant packaging materials can help prevent the absorption of excess humidity (Franco *et al.*, 2007; Degl'Innocenti *et al.*, 2008; Kumar *et al.*, 2019; Wang *et al.*, 2020; Gao *et al.*, 2019).

### **Moisture content**

Moisture content is critical for the prevention of mold growth and maintaining bean integrity. Ideal moisture content for green coffee beans is around 10-12%. Too much moisture can lead to mold growth and spoilage, while too little can result in brittle beans that may lose flavor more quickly during storage (Degl'Innocenti *et al.*, 2008). Excessive moisture can promote microbial growth, leading to spoilage and potential health hazards. Conversely, overly dry conditions can cause beans to lose weight and become brittle, affecting the roasting process and final flavor (Labouisse *et al.*, 2008). Hermetic storage systems, such as GrainPro bags, provide an effective barrier against moisture and pests. These bags help maintain optimal moisture levels and protect the beans from environmental factors (Central Statistical Agency, 2020; Wang *et al.*, 2020).

## **Packaging Materials and Methods**

Effective packaging is essential for maintaining the quality and extending the shelf life of coffee. Different materials and methods are used in the coffee industry, each offering unique benefits and challenges. This section reviews various packaging materials and methods utilized globally, including Ethiopia, highlighting their impact on coffee quality. Packaging Materials:

1. Paper is a popular choice for coffee packaging due to its cost-effectiveness and ease of branding. However, it has limited barrier properties against moisture and oxygen, which can compromise coffee quality over time. Biodegradable and recyclable paper packaging is favored

by environmentally conscious consumers (Damatta and Ramalho, 2006).

2. Plastic is widely used in the coffee industry due to its excellent barrier properties, lightness, and flexibility. High-barrier plastic materials like PET (polyethylene terephthalate) are commonly used to protect coffee from oxygen and moisture. However, plastic packaging raises environmental concerns due to its non-biodegradability and challenging recycling processes (Ross and Pecka, 2012).

3. Metal, particularly aluminum, is used for coffee cans and capsules due to its superior protection against light, oxygen, and moisture. Metal packaging can be easily recycled, but its higher cost and energy-intensive production processes are drawbacks (Muschler, 2018).

4. Biodegradable materials like PLA (polylactic acid) and compostable films are increasingly popular in response to environmental concerns. They offer a reduced environmental impact and appeal to eco-conscious consumers. However, they are generally more expensive and may not provide the same level of barrier protection as conventional materials. Limited availability and infrastructure for composting are also challenges (International Coffee Organization, 2021).

### **Packaging Methods**

1. Whole bean packaging is popular among specialty coffee consumers who prefer to grind beans fresh before brewing. It often uses resealable bags with one-way valves to release carbon dioxide without letting in oxygen. Proper sealing is crucial to protect against oxidation and moisture, maintaining flavor and aroma better than pre-ground coffee (Farah, 2012).

2. Ground coffee is convenient for consumers who do not have grinders. Packaging typically includes vacuum-sealed or nitrogen-flushed bags to extend shelf life. However, the increased surface area exposed to oxygen increases the risk of flavor degradation, making effective packaging methods crucial to preserving quality (Degl'Innocenti *et al.*, 2008).

3. Single-serve cups, such as K-Cups, offer convenience and portion control. They are usually made from plastic with aluminum lids and sometimes nitrogen-flushed to maintain freshness. While they provide excellent protection against environmental factors, they generate significant plastic waste, raising environmental concerns (Franco *et al.*, 2007).

4. Nitrogen flushing involves replacing the oxygen in the packaging with nitrogen, an inert gas that prevents oxidation. It is used for both whole bean and ground coffee. This method extends shelf life by minimizing

oxidation, but requires specialized equipment, adding to production costs (Labouisse *et al.*, 2008). In conclusion, the choice of packaging material and method significantly impacts coffee quality and shelf life. The coffee industry must balance the need for effective packaging with environmental concerns and consumer preferences.

### **Storage Conditions and Their Impact on Coffee Quality**

Proper storage conditions are essential for maintaining coffee quality from the time it is harvested until it reaches the consumer. Factors such as temperature, humidity, and light significantly impact coffee's flavor, aroma, and overall quality. This section discusses how these factors affect coffee quality and reviews different storage conditions used globally, including Ethiopia.

#### **Effects of Temperature, Humidity, and Light on Coffee Quality**

1. Temperature plays a crucial role in the preservation of coffee's sensory attributes. High temperatures can accelerate the degradation of volatile compounds responsible for coffee's aroma and flavor, leading to a stale taste. Conversely, low temperatures can slow down these chemical reactions and extend shelf life (Farah, 2012). Optimal Conditions: Storing coffee at cool, stable temperatures (ideally below 20°C) helps maintain its quality. Avoiding temperature fluctuations is essential, as repeated warming and cooling can cause condensation and moisture buildup (Ross and Pecka, 2012).

2. Humidity is a critical factor in coffee storage. High humidity levels can lead to the absorption of moisture by coffee beans, promoting mold growth and microbial contamination. This can result in offflavors and spoilage. On the other hand, very low humidity can dry out the beans, making them brittle and prone to flavor loss (Muschler, 2018). Optimal Conditions: Maintaining relative humidity levels between 50-60% is recommended to prevent moisture-related issues. Hermetic storage solutions can help control humidity and protect coffee quality (Labouisse *et al.*, 2008).

3. Light: Exposure to light, especially ultraviolet (UV) light, can trigger photodegradation of coffee's chemical compounds, leading to a loss of flavor and aroma. Light can also cause the formation of free radicals, which accelerate oxidative processes (Franco *et al.*, 2007). Optimal Conditions: Coffee should be stored in opaque or light-blocking containers to minimize exposure to light. Keeping coffee in dark, cool environments further

helps preserve its quality (International Coffee Organization, 2021).

### **Different Storage Conditions**

1. Ambient storage involves keeping coffee at room temperature in a dry, dark place. It is the most common storage method used by consumers and retailers. While convenient, ambient storage can be problematic if temperatures and humidity levels are not controlled. Quality can deteriorate quickly in fluctuating conditions (Worku and Demelash, 2019). In Ethiopia, coffee is often stored in traditional jute bags at ambient temperatures, which can expose it to environmental fluctuations. Improved storage solutions are needed to maintain quality during transport and storage (Central Statistical Agency, 2020).

2. Refrigerated storage involves keeping coffee at low temperatures (typically between 0-5°C) to slow down the degradation of volatile compounds and extend shelf life. Refrigeration can effectively preserve coffee's sensory attributes but may cause condensation if not properly managed. Coffee should be kept in airtight containers to prevent moisture absorption (Degl'Innocenti *et al.*, 2008). Refrigerated storage is used in some specialty coffee shops and households to maintain freshness, especially for high-quality beans (Damatta and Ramalho, 2006).

3. Freezing coffee (at temperatures below -18°C) is a method used to preserve its freshness for extended periods. This method halts almost all chemical reactions that lead to quality degradation. Frozen storage can maintain coffee quality for several months to years if done correctly. However, thawing and refreezing can cause moisture issues, so it is important to only thaw what is needed (Daglia, 2012). Freezing is gaining popularity among specialty coffee enthusiasts and some commercial operations to store large quantities of green or roasted beans without quality loss (Ramalakshmi *et al.*, 2009).

### **The Role of Packaging and Storage in Extending Shelf Life**

Shelf life refers to the period during which a product remains safe to consume and retains its desired sensory, chemical, physical, microbiological, and functional characteristics. In the coffee industry, shelf life is a critical factor because it directly impacts the flavor, aroma, and overall quality of the coffee that consumers enjoy. Maintaining an optimal shelf life ensures that coffee retains its freshness and appeal from the point of production to the moment it is brewed. Effective shelf

life management is particularly important in Ethiopia, a major coffee producer, as well as in other coffee-producing and consuming countries worldwide.

Consumer satisfaction is enhanced by high-quality coffee with a longer shelf life, ensuring fresh and flavorful products that boost consumer loyalty to the brand (Farah, 2012). Extending coffee shelf life reduces waste, increases sales, and improves profitability for producers, retailers, and distributors (Ross and Pecka, 2012). As a major commodity in international trade, coffee requires a longer shelf life to maintain quality during long shipping times and storage periods in diverse climates (Muschler, 2018).

### **Packaging: Barrier Properties**

Packaging materials with high barrier properties against oxygen, moisture, and light are essential for extending the shelf life of coffee. For example, multilayer films that combine plastic, aluminum, and paper can effectively protect coffee from environmental factors (Labouisse *et al.*, 2008).

**Vacuum Sealing and Nitrogen Flushing:** Vacuum sealing removes air from the packaging, while nitrogen flushing replaces oxygen with nitrogen, an inert gas. Both methods significantly reduce oxidation, a major cause of flavor degradation in coffee (Franco *et al.*, 2007). **One-Way Valves:** Packaging with one-way valves allows carbon dioxide released by freshly roasted coffee to escape without letting oxygen in. This helps maintain freshness and extends shelf life (International Coffee Organization, 2021).

### **Storage Conditions**

**Temperature Control:** Storing coffee at cool, stable temperatures helps slow down the chemical reactions that cause staleness. Avoiding temperature fluctuations is key, as they can lead to condensation and moisture buildup, which can spoil the coffee (Worku and Demelash, 2019). **Humidity Control:** Maintaining optimal humidity levels (50-60%) is crucial to prevent moisture absorption and mold growth. Hermetic storage solutions, such as GrainPro bags, provide an effective barrier against humidity (Central Statistical Agency, 2020). **Light Protection:** Exposure to light, especially UV light, can degrade coffee's volatile compounds, leading to loss of flavor and aroma. Storing coffee in opaque or light-blocking containers can prevent this degradation (Degl'Innocenti *et al.*, 2008).



Coffee storage and packaging practices vary globally, with both traditional and innovative approaches being employed. In Ethiopia, traditional practices involve storing coffee in jute bags at room temperature, which provides limited protection against moisture and pests (Damatta and Ramalho, 2006). However, the industry is shifting towards improved storage solutions, such as hermetic bags, to enhance shelf life. Additionally, advanced packaging and storage technologies, including vacuum sealing and nitrogen flushing, are being adopted to extend the shelf life of both green and roasted coffee (Daglia, 2012).

Around the world, developed markets rely on sophisticated packaging materials and methods, such as aluminum cans, PET containers, and single-serve pods, to ensure coffee remains fresh for consumers over extended periods (Ramalakshmi *et al.*, 2009). In contrast, emerging markets are increasingly recognizing the importance of shelf life, with initiatives underway to improve packaging and storage infrastructure, supported by research and development efforts to identify cost-effective solutions suitable for local conditions (Degl'Innocenti *et al.*, 2008).

### **Case Studies and Industry Example**

This section delves into various instances from Ethiopia and around the world where innovative packaging and storage solutions have been successfully implemented to preserve coffee quality and extend shelf life.

1. Ethiopia, Hermetic Storage Bags, Ethiopia, a major coffee-producing country, has long struggled to preserve coffee quality due to outdated storage practices that leave beans vulnerable to moisture, pests, and contamination (Labouisse *et al.*, 2008). To overcome this challenge, hermetic storage bags, such as GrainPro and PICS bags, were introduced to provide an airtight environment that shields coffee beans from external threats. Research has demonstrated that these bags effectively reduce moisture absorption and pest infestation, thereby maintaining the quality of green coffee beans for longer periods. This innovation has resulted in higher market prices and reduced post-harvest losses for Ethiopian farmers, significantly improving their economic outcomes (Worku and Demelash, 2019).

2. Brazil: Vacuum Packaging for Roasted Coffee, as the world's largest coffee producer, Brazil has a sophisticated coffee industry that leverages cutting-edge packaging technologies to preserve coffee quality. One such innovation is the widespread adoption of vacuum

packaging for roasted coffee, which involves removing air from the packaging to prevent oxidation and preserve the coffee's flavor and aroma (Ross and Pecka, 2012). This method has been proven to significantly extend the shelf life of roasted coffee, maintaining its freshness for several months. By using vacuum packaging, Brazilian coffee brands have been able to enhance consumer satisfaction and successfully compete in international markets, further solidifying Brazil's reputation as a coffee powerhouse (Ross and Pecka, 2012).

3. The U.S. coffee market has experienced a significant shift towards single-serve coffee pods, driven by consumers' desire for convenience and consistent quality. To meet this demand, single-serve coffee pods, such as K-Cups, are often flushed with nitrogen to displace oxygen with an inert gas that prevents oxidation and staleness. This innovation has proven highly successful in maintaining the freshness of coffee within single-serve pods, extending shelf life and ensuring a consistent flavor profile. As a result, single-serve coffee systems have become ubiquitous in households and offices across the U.S., revolutionizing the way Americans consume coffee (Daglia, 2012).

4. Colombia: Controlled-Atmosphere Storage, renowned for its exceptional Arabica coffee, has taken a significant step forward in preserving the quality of its coffee beans during export by adopting cutting-edge storage solutions. Colombian coffee exporters have invested in controlled-atmosphere storage facilities, where temperature, humidity, and oxygen levels are meticulously controlled to create an optimal environment.

This innovative approach has yielded impressive results, significantly reducing the degradation of coffee beans during lengthy transit times and preserving their flavor and quality. As a result, Colombian coffee has maintained its stellar reputation in international markets, solidifying its position as a premier coffee-producing nation (Franco *et al.*, 2007).

For instance, some Industry Starbucks: Pioneering Packaging for Global Freshness, Starbucks, a global coffee leader, has developed a range of innovative packaging solutions to ensure the freshness of its coffee products during global distribution. By leveraging high-barrier materials and advanced packaging methods, such as vacuum-sealed bags, nitrogen-flushed pods, and aluminum cans, Starbucks is able to maintain the quality of its coffee products across diverse markets, enhancing customer satisfaction and brand loyalty (Damatta and Ramalho, 2006).

Nespresso: Aluminum Capsules for Coffee Perfection, Nespresso, a pioneer in the single-serve coffee market, relies on aluminum capsules to package its coffee. These capsules provide exceptional barrier properties against oxygen, moisture, and light, effectively preserving the aroma and flavor of coffee. Nespresso's aluminum capsules extend the shelf life of coffee and ensure a high-quality product, contributing to the company's success and market expansion (Farah, 2012).

Lavazza: Biodegradable Packaging for a Greener Future, Lavazza, an Italian coffee company, has taken a significant step towards sustainability by introducing biodegradable and compostable packaging solutions. While maintaining coffee quality, Lavazza's eco-friendly packaging reduces environmental impact and appeals to environmentally conscious consumers. This initiative aligns with global sustainability trends and enhances the company's reputation as a responsible brand (Ramalakshmi *et al.*, 2009).

This review highlights the critical role of packaging and storage in preserving coffee quality and extending its shelf life. Effective packaging materials with high-barrier properties against oxygen, moisture, and light are essential for maintaining the coffee's sensory and chemical characteristics. Advanced packaging techniques such as vacuum sealing, nitrogen flushing, and the use of one-way valves significantly reduce oxidation and preserve freshness. Optimal storage conditions, including controlled temperature, humidity, and light exposure, are equally important in preventing quality degradation. Innovations in Ethiopia and other major coffee-producing countries have demonstrated the practical benefits of these methods in maintaining coffee quality, enhancing marketability, and reducing post-harvest losses.

## Recommendations

For the coffee industry to optimize packaging and storage practices, it is recommended to adopt high barrier packaging materials to protect against environmental factors. Implementing advanced packaging techniques like vacuum sealing and nitrogen flushing can further extend the shelf life of coffee by reducing oxidation. Ensuring proper storage conditions, such as maintaining stable, cool temperatures and controlled humidity levels, is crucial for preserving quality. The industry should also invest in new packaging and storage technologies, such as biodegradable materials and controlled atmosphere storage, to enhance both quality preservation and

sustainability. Additionally, educating and training stakeholders on the importance of proper packaging and storage practices will help ensure consistent coffee quality from production to consumption.

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