# From Harvest to Market: Effective Postharvest Handling and Storage Techniques for Marigold

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## Abstract

Marigolds (*Tagetes* spp.) are widely cultivated for their ornamental value and therapeutic applications, making effective postharvest handling and storage critical for preserving quality and extending market viability. This review systematically evaluates the current methodologies and advancements in postharvest management of marigolds, encompassing harvesting techniques, processing protocols, and storage conditions. It explores the influence of environmental parameters such as temperature, relative humidity, and packaging materials on preserving floral integrity and shelf life. Recent technological innovations, including novel preservative treatments and advanced packaging solutions, are examined for their efficacy in mitigating postharvest deterioration. The review also addresses prevalent challenges such as pathogen control and market variability, providing evidence-based recommendations for optimizing handling practices. By integrating research findings and practical approaches, this review offers a comprehensive framework for improving postharvest processes, thereby enhancing the quality and economic value of marigold products.

**Keywords:** Ethylene, grading, humidity, light, precooling, sorting, temperature

## Introduction

Marigolds belonging to the Asteraceae family are a prominent group of flowering plants valued for their vivid coloration and diverse applications (Y. C. Gupta *et al*., 2022).[1] They are mainly divided into two species used in cultivation: *Tagetes erecta*, commonly referred to as African marigold, and *Tagetes patula*, known as French marigold. These species are distinguished by their specific traits, such as flower size, color, and growth patterns, contributing to their widespread use in horticulture (Cicevan *et al*., 2022).[2] Marigolds are extensively grown for their ornamental value, adding striking visual appeal to gardens and floral arrangements with various colors from yellow to red. Their extended blooming period and low maintenance requirements make them popular among both amateur and professional gardeners. In addition to their esthetic benefits, marigolds serve a functional role in pest management, acting as companion plants to repel pests such as nematodes and aphids (Marucci *et al*., 2018).[3]

Historically, marigolds have been employed in traditional medicine, with various plant parts such as flowers, leaves, and stems being utilized in ethnomedicinal practices across cultures. Marigold extracts are recognized for their anti-inflammatory, antimicrobial, and antioxidant properties, attributed to bioactive compounds such as flavonoids, carotenoids, and essential oils (Mir *et al*., 2019).[4] These therapeutic qualities have facilitated the use of marigold-based remedies in treating a range of conditions, including dermatological, digestive, and respiratory ailments.

Nevertheless, marigolds encounter significant postharvest challenges that affect their quality and marketability. The interval between harvest and market is critical for preserving the flowers' freshness, appearance, and overall quality (Fernandes *et al*., 2019).[5] To maximize their market value and extend their shelf life, it is crucial to maintain their esthetic and functional qualities postharvest. Effective postharvest management encompasses

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harvesting, processing, conditioning, and storage, all of which impact the final product (Kiaya, 2014).[6] These practices are essential to reduce physiological, biochemical, and microbial degradation, which can adversely affect the flowers' quality. Due to their high perishability, marigolds are susceptible to issues such as wilting, discoloration, and microbial contamination if not properly managed (Dhiman *et al*., 2021).[7]

Harvesting marigolds at the right stage of maturity, preferably in the cooler early morning hours, helps preserve their water content and minimize stress (Markam, 2017).[8] Postharvest treatments, such as sorting, cleaning, and applying chemical preservatives, are important for maintaining the flower's integrity and appearance. Optimal storage conditions, including low temperatures (0°C–4°C) and high humidity (85%–90%), are critical for slowing down respiration and senescence while preventing desiccation and wilting (Markam, 2017).[8] However, it is necessary to manage these conditions carefully to avoid chilling injuries and excessive moisture that could lead to mold growth. Proper packaging and transportation are also key to ensuring that marigolds reach the market in optimal condition. Using breathable packaging materials that allow for air circulation while protecting against physical damage, along with refrigerated transport, helps maintain the desired environmental conditions (J. Singh and Singh, 2019).[9] Addressing challenges such as mechanical damage, microbial growth, and ethylene sensitivity through training, hygiene practices, and ethylene inhibitors is essential. A scientifically based approach to postharvest handling and storage of marigolds enhances their economic value. It ensures that these flowers retain their natural beauty and utility, meeting the high standards expected by consumers.

Recent technological advancements and research have led to improved postharvest techniques, such as modified atmosphere packaging (MAP) and controlled atmosphere storage (CAS), which help prolong the shelf life of agricultural commodities (Soltani *et al*., 2015).[10] Innovations in packaging materials, including biodegradable and antimicrobial options, further enhance preservation while minimizing environmental impact (Kamarudin *et al*., 2022).[11] The marigold industry, spanning both ornamental and medicinal sectors, is economically significant. Stakeholders including growers, distributors, and retailers continuously strive to refine postharvest practices to align with market demands and enhance profitability. Market dynamics, such as seasonal demand fluctuations and price volatility, underscore the necessity for effective postharvest management (Bonuedi *et al*., 2022; Muflikh *et al*., 2024).[12,13] Continued research into environmental effects on marigold preservation, new preservation technologies, and sustainable practices is essential. Collaboration among researchers, industry experts, and growers will drive innovation and improve postharvest strategies for marigold products.

This review endeavors to deliver a thorough examination of the postharvest handling and storage methodologies for marigolds. Its objective is to aggregate and analyze existing research and practical strategies to create a detailed reference for optimizing postharvest management. By incorporating recent technological advancements and pinpointing existing research deficiencies, this review aims to assist growers, distributors, and researchers in advancing the quality and marketability of marigold products. To develop a comprehensive review of postharvest handling and storage techniques for marigolds, a broad spectrum of sources was utilized to ensure a thorough understanding of the subject. The primary sources included peer-reviewed scientific papers and articles from reputable journals, which offered detailed analyses and empirical data on marigold postharvest practices. These scholarly materials were accessed through major academic databases such as PubMed, Scopus, and Google Scholar. Additionally, industry magazines and horticultural publications were reviewed to incorporate practical insights and current trends in the field. To gauge public perceptions and recent advancements, newspapers and popular media sources were also examined. Complementing these written sources, interviews with experts including horticulturists, agricultural extension officers, and industry professionals were conducted. These interviews provided valuable firsthand perspectives and practical experiences, enriching the review with contemporary practices and challenges encountered by practitioners. The integration of these varied sources facilitated a comprehensive analysis of postharvest techniques, encompassing both established methods and innovative approaches within the domain.

## Postharvest Physiology of Marigolds

### Factors affecting postharvest quality

#### *Temperature*

Temperature is critical in maintaining the postharvest quality of marigolds (Erma and Hanji, 2022).[14] Marigolds are sensitive to both high and low temperatures. Higher temperatures elevate respiration rates, causing quicker degradation and reducing shelf life, whereas lower temperatures slow down respiration, thus preserving the flowers for longer (J. Gupta and Dubey, 2018).[15] Additionally, elevated temperatures increase transpiration, leading to significant water loss and wilting, while cooler temperatures help retain moisture, keeping the flowers fresh and turgid (AYDIN, 2023).[16] Marigolds are sensitive to ethylene, a natural plant hormone that accelerates aging and senescence; higher temperatures boost ethylene production and sensitivity, hastening flower decay (Reid and Wu, 1992).[17] Conversely, cooler storage conditions reduce the effects of ethylene, extending the visual appeal of the flowers. Warm temperatures also promote the growth of bacteria and fungi, leading to diseases and rotting, whereas low temperatures inhibit microbial growth, preventing spoilage (Eason *et al*., 2002).[18] Furthermore, temperature affects pigmentation and fragrance; extreme temperatures can cause color fading and loss of scent, diminishing both esthetic and commercial values. To maximize postharvest quality, marigolds should be stored at temperatures between 1°C and 5°C (34°F–41°F) with high humidity, around 90%–95%, to minimize water loss and maintain freshness (P. Sharma *et al*., 2021).[19]

### Humidity

Humidity significantly influences the postharvest longevity of marigolds. High humidity levels are essential as they minimize transpiration and water loss, maintaining the flowers' turgidity and freshness. Conversely, low humidity can cause rapid dehydration, leading to wilting and shrinkage. While excessive humidity can promote the growth of mold, bacteria, and fungi, maintaining controlled humidity is beneficial, as it ensures water retention without encouraging excessive microbial growth (J. Gupta and Dubey, 2018).[15] Proper humidity levels also help preserve the structural integrity of the flowers, reducing their susceptibility to the harmful effects of ethylene. Optimal storage conditions for marigolds involve maintaining high humidity in conjunction with appropriate temperatures (1°C–5°C or 34°F–41°F) to minimize water loss, prevent microbial spoilage, and extend their overall postharvest life (P. Sharma *et al*., 2021).[19] High humidity preserves the vibrant color and structural integrity of marigolds, while low humidity can result in color fading and brittle petals, reducing their esthetic appeal and market value. Therefore, maintaining high humidity levels is crucial for reducing water loss, preserving freshness, and extending the postharvest life as long as it is carefully controlled to prevent microbial growth and spoilage (Paull, 1999).[20]

### Ethylene sensitivity

Ethylene sensitivity profoundly impacts the postharvest longevity of marigolds by accelerating senescence, increasing decay rates, and causing pigment loss. Exposure to ethylene accelerates aging leading to premature wilting and petal shedding, thereby reducing visual appeal and market value (Dhall, 2013).[21] Higher levels of ethylene also heighten susceptibility to decay and microbial infections, hastening their deterioration and spoilage (Majumder and Sharangi, 2024).[22] Furthermore, ethylene contributes to the fading of petal color, diminishing their vibrant appearance and overall quality. These combined effects result in a notably shortened shelf life for marigolds, impacting their commercial viability and usability. To mitigate ethylene sensitivity's effects and prolong the postharvest life of marigolds, it is crucial to store them in environments with minimal ethylene exposure, employ ethylene inhibitors or absorbers when feasible, and maintain suitable storage temperatures (1°C–5°C or 34°F–41°F) (P. Sharma *et al*., 2021).[19]

### Light

Light plays a pivotal role in determining the postharvest characteristics of flowers through its influence on photomorphogenesis, photosynthesis, and photoperiodic responses (J. Gupta and Dubey, 2018).[15] It governs diverse physiological processes in marigolds, impacting their growth, development, and overall physiological health. Light is indispensable for photosynthesis, providing the energy necessary for the growth and maintenance of plant tissues, including flowers. The duration and quality of light exposure profoundly influence flowering patterns and the production of secondary metabolites, crucial for enhancing the quality of floral blooms (Ebrahimzadeh *et al*., 2008).[23] Additionally, different light wavelengths affect flower pigmentation, fragrance, and overall esthetic appeal (Kellenberger and Glover, 2023).[24] However, excessive exposure to ultraviolet radiation can be detrimental to marigold tissues, leading to color fading and reduced petal durability, thereby compromising flower quality. Therefore, managing light intensity, duration, and quality during both the cultivation and storage phases is essential to optimize photosynthesis, promote healthy flower development, and enhance the postharvest longevity of flowers (J. Gupta and Dubey, 2018).[15]

### Harvesting techniques

Harvesting timing plays a crucial role in determining the postharvest life and quality of flowers. Harvesting flowers at the right maturity stage ensures optimal flower quality and longevity. Marigolds are typically harvested manually using sharp tools to minimize damage. Harvesting should be done during the cooler parts of the day, such as early morning or late afternoon, to reduce heat stress on the flowers (J. Gupta and Dubey, 2018).[15] Flowers harvested too early may lack fully developed color, size, or fragrance, compromising their market appeal and durability. Stem length is also critical, influencing how flowers are handled and transported; longer stems are preferred for floral arrangements, but excessively long stems can pose logistical challenges and lead to damage during handling (Prinzing, 2024).[25] Harvesting marigolds when buds are just beginning to open can extend their vase life, as flowers harvested at full bloom tend to have shorter shelf lives due to increased respiration rates and quicker petal senescence. Environmental conditions during harvest, such as cooler temperatures in the early morning or late evening, help preserve freshness by reducing water loss (Jezdinsk *et al*., 2022).[26] Careful handling practices are essential to prevent physical damage to petals and stems, which can accelerate wilting and decrease market value (Lees, 2019).[27] Proper storage and immediate cooling after harvest are crucial to maintain marigold quality during transportation to market or processing facilities. Adopting these practices ensures that marigolds reach consumers with optimal freshness and esthetic appeal, enhancing their overall postharvest longevity.

### Postharvest handling

The handling practices undertaken after harvesting have a significant impact on the quality and longevity of marigolds. It is crucial to handle them gently to prevent physical damage such as bruising or tearing of petals, which can accelerate wilting and diminish their esthetic appeal (Reid, 2004).[28] After harvesting, flowers should be sorted and graded based on size, color, and quality. This step helps in standardizing the product for the market and removing any damaged or diseased flowers (A. K. Singh, 2023).[29] Immediately cooling marigolds after grading and sorting helps to reduce respiration rates and minimize water loss, with optimal storage temperatures typically maintained between 1°C and 5°C (34°F–41°F) to slow down aging processes and inhibit microbial growth (J. Gupta and Dubey, 2018).[15] Hydrating the stems promptly after harvest replenishes lost moisture and helps maintain turgidity. Given their sensitivity to ethylene, it is essential to manage exposure carefully, avoiding contact with ethylene-producing fruits and utilizing inhibitors or absorbers during storage to extend shelf life (Wei *et al*., 2021).[30] Thorough cleaning and sanitization of equipment and containers are necessary to prevent microbial contamination that could lead to decay. Proper packaging is essential, balancing ventilation to prevent moisture buildup while protecting from physical damage and light exposure during transportation and storage (Ait-Oubahou *et al*., 2019).[31] Regular quality inspections enable the timely removal of damaged flowers, ensuring that only high-quality marigolds reach the market. These practices collectively optimize the postharvest life of marigolds, preserving their visual appeal and market value while enhancing customer satisfaction and minimizing waste.

## Technological innovations

Technological advancements have significantly transformed postharvest management for marigolds, providing sophisticated methods to enhance product quality and extend shelf life. One notable development is MAP, which involves altering the atmospheric composition inside the packaging by decreasing oxygen levels and increasing carbon dioxide concentrations (Belay *et al*., 2016).[32] This adjustment slows the metabolic processes of marigolds, thus delaying senescence and preserving their vibrant appearance. MAP can extend the shelf life of marigolds making it an essential tool for maintaining floral quality during storage and transportation (Pal *et al*., 2016).[33]

Another key advancement is CAS, which goes beyond MAP by regulating not only gas composition but also temperature and humidity (Thompson *et al*., 2018).[34] CAS systems create a low-oxygen, high-carbon dioxide environment that significantly retards the aging process of marigolds. This method is particularly advantageous for long-term storage and transportation, extending the freshness of flowers by several weeks (Nirmala *et al*., 2023).[35] The incorporation of temperature control within CAS systems further improves preservation by mitigating temperature-related stress and decay.

Cold chain management is crucial for sustaining marigold quality throughout the supply chain (Prakash *et al*., 2023).[36] This approach ensures a continuous low-temperature environment from harvest to retail, using refrigerated transport, temperature-controlled storage facilities, and real-time temperature monitoring. Maintaining marigolds at optimal temperatures (generally between 4°C and 7°C) helps prevent premature wilting and spoilage, ensuring that marigolds arrive at the market in excellent condition (J. Gupta and Dubey, 2018).[15]

Advancements in packaging materials also contribute significantly to postharvest management. Breathable packaging films, made from perforated plastics or microporous materials, facilitate controlled gas exchange between the harvest and the environment (Awasthi *et al*., 2022).[37] This prevents condensation, reduces mold risk, and preserves visual appeal. Recent innovations include biodegradable and compostable films, which provide environmentally friendly alternatives to conventional plastics while effectively protecting and preserving marigolds.

Antimicrobial coatings represent another significant technological advancement. These coatings, which can be applied to packaging materials, incorporate agents such as silver nanoparticles or essential oils that inhibit microbial growth (Chawla *et al*., 2021).[38] By reducing bacterial and fungal contamination, antimicrobial coatings help maintain marigold quality and extend shelf life, crucial for preventing decay and ensuring freshness during storage and transport.

Smart packaging technologies further enhance postharvest management by integrating sensors and indicators that monitor and report on the condition of marigolds. Temperature sensors, humidity monitors, and gas sensors provide real-time data on environmental conditions, allowing for precise management of storage and transport. Time-temperature indicators alert stakeholders to deviations from optimal conditions, facilitating timely interventions to prevent quality deterioration.

Ethylene absorbers and preservative solutions address specific postharvest challenges. Ethylene absorbers, such as potassium permanganate or zeolite-based materials, remove ethylene gas, which accelerates ripening and senescence (Álvarez-Hernández *et al*., 2018).[39] By mitigating ethylene accumulation, these absorbers help maintain marigold freshness. Preservative solutions, including sugars, acids, and biocides, enhance hydration and control microbial growth, further extending marigold shelf life (A. Sharma *et al*., 2023).[40]

The emphasis on sustainability has driven the development of biodegradable and eco-friendly materials for postharvest management. Innovations such as plant-based packaging, biodegradable films, and compostable trays reduce reliance on conventional plastics and minimize environmental impact, aligning with global efforts to promote sustainable agricultural and horticultural practices.

Overall, these technological innovations provide a comprehensive approach to marigold postharvest management. By integrating advanced preservation technologies, novel packaging materials, and smart monitoring systems, these advancements improve the efficiency and effectiveness of postharvest practices. Ongoing research and development will continue to advance these technologies, leading to further enhancements in the preservation and marketability of marigolds.

## Challenges and solutions

Postharvest management of marigolds presents several significant challenges that affect their quality and marketability, but innovative solutions are emerging to address these issues effectively. A primary challenge is the high perishability and rapid senescence of marigolds, which can result in wilting and discoloration if not properly managed (Rani and Singh, 2014).[41] Advanced preservation methods, such as MAP and CAS, have been adopted to mitigate these issues. MAP adjusts the gas composition within the packaging to slow the flowers' metabolic processes, thereby extending their shelf life (Kou *et al*., 2012).[42] CAS offers more precise control over environmental factors, including temperature and humidity, which further delay aging and maintain freshness. Complementing these methods, cold chain management systems ensure a consistent low-temperature environment throughout storage and transportation, which is crucial for preserving marigold quality (Prakash *et al*., 2023).[36]

Microbial contamination is another challenge, as high humidity levels in storage environments can lead to mold and rot (J. Gupta and Dubey, 2018).[15] Solutions such as antimicrobial coatings and ethylene absorbers have been developed to address microbial growth and spoilage (Álvarez-Hernández *et al*., 2018; Chawla *et al*., 2021).[38,39] Antimicrobial coatings, applied to packaging materials, inhibit pathogen growth, while ethylene absorbers manage gas levels that can exacerbate microbial issues (Suppakul *et al*., 2003).[43] Temperature fluctuations during storage and transportation can negatively impact marigolds, causing premature senescence or chilling injuries. Investing in reliable temperature control systems and real-time monitoring technologies is essential for maintaining optimal conditions and preventing temperature-related damage. Handling and transportation damage is also a significant concern, given the delicate nature of marigolds, which are prone to bruising and breakage (Faust and Dole, 2021).[44] Improved handling practices, such as gentle techniques and the use of cushioned packaging materials, can minimize physical damage. Enhanced packaging solutions, including breathable films and protective trays, also help maintain flower integrity (Selke, 2003).[45] Market and supply chain dynamics, such as fluctuating demand and logistical challenges, further complicate postharvest management. Effective demand forecasting, inventory management, and collaboration with supply chain partners are critical for aligning harvest schedules with market needs and reducing waste. In regions with limited access to advanced technologies, promoting affordable and scalable solutions is essential for improving practices.

Finally, ongoing research and development are crucial for advancing postharvest technologies and addressing emerging challenges. By exploring new preservation methods, developing innovative materials, and refining handling techniques, stakeholders can continually enhance postharvest management and ensure the high quality and marketability of marigolds.

### Future directions and research needs

The future of marigold postharvest management is set to advance significantly through several key research and development areas. One promising avenue involves integrating advanced technologies, such as combining MAP with CAS and smart packaging systems (De Reuck *et al*., 2010; Wasala *et al*., 2014).[46,47] This integrated approach could enhance preservation efficacy by enabling real-time monitoring and precise control of environmental conditions, thereby extending the shelf life and quality of marigolds. Sustainable practices are also critical, with research focusing on biodegradable and compostable packaging materials that reduce environmental impact while maintaining effective preservation. Energy-efficient cold chain management systems and the adoption of renewable energy sources could further support these sustainable practices (Prakash *et al*., 2023).[36] Exploring novel preservation methods is essential, including the investigation of natural preservatives like plant extracts and nonthermal treatments such as high-pressure processing or pulsed light. These methods could provide alternative ways to extend shelf life without relying on chemical additives (Allai *et al*., 2023).[48] Improving microbial control strategies remains a priority, with future research aimed at developing new antimicrobial agents and coatings, as well as biological control methods using beneficial microorganisms. Enhancements in handling and logistics are also necessary to minimize physical damage during harvesting and transportation. This could involve the adoption of automation, robotics, and optimized logistical practices to ensure marigold quality. Assessing the economic and market impacts of various postharvest technologies will be crucial for their widespread adoption, with research focusing on cost-effectiveness and consumer preferences. Collaborative efforts between researchers, industry stakeholders, and technology developers will drive innovation, while attention to regional and local practices will ensure that postharvest solutions are tailored to specific conditions and needs.

## Conclusion

Effective postharvest handling and storage of marigolds are critical to preserving their quality and extending their market life. The review highlights several key advancements and challenges in this field, from innovative preservation techniques such as MAP and CAS to the importance of maintaining consistent temperature and humidity levels. Addressing challenges such as microbial contamination and physical damage through antimicrobial coatings, improved handling practices, and advanced packaging solutions is crucial for ensuring the optimal quality of marigolds. The integration of smart technologies and sustainable practices offers promising avenues for enhancing postharvest management, making it possible to balance quality preservation with environmental responsibility. Future research is essential to explore and develop novel preservation methods, improve microbial control strategies, and optimize handling and logistics. By focusing on these areas, stakeholders can address current limitations and advance the field, ensuring that marigolds retain their esthetic and commercial value from harvest through to market. Collaborative efforts and continued innovation will be key to overcoming existing challenges and adapting to evolving market demands, ultimately contributing to a more efficient and sustainable marigold supply chain.

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