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Influence of conventional and emerging processing technologies on the quality attributes of ready-to-eat spice gravies

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Abstract
Ready-to-Eat (RTE) spice gravies have become increasingly popular due to growing consumer demand for convenient, safe, and high-quality foods with extended shelf life. Processing technologies play a crucial role in determining the physicochemical, nutritional, microbiological, and sensory attributes of these products. Conventional methods such as roasting, frying, cooking, homogenization, and retort sterilization ensure product safety but may reduce the retention of heat-sensitive nutrients, color, and flavor. In contrast, emerging technologies, including High-Pressure Processing (HPP), Microwave-Assisted Thermal Sterilization (MATS), Ohmic Heating, and High-Intensity Ultrasound, offer improved preservation of quality while maintaining microbial safety. This review summarizes the principles and applications of conventional and emerging processing technologies and evaluates their influence on the quality attributes, safety, and shelf life of RTE spice gravies. It also highlights current challenges and prospects for developing high-quality, minimally processed, and commercially viable RTE spice gravy products.

Keywords: Ready-to-eat spice gravies, conventional processing, emerging processing technologies, quality attributes, food preservation

Introduction
Ready-to-eat (RTE) foods are commercially processed food products that are fully cooked or pre-prepared and can be consumed directly or after minimal reheating. The growing demand for convenience foods, driven by rapid urbanization, busy lifestyles, increased workforce participation, and changing dietary patterns, has significantly accelerated the expansion of the global RTE food industry. Among these products, Ready-to-Eat (RTE) spice gravies have gained considerable attention because they provide consumers with authentic traditional Flavors while eliminating the time-consuming processes of ingredient preparation, spice blending, and cooking. These gravies serve as versatile culinary bases for numerous Indian and international dishes, including paneer butter masala, butter chicken, chole, rajma, vegetable curries, and other ethnic preparations. Their convenience, consistency, and extended shelf life have made them increasingly popular in households, restaurants, catering services, and institutional food sectors (Fellows, 2017; Grand View Research, 2024) [3, 23].

RTE spice gravies are complex semi-solid food systems composed of vegetables such as onion, tomato, ginger, and garlic, edible oils or fats, water, spice blends, salt, thickening agents, emulsifiers, and other functional ingredients. These components contribute not only to the characteristic taste, aroma, color, and texture but also to the nutritional value and overall consumer acceptability of the final product. Spices such as turmeric, cumin, coriander, black pepper, cardamom, cinnamon, cloves, and red Chilli contain numerous bioactive compounds including curcumin, piperine, capsaicin, eugenol, cinnamaldehyde, and linalool, which possess antioxidant, antimicrobial, anti-inflammatory, and health-promoting properties. Preserving these valuable compounds during processing remains a major technological challenge in producing high-quality RTE spice gravies (Peter, 2012; Shahidi & Ambigaipalan, 2015) [31, 33].

A combination of physicochemical, microbiological, nutritional, and sensory characteristics determines the quality of RTE spice gravies. Important quality attributes include color stability, viscosity, texture, emulsion stability, pH, water activity, flavor profile, aroma retention, nutrient composition, microbial safety, and storage stability. Since these products generally possess moderate moisture content and contain oil, proteins, carbohydrates, and various natural pigments, they are susceptible to microbial spoilage, lipid oxidation, pigment degradation, phase separation, and flavor deterioration during storage. Therefore, appropriate processing and preservation strategies are essential to maintain product quality while ensuring consumer safety (Rahman, 2020) [13].

Conventional processing technologies, including washing, peeling, grinding, roasting, frying, cooking, homogenization, hot filling, and retort sterilization, have traditionally been employed in the manufacture of RTE spice gravies. Roasting and frying facilitate flavor development through Maillard reactions, caramelization, and the release of essential oils from spices. Cooking softens vegetable tissues, gelatinizes starch, and enhances ingredient integration, whereas homogenization improves particle size distribution, emulsion stability, and mouthfeel. Retort processing remains the most widely used commercial preservation method because it provides commercial sterility by eliminating vegetative microorganisms and bacterial spores, thereby allowing ambient storage for several months. However, prolonged exposure to high temperatures can adversely affect heat-sensitive vitamins, natural pigments, volatile flavor compounds, and antioxidant molecules, resulting in changes in color, aroma, texture, and nutritional quality (Fellows, 2017; Holdsworth & Simpson, 2016) [23, 25].

The limitations of conventional thermal processing, several emerging food processing technologies have been developed during the past two decades. High-Pressure Processing (HPP), Microwave-Assisted Thermal Sterilization (MATS), Ohmic Heating, and High-Intensity Ultrasound are among the most promising technologies for processing semi-solid foods such as spice gravies. Unlike conventional heating, these innovative techniques are designed to reduce processing time, improve heating uniformity, minimize thermal damage, and preserve the fresh characteristics of foods. High-Pressure Processing inactivates microorganisms by applying extremely high hydrostatic pressure without extensive heating, thereby retaining natural color, flavor, texture, and nutritional quality. Microwave-Assisted Thermal Sterilization provides rapid volumetric heating, resulting in shorter processing times and improved quality retention. Ohmic Heating generates internal heat through electrical resistance, ensuring uniform heating and minimizing localized overheating. High-Intensity Ultrasound enhances mass transfer, emulsification, and extraction of bioactive compounds while also contributing to microbial reduction when combined with mild heat treatments (Misra *et al*., 2017; Jaeger *et al*., 2016) [24, 26].

The selection of an appropriate processing technology significantly influences the final quality of RTE spice gravies. Parameters such as processing temperature, heating rate, residence time, pressure intensity, and energy input determine the extent of microbial inactivation and the preservation of physicochemical, nutritional, and sensory attributes. Furthermore, the effectiveness of these technologies is closely linked with suitable packaging systems, including retort pouches, multilayer flexible laminates, glass containers, metal cans, vacuum packaging, and modified atmosphere packaging. The integration of advanced processing methods with innovative packaging solutions has the potential to enhance product safety, improve storage stability, reduce food waste, and meet consumer demand for clean-label, minimally processed foods.

Composition and Characteristics of Ready-to-Eat (RTE) Spice Gravies

Ready-to-Eat (RTE) spice gravies are semi-solid, thermally processed food products formulated from vegetables, spices, edible oils, water, and functional ingredients to provide desirable sensory quality, nutritional value, and microbiological safety. These gravies serve as convenient bases for a wide range of traditional dishes and are designed to offer extended shelf life while retaining authentic flavor, aroma, and texture. With increasing consumer preference for convenient, minimally processed, and clean-label foods, the formulation of RTE spice gravies has evolved to include ingredients and processing methods that improve quality, stability, and consumer acceptability. Their final quality is governed by ingredient composition, processing conditions, packaging systems, and storage environment (Cui *et al*., 2024; Zhang *et al*., 2025) [1, 2].

The formulation of RTE spice gravies typically consists of onions, tomatoes, ginger, garlic, edible vegetable oils, spice blends, salt, water, and stabilizers or thickening agents. Onion and tomato constitute the primary gravy base, contributing sweetness, acidity, body, natural color, and moisture. Ginger and garlic enhance flavor while providing natural antimicrobial and antioxidant compounds. Vegetable oils act as carriers of fat-soluble flavor compounds and improve mouthfeel and texture. Depending on the product type, ingredients such as cream, coconut milk, cashew paste, yogurt, starches, gums, and emulsifiers are incorporated to enhance viscosity, emulsion stability, and overall sensory quality. Modern formulations increasingly emphasize clean-label ingredients and natural stabilizers to satisfy consumer demand for minimally processed foods (Cui *et al*., 2024; Fellows, 2017) [2, 23]. Spices are the most important functional ingredients in RTE gravies, providing characteristic flavor, aroma, color, and numerous bioactive compounds. Turmeric contains curcumin, which contributes yellow color and strong antioxidant activity. Red Chilli provides capsaicin responsible for pungency and red pigmentation, while black pepper contains piperine, which enhances flavor perception and improves the bioavailability of several phytochemicals. Coriander, cumin, cinnamon, cloves, cardamom, and bay leaves are rich in essential oils and phenolic compounds that contribute to aroma, antioxidant capacity, and antimicrobial activity. Recent studies have shown that spices are excellent sources of polyphenols, flavonoids, terpenoids, and volatile compounds that improve both sensory quality and the functional properties of processed foods (Lazaridis *et al*., 2024; Peter, 2012) [5, 33].

The physicochemical characteristics of RTE spice gravies determine their processing behavior, product stability, and consumer acceptance. Important quality parameters include pH, titratable acidity, moisture content, water activity, total soluble solids, viscosity, particle size distribution, emulsion stability, and color (L*, a*, b*). Most tomato-based gravies exhibit a pH between 4.2 and 5.5, which influences microbial stability and preservation requirements. Viscosity is a critical rheological parameter affecting pourability, mouthfeel, and consistency, whereas emulsion stability prevents oil separation during storage. Color stability is equally important because pigment degradation during processing directly affects consumer perception (Rahman, 2020; Jadhav & Choudhary, 2024) [4, 13]. RTE spice gravies provide carbohydrates, proteins, lipids, dietary fiber, vitamins, minerals, and a wide range of bioactive phytochemicals originating from vegetables and spices. Tomatoes are rich in lycopene and vitamin C, onions contain quercetin and Sulphur-containing compounds, whereas spices contribute curcuminoids, capacious, piperine, phenolic acids, flavonoids, and essential oils. These phytochemicals exhibit antioxidant, anti-inflammatory, antimicrobial, and health-promoting properties. However, prolonged thermal processing may reduce the concentration of heat-sensitive vitamins, phenolic compounds, and volatile constituents. Consequently, emerging processing technologies are increasingly being investigated to improve the retention of nutrients and functional compounds while ensuring food safety (Lazaridis *et al*., 2024; Shahidi & Ambigaipalan, 2015) [5, 31].

Maintaining the quality of RTE spice gravies during processing and storage remains a significant technological challenge. High-temperature processing may lead to degradation of natural pigments, destruction of volatile aroma compounds, nutrient losses, lipid oxidation, and changes in viscosity and texture. Phase separation and emulsion instability may occur during prolonged storage, reducing consumer acceptability. Microbial contamination must be effectively controlled without excessive thermal treatment that compromises product quality. The growing demand for preservative-free and clean-label foods has encouraged the adoption of innovative processing technologies and advanced packaging systems that minimize quality deterioration while ensuring microbial safety (Jadhav & Choudhary, 2024; Zhang *et al*., 2025) [1, 4].

Conventional Processing Technologies

Conventional processing technologies play a vital role in the production of Ready-to-Eat (RTE) spice gravies by ensuring product safety, desirable sensory attributes, and extended shelf life. These processes involve a sequence of operations, including raw material preparation, spice roasting, frying or sautéing, cooking, homogenization, and thermal sterilization. Each processing step significantly influences the physicochemical, microbiological, nutritional, and sensory quality of the final product (Fellows, 2017) [23]. Optimizing these operations is essential to achieve a balance between microbial safety and quality retention while preserving the characteristic flavor, color, and nutritional quality of spice gravies (Rahman, 2020; Zhang *et al*., 2025) [1, 13].

1. Raw Material Preparation

Raw material preparation is the first and one of the most critical steps in RTE spice gravy production. Fresh vegetables such as onion, tomato, ginger, and garlic, along with high-quality spices, edible oils, and other ingredients, are selected based on their maturity, freshness, color, and absence of physical defects **(Fellows, 2017) [23]**. Washing removes soil, dust, pesticide residues, and surface microorganisms, thereby improving product safety and reducing the initial microbial load (Jadhav & Choudhary, 2024) [4]. Peeling eliminates unwanted outer layers that may contain contaminants or affect texture; while cutting and grinding reduce particle size and facilitate uniform heat transfer during subsequent processing. Proper raw material preparation minimizes microbial contamination, improves texture and color uniformity, enhances flavor development, and increases overall process efficiency (Rahman, 2020; Cui *et al*., 2024) [2, 13].

2. Roasting of Spices

Roasting is performed either by dry heating or oil roasting to enhance the sensory quality of spices before incorporation into the gravy. During roasting, volatile aroma compounds are released, and Maillard reactions generate characteristic roasted Flavors and desirable brown pigments (Peter, 2012) [33]. Controlled roasting also improves antioxidant activity through the formation of antioxidant Maillard reaction products and the release of phenolic compounds (Shahidi & Bigitalin, 2015) [31]. However, excessive roasting may degrade essential oils, reduce volatile flavor compounds, and decrease the concentration of heat-sensitive phytochemicals. Therefore, optimization of roasting temperature and time is essential for achieving desirable aroma, color, and flavor complexity (Jadhav & Choudhary, 2024) [4].

3. Frying/Sauteing

Frying or sauteing involves cooking onions, tomatoes, ginger-garlic paste, and spices in edible oil to develop the characteristic flavor and texture of spice gravies. Flavor formation occurs through caramelization and Maillard reactions, while oil acts as a carrier for fat-soluble flavor compounds and pigments (Fellows, 2017) [23]. Processing parameters such as oil temperature, frying duration, and oil quality strongly influence product quality. Although frying improves viscosity, texture, and sensory acceptance, prolonged heating accelerates lipid oxidation, nutrient degradation, and the formation of undesirable compounds (Rahman, 2020; Zhang *et al*., 2025) [1, 13].

4. Cooking

Cooking combines all ingredients into a homogeneous gravy while ensuring adequate microbial reduction and achieving the desired consistency. Heat treatment softens vegetable tissues, gelatinizes starch, denatures proteins, and enhances flavor development (Fellows, 2017) [23]. Cooking also destroys spoilage microorganisms and inactivates enzymes responsible for quality deterioration. However, excessive cooking may lead to losses of heat-sensitive vitamins, pigments, and volatile aroma compounds, thereby affecting the nutritional and sensory quality of the final product (Rahman, 2020; Jadhav & Choudhary, 2024) [4, 13].

5. Homogenization

Homogenization reduces particle size and produces a stable oil-in-water emulsion, thereby improving the consistency and stability of RTE spice gravies. High-pressure or rotor-stator homogenizers enhance creaminess, viscosity, and mouthfeel while preventing oil separation during storage (Fellows, 2017) [23]. A uniform particle size distribution also improves visual appearance, emulsion stability, and overall consumer acceptability (Cui *et al*., 2024) [2].

6. Thermal Sterilization (Retort Processing)

Retort processing is the most widely used preservation technique for commercially sterile RTE spice gravies. The packaged product is processed at temperatures of approximately 121°C to destroy pathogenic microorganisms and bacterial spores, thereby ensuring commercial sterility (Holdsworth & Simpson, 2016) [25]. The effectiveness of thermal sterilization is evaluated using the F_0 value, which represents the equivalent sterilization time at 121.1°C required to achieve the desired level of microbial destruction. Adequate heat penetration is essential for uniform sterilization and shelf-life extension (Rahman, 2020) [13]. Although retort processing effectively improves microbial safety and allows ambient storage, it may also cause degradation of vitamins, pigment discoloration, texture softening, and loss of volatile flavor compounds if processing conditions are not carefully optimized (Zhang *et al*., 2025; Jadhav & Choudhary, 2024) [1, 4].

Emerging Processing Technologies

Emerging food processing technologies have gained considerable attention in the food industry due to their ability to produce safe, high-quality products while minimizing the adverse effects associated with conventional thermal processing. Unlike traditional heat treatments, these technologies aim to preserve the nutritional, physicochemical, and sensory properties of foods through reduced processing time, improved heating efficiency, or non-thermal preservation mechanisms. In Ready-to-Eat (RTE) spice gravies, emerging technologies help retain natural color, aroma, texture, and bioactive compounds while ensuring microbial safety and extending shelf life (Jadhav & Choudhary, 2024; Zhang *et al*., 2025) [1, 4].

7. High-Pressure Processing (HPP)

High-Pressure Processing (HPP) is a non-thermal preservation technology in which packaged foods are subjected to uniform hydrostatic pressures ranging from 400 to 600 MPa for a predetermined period. Pressure is transmitted instantaneously and uniformly throughout the product, regardless of its size or shape, resulting in effective microbial inactivation without significant heat generation (Balasubramaniam *et al*., 2015) [29]. Unlike thermal treatments, HPP primarily affects microbial cell membranes and enzyme systems while causing minimal changes to low-molecular-weight compounds responsible for flavor, color, and nutritional quality. The application of HPP in RTE spice gravies offers several quality advantages. It effectively reduces spoilage and pathogenic microorganisms while preserving the natural color, fresh aroma, and characteristic flavor of spices. Heat-sensitive nutrients, vitamins, phenolic compounds, and volatile essential oils are retained to a greater extent than in conventional thermal processing (Jadhav & Choudhary, 2024) [4]. HPP also delays enzymatic deterioration, enhances storage stability, and extends refrigerated shelf life without the need for excessive preservatives. However, bacterial spores generally require combination treatments with mild heat for complete inactivation (Balasubramaniam *et al*., 2015; Zhang *et al*., 2025) [1, 29].

8. Microwave-Assisted Thermal Sterilization (MATS)

Microwave-Assisted Thermal Sterilization (MATS) is an advanced thermal processing technology that combines microwave energy with pressurized hot water to achieve rapid and uniform volumetric heating. Unlike conventional retort processing, microwave energy penetrates the food matrix, reducing heating time and minimizing temperature gradients within the product (Tang, 2015) [32]. MATS significantly improves processing efficiency by shortening heating and cooling times, thereby reducing thermal damage to heat-sensitive components. Rapid heating helps preserve natural pigments, volatile aroma compounds, vitamins, and antioxidants while maintaining desirable texture and viscosity. The technology also ensures effective microbial destruction and commercial sterility, making it suitable for shelf-stable packaged foods. Compared with conventional retorting, MATS provides superior nutrient retention, better sensory quality, and improved energy efficiency (Tang, 2015; Zhang *et al*., 2025) [1, 32].

9. Ohmic Heating

Ohmic heating is an innovative thermal processing method in which an alternating electric current passes directly through the food, generating heat internally due to the electrical resistance of the food material. Because heating occurs uniformly throughout the product, temperature gradients are minimized, leading to faster and more efficient processing (Sastry, 2008) [35]. Ohmic heating reduces cooking time while maintaining uniform temperature distribution throughout the semi-solid matrix. The rapid internal heating minimizes nutrient degradation, pigment loss, and flavor deterioration commonly associated with prolonged conventional heating. It also improves viscosity, emulsion stability, and overall product consistency by preventing localized overheating. Furthermore, ohmic heating has lower energy consumption and improved process efficiency, making it an environmentally sustainable alternative for industrial food processing (Jadhav & Choudhary, 2024; Sastry, 2008) [4, 35].

10. High-Intensity Ultrasound Processing

High-intensity ultrasound processing utilizes sound waves with frequencies above 20 kHz to generate acoustic cavitation within liquid food systems. The formation and collapse of microscopic bubbles create localized high temperatures and pressures, enhancing mass transfer and improving physical and chemical processes without extensive heating (Chemat *et al*., 2017) [22]. In RTE spice gravies, ultrasound processing enhances the extraction of bioactive compounds, pigments, and essential oils from spices, resulting in improved flavor intensity and antioxidant activity. The technology also promotes better emulsification, producing stable oil-in-water emulsions with improved homogeneity, viscosity, and mouthfeel. When combined with mild heat or other preservation methods, ultrasound contributes to microbial reduction while minimizing quality deterioration. Consequently, high-intensity ultrasound has emerged as a promising green technology for improving product quality, process efficiency, and shelf-life stability of spice-based food products (Chemat *et al*., 2017; Jadhav & Choudhary, 2024) [4, 22].

Comparative Effect of Processing Technologies on Product Quality

The quality of Ready-to-Eat (RTE) spice gravies is significantly influenced by the processing technology employed during manufacturing. Conventional thermal methods such as retort sterilization ensure microbial safety but may adversely affect color, flavor, nutrients, and texture due to prolonged heat exposure. In contrast, emerging technologies such as High-Pressure Processing (HPP), Microwave-Assisted Thermal Sterilization (MATS), Ohmic Heating, and High-Intensity Ultrasound are designed to minimize quality deterioration while maintaining product safety and extending shelf life (Jadhav & Choudhary, 2024; Zhang *et al*., 2025) [1, 4].

11. Physical Quality

Physical quality attributes determine the visual appearance and consumer acceptance of RTE spice gravies. Important parameters include color (L*, a*, b*), texture, viscosity, and water activity (aw). Conventional thermal processing often causes pigment degradation, browning, and viscosity changes due to prolonged heating. In contrast, HPP and MATS better preserve natural color by reducing thermal exposure, while Ohmic Heating provides rapid and uniform heating that minimizes localized overheating and improves texture. Ultrasound processing enhances emulsion stability and viscosity by producing finer particle dispersion and improved homogenization (Balasubramaniam *et al*., 2015; Tang, 2015) [29, 32].

12. Chemical Quality

Chemical quality is evaluated through parameters such as pH, titratable acidity, lipid oxidation, nutrient retention, and bioactive compound stability. Extended thermal processing may accelerate lipid oxidation and degrade vitamins, phenolic compounds, carotenoids, and volatile essential oils. Emerging technologies reduce these undesirable changes by shortening processing time or avoiding excessive heat. HPP effectively preserves heat-sensitive nutrients and antioxidant compounds, while Ohmic Heating and MATS minimize nutrient degradation through rapid and uniform heating. Ultrasound processing enhances the extraction and retention of bioactive compounds from spices, thereby improving antioxidant potential (Chemat *et al*., 2017; Jadhav & Choudhary, 2024) [4, 22].

13. Microbiological Quality

Microbial safety is one of the primary objectives of food processing. Conventional retort processing provides commercial sterility by effectively destroying vegetative microorganisms and bacterial spores, allowing long-term ambient storage. HPP efficiently inactivates vegetative microorganisms but may require combination with mild heat to eliminate bacterial spores. MATS achieves rapid microbial destruction with less thermal damage than conventional retorting, whereas Ohmic Heating provides uniform microbial inactivation through volumetric heating. Ultrasound processing alone has limited antimicrobial activity but can significantly reduce microbial populations when combined with mild heat or other preservation methods (Balasubramaniam *et al*., 2015; Tang, 2015; Zhang *et al*., 2025) [1, 29, 32].

14. Sensory Quality

Sensory attributes, including appearance, aroma, taste, mouthfeel, and overall acceptability, are major determinants of consumer preference. Conventional thermal treatments may cause cooked flavors, pigment degradation, and loss of volatile aroma compounds. Emerging technologies generally provide superior sensory quality by minimizing thermal damage. HPP preserves fresh flavor and natural color, MATS retains texture and aroma due to shorter heating times, Ohmic Heating improves consistency and mouthfeel through uniform heating, and Ultrasound enhances flavor release by improving the extraction of volatile compounds from spices (Chemat *et al*., 2017; Jadhav & Choudhary, 2024) [4, 22].

15. Effect on Shelf Life

Shelf life of RTE spice gravies depends on microbial stability, oxidation reactions, moisture migration, pigment degradation, and flavor retention. Conventional retort processing provides the longest ambient shelf life due to commercial sterility; however, quality deterioration may occur during prolonged storage because of thermal damage. HPP effectively extends refrigerated shelf life by reducing microbial growth while preserving fresh characteristics. MATS and Ohmic Heating provide improved shelf-life stability through rapid and uniform processing with reduced nutrient losses. Ultrasound processing contributes to shelf-life extension mainly by improving emulsion stability and enhancing the effectiveness of combined preservation treatments. Overall, emerging technologies provide better quality retention while maintaining comparable microbial safety under appropriate storage conditions (Zhang *et al*., 2025; Jadhav & Choudhary, 2024) [1, 4].

16. Packaging Technologies

Packaging is an essential component of RTE spice gravy preservation because it protects the product from physical damage, oxygen, moisture, light, and microbial contamination. Common packaging materials include retort pouches, metal cans, glass jars, multilayer flexible pouches, vacuum packaging, Modified Atmosphere Packaging (MAP), and active packaging systems (Robertson, 2016) [28]. Retort pouches are widely used because they provide excellent heat resistance, low oxygen permeability, reduced processing time, and lower transportation costs. Metal cans offer superior mechanical strength and excellent barrier properties, making them suitable for long-term storage. Glass jars are chemically inert and provide good product visibility but are heavier and more fragile. Multilayer flexible pouches combine different polymer layers to achieve high oxygen and moisture barrier properties while maintaining flexibility and reduced packaging weight. Vacuum packaging removes oxygen from the package, thereby reducing lipid oxidation and microbial growth. Modified Atmosphere Packaging (MAP) replaces air with controlled gas mixtures to delay spoilage and preserve product quality. Active packaging incorporates oxygen scavengers, antimicrobial agents, or moisture absorbers that further extend shelf life and maintain sensory quality (Robertson, 2016; Jadhav & Choudhary, 2024) [4, 28].

Table 1: Packaging Materials and Their Influence on Product Quality and Shelf Life

Packaging Material	Advantages	Limitations	Recent References
Retort pouch	Lightweight, excellent heat transfer, superior oxygen and moisture barrier, suitable for commercial sterilization, extended ambient shelf life	Easily punctured, difficult to recycle	Holdsworth & Simpson (2016); Zhang *et al*. (2025) [1, 25]
Metal can	Excellent barrier against oxygen, moisture, and light; high mechanical strength; long shelf life	Heavy, expensive, corrosion possible if coating is damaged	Robertson (2016); Zhang *et al*. (2025) [1, 28]
Glass jar	Chemically inert, transparent, reusable, excellent product visibility	Fragile, heavy, higher transportation cost	Robertson (2016); Chen *et al*. (2023) [7, 28]
Multilayer flexible pouch	High oxygen and moisture barrier, lightweight, flexible, excellent shelf-life performance	Difficult to recycle due to multilayer structure	Robertson (2016); Kumar *et al*. (2023) [8, 28]
Vacuum packaging	Reduces oxygen, delays lipid oxidation, inhibits aerobic microorganisms, preserves flavor	Limited protection against anaerobic microorganisms; refrigeration often required	Rahman (2020); Chen *et al*. (2023) [7, 13]

Challenges

Advancements in conventional and emerging processing technologies, several challenges remain in the production of high-quality Ready-to-Eat (RTE) spice gravies. A major concern is the loss of volatile aroma compounds during thermal processing, as prolonged exposure to high temperatures can reduce the concentration of essential oils and flavor-active compounds responsible for the characteristic aroma of spices. Similarly, color degradation resulting from pigment oxidation, enzymatic browning, and Maillard reactions can adversely affect the visual appeal and consumer acceptability of the final product (Fellows, 2017; Jadhav & Choudhary, 2024) [4, 23]. Another significant challenge is oil separation during storage, which occurs due to emulsion instability and changes in the physicochemical properties of the gravy matrix. Phase separation negatively affects texture, appearance, and mouthfeel, reducing overall product quality. The development of stable emulsions requires optimized formulations, appropriate homogenization techniques, and the use of suitable stabilizers or hydrocolloids (Rahman, 2020) [13].

Emerging technologies such as High-Pressure Processing (HPP), Microwave-Assisted Thermal Sterilization (MATS), Ohmic Heating, and High-Intensity Ultrasound offer significant quality advantages, their commercial implementation is constrained by high capital investment, equipment maintenance costs, and specialized operational requirements. These limitations are particularly significant for small- and medium-scale food industries, especially in developing countries (Balasubramaniam *et al*., 2015; Jadhav & Choudhary, 2024) [4, 29]. Consumer preferences also present important challenges for manufacturers. Modern consumers increasingly demand products with fresh flavor, natural ingredients, minimal processing, and clean-label formulations while expecting long shelf life and assured food safety. Reducing or eliminating synthetic preservatives without compromising microbial stability remains a major formulation challenge (Zhang *et al*., 2025; Jadhav & Choudhary, 2024) [1, 4].

Future aspect

Future research on RTE spice gravies should focus on the integration of innovative processing technologies with digital and sustainable manufacturing approaches. Artificial Intelligence (AI)-assisted process optimization can improve processing efficiency by predicting optimal processing conditions, reducing energy consumption, and ensuring consistent product quality. Machine learning and real-time process monitoring are expected to play an increasingly important role in intelligent food manufacturing (Zhang *et al*., 2025) [1].

The development of green processing technologies, including energy-efficient heating systems and environmentally friendly manufacturing practices, will contribute to sustainable food production. The application of natural preservatives, such as plant extracts, essential oils, bacteriocins, and natural antioxidants, offers opportunities to replace synthetic additives while maintaining microbial safety and product stability (Jadhav & Choudhary, 2024) [4].

Conclusion

The selection of an appropriate processing technology is fundamental to ensuring the quality, safety, nutritional value, sensory characteristics, and shelf life of Ready-to-Eat (RTE) spice gravies. Conventional processing methods, including roasting, frying, cooking, homogenization, and retort sterilization, remain the backbone of commercial production due to their proven ability to achieve microbial safety and commercial sterility. However, prolonged thermal processing can adversely affect product quality by causing degradation of heat-sensitive nutrients, volatile aroma compounds, natural pigments, and desirable textural attributes. Emerging technologies such as High-Pressure Processing (HPP), Microwave-Assisted Thermal Sterilization (MATS), Ohmic Heating, and High-Intensity Ultrasound have emerged as promising alternatives for producing high-quality RTE spice gravies with minimal thermal damage. These technologies improve the retention of natural color, flavor, bioactive compounds, and nutrients while ensuring effective microbial control and extending shelf life. Their application also supports the growing consumer demand for minimally processed, clean-label, and high-quality convenience foods.

The widespread commercial adoption of these technologies is limited by challenges such as high capital investment, equipment complexity, process standardization, scale-up, and regulatory considerations. Therefore, future research should focus on integrating emerging processing technologies with sustainable packaging systems, natural preservatives, nanoencapsulation strategies, and artificial intelligence (AI)-based process optimization to enhance product quality, safety, and processing efficiency.

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